ENERGINET

ENERGINET`S EXPERIENCE FOR THE POWER ELECTRONICS CONVERTER RELATED TRANSIENT STUDIES

Transient studies in Kriegers Flak project

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IEEE pels

AGENDA

- Introduction
  - Kriegers Flak - Combined Grid Solution (KF-CGS) project
  - Problems and Issues
- Full scale EMT model
- Transient studies and influences from power converters
  - Cable Energization
  - Transformer (Reactor) Energization
  - Harmonic oscillation related issues
    - ✓ High frequency oscillations
    - ✓ ~~Long transient time / Harmonic Oscillations / Low frequency oscillations / Sub synchronous oscillations~~
- Conclusions

INTRODUCTION

Kriegers Flak – Combined Grid Solutions (KF-CGS) project

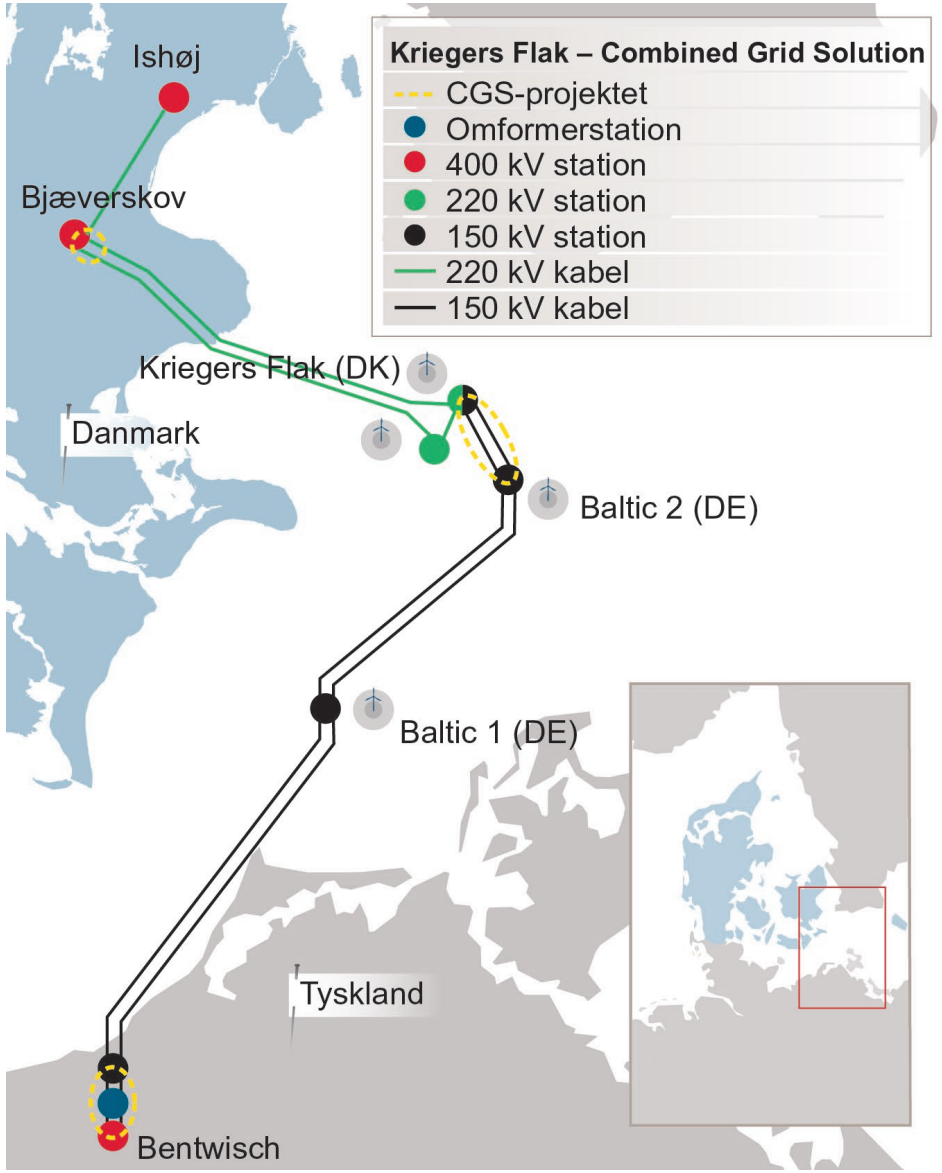
KF AC Project:

220kV HVAC connection of Kriegers Flak offshore wind turbines to the Danish transmission system.

KF CGS Project:

Establishment of electrical connection to Germany via the Kriegers Flak AC.

Both Kriegers Flak projects shall be in operation by Dec. 2018 though the Danish offshore wind turbines arrive later.

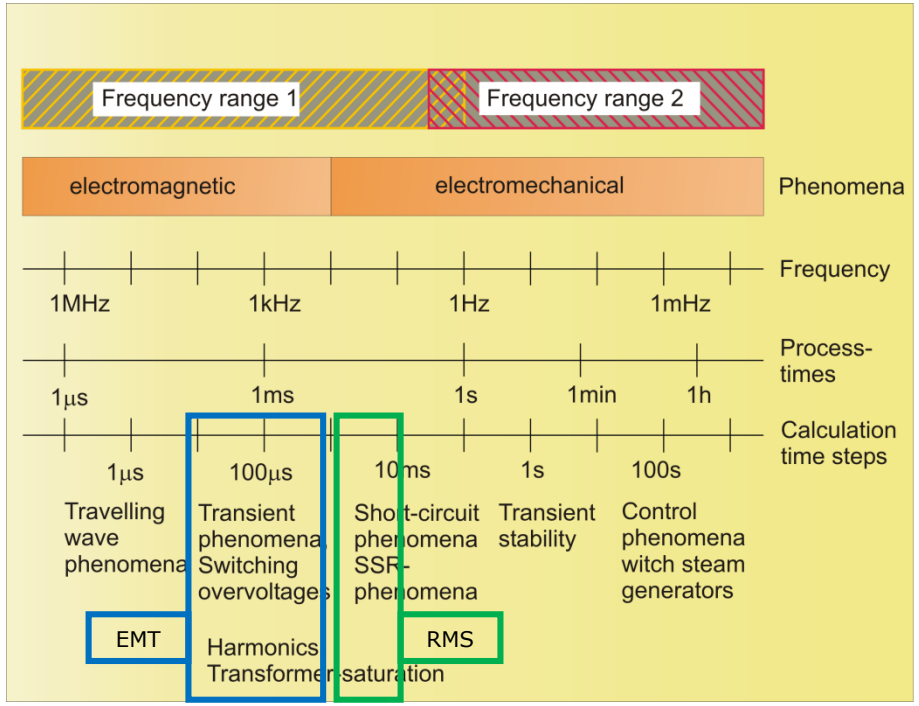


INTRODUCTION

Problems and issues

As a TSO (Transmission System Operator), Transient studies are really important tasks to ensure that all properties installed in Denmark operate safely.

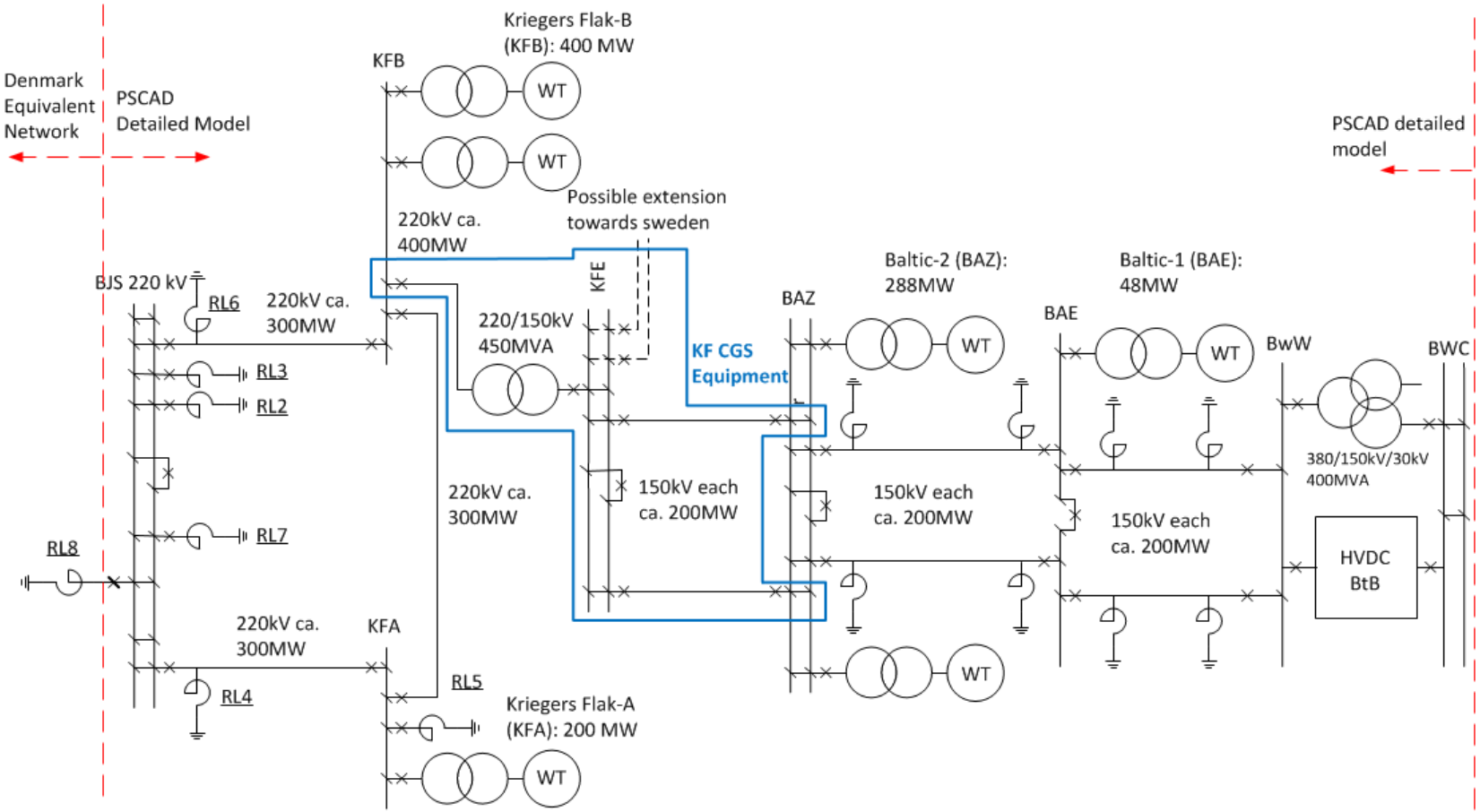
- Cable energization / De-energization
- Transformer energization
- Fault, VRT (Voltage Ride Through) and trip behaviour
- ~~Sub-Synchronous Oscillations (SSO)~~



Depending on operational scheme and dispatch, the introduced transient behaviour occurs many times every day. It is therefore very important to keep all components and equipment under operation correctly during any transient behaviour.

FULL-SCALE EMT MODEL

Implementation in PSCAD



Key power electronic converters installed in the KF-CGS project

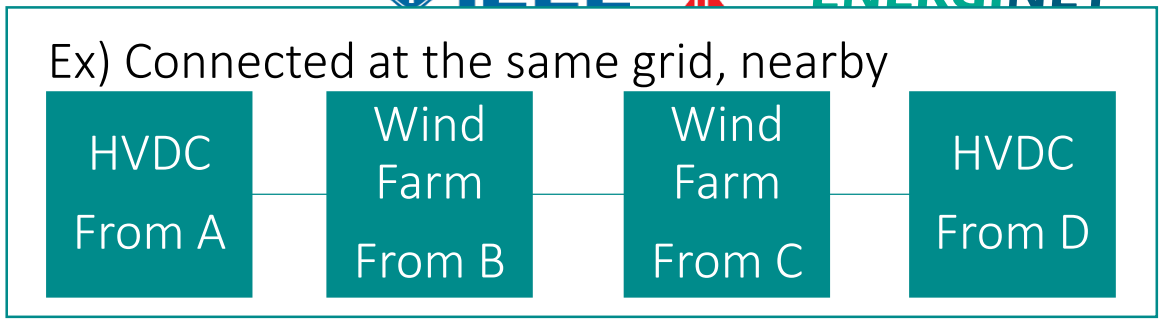
- Kriegers Flak offshore wind farm (600 MW)
- Baltic offshore wind farm (336 MW)
- Back-to-Back HVDC (VSC type)

All passive components (ex : cables etc) are implemented through Frequency dependent model considering geometrical information

All set points for dispatch are also implemented with some assumptions.

FULL-SCALE EMT MODEL

Problems and Challenges



As a TSO, “Black box” models from different manufactures are always problematic ! What could happen then if the model is not verified fully ?

- Different fault behavior depending on time-step/PSCAD version / compiler version etc
- Numerical Instability issue, where it is difficult to judge correctly
- Etc.

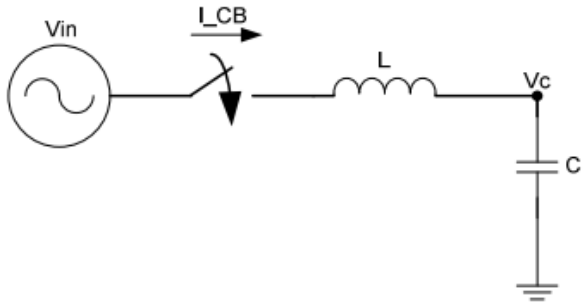
Difficult to communicate with the manufacture regarding the same problems or issues.

- Manufacture can not guarantee their model if we don’t use the specific version that they have mentioned in their guide line.

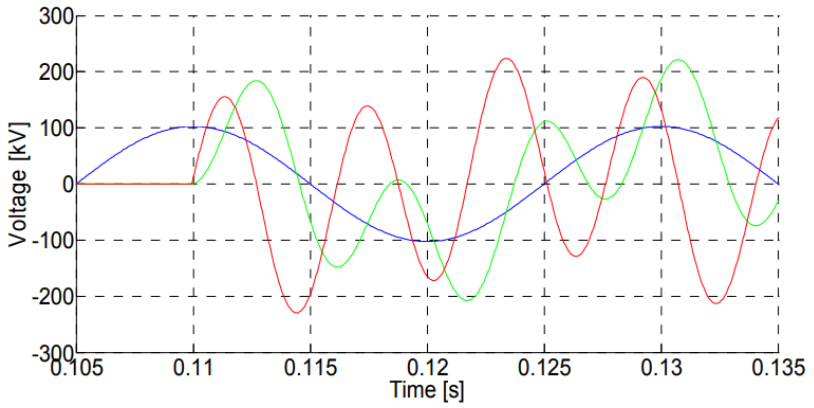
- Energinet developed internal procedure to validate the black box model in detail in order to verify the model works properly for all interesting operating conditions.
- Measuring impedance of power converters and verifications are also very important tasks.

TRANSIENT STUDIES AND INFLUENCES FROM POWER CONVERTERS

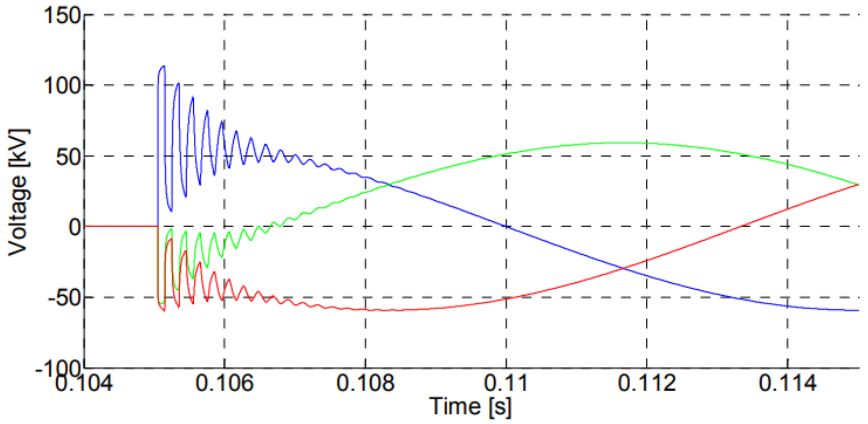
Cable energization – Theory [1]



Normal LC Circuit to represent the cable energization



Voltages and current (current not at scale) for LC circuit when connected at peak voltage. (Blue: Vin, Green: Vc, Red: I_CB)



Voltage in cable open end during its energization using an ideal voltage source (Blue: Phase A, Green: Phase B, Red: Phase C)

[1] Back-to-Back Energization of a 60kV Cable Network - Inrush Currents Phenomenon, F.F Silva, C. L. Bak, M.L. Hansen

TRANSIENT STUDIES AND INFLUENCES FROM POWER CONVERTERS

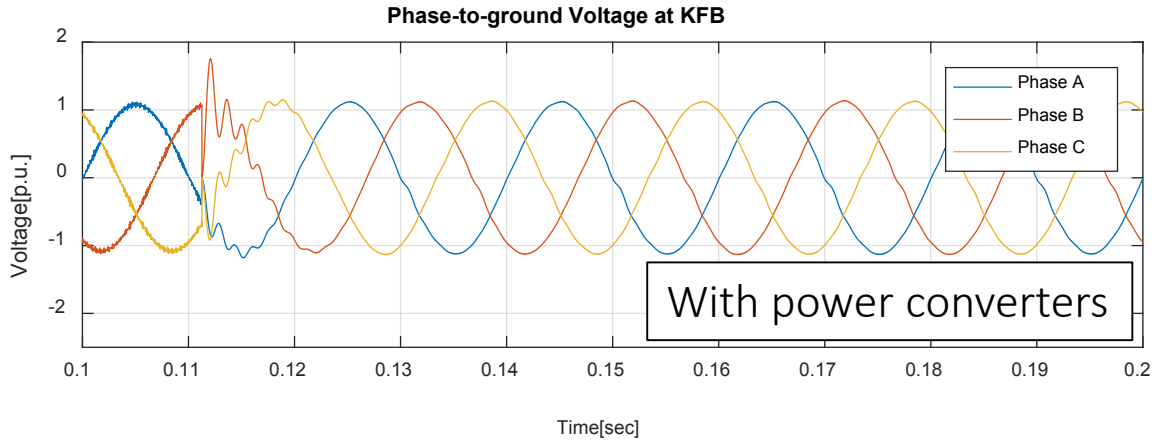
Cable energization – Example from KF project

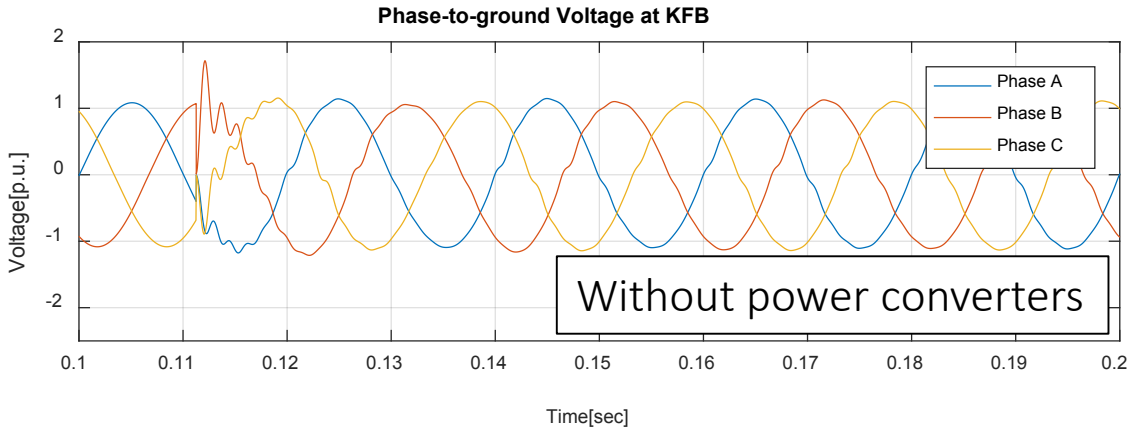
Test scenario

- Energization of high voltage cable at KFB busbar
- w/wo power converters

Results for discussion

- Since a controller bandwidth of power converters is normally very below (fsw/2), transient occurred by cable energization (>1 kHz) can not be properly controlled.
- Even if power converters are connected to the grid, it is difficult to expect any damping effect by power converters.





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Transformer energization – Theory [2]

TOV / TUV can occur and be big problems in power system oeprations.

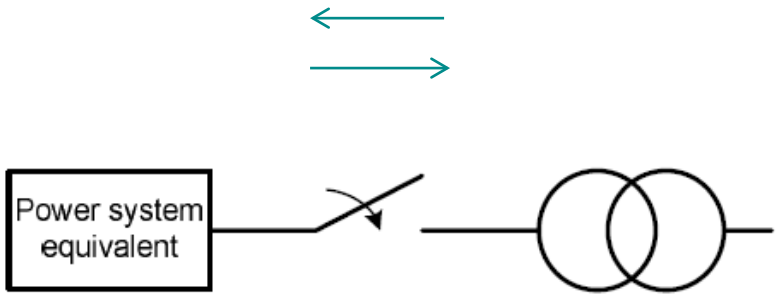
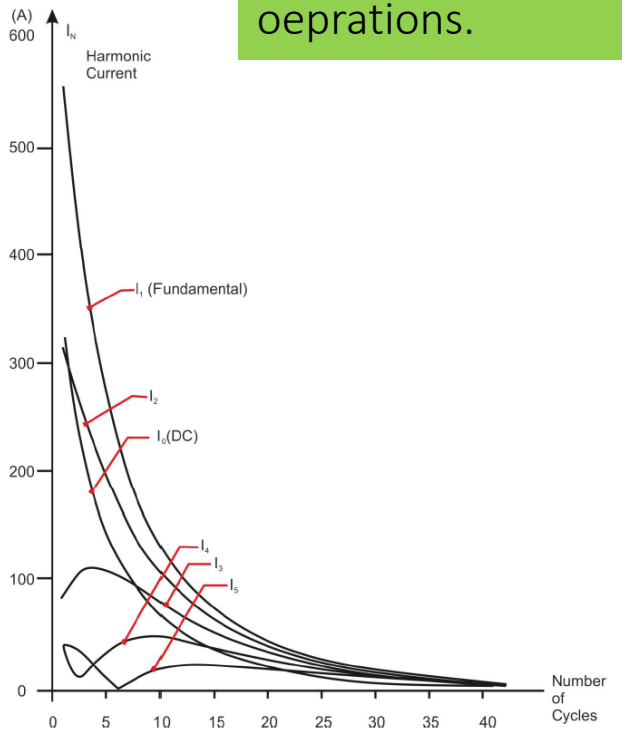
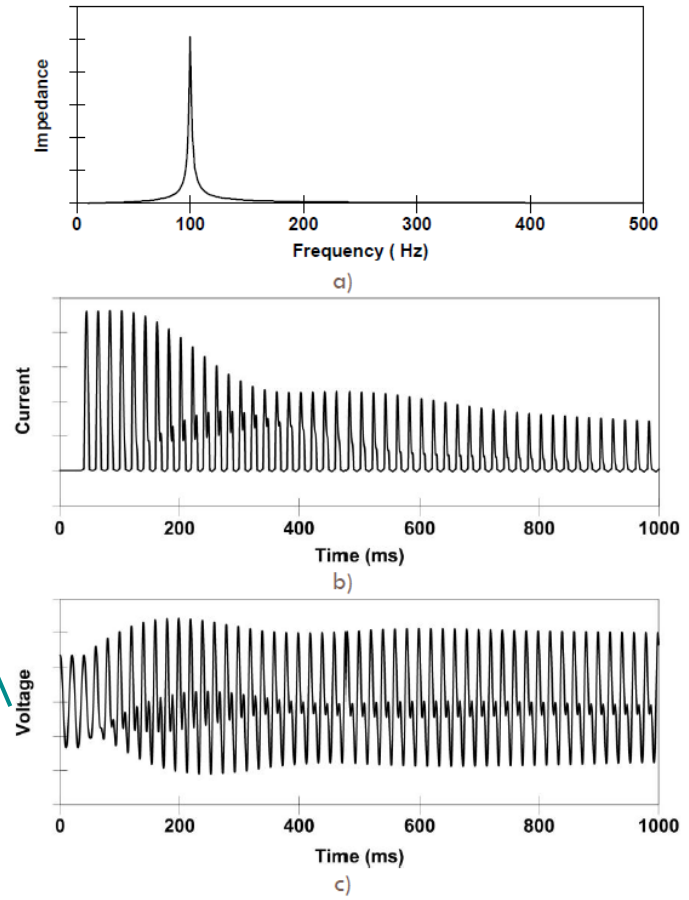


Diagram of the test system



Harmonic components of inrush current
(Even order Harmonics are mainly problems)



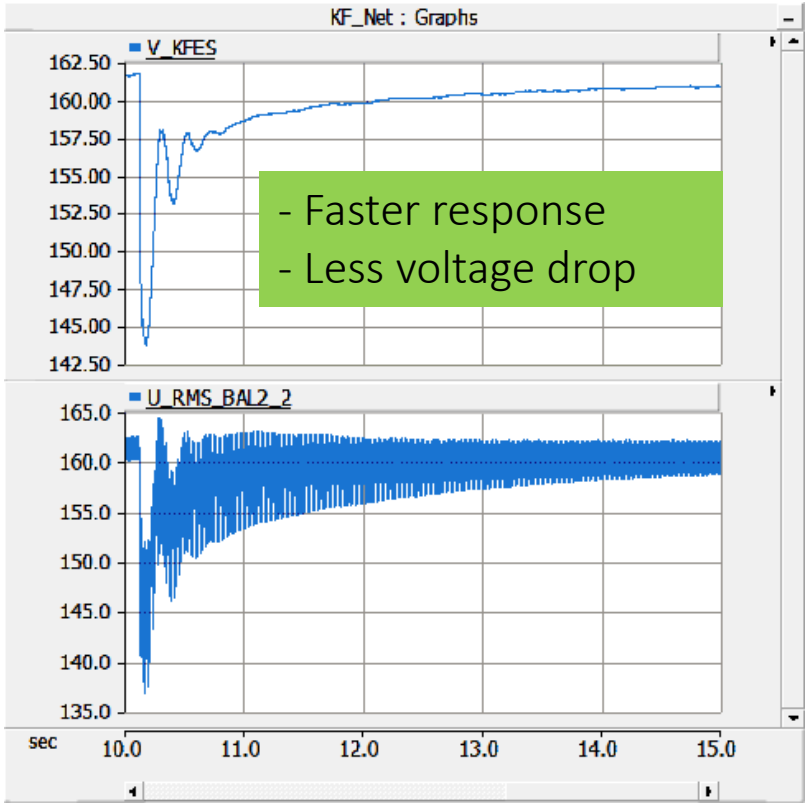
(a) Impedance at trans. bus. (b) Trans. Current during energization, (c) Trans. Terminal voltage

[2] Transformer Energization in Power Systems: A Study Guide – Cigre Working group brochure (C4. 307)

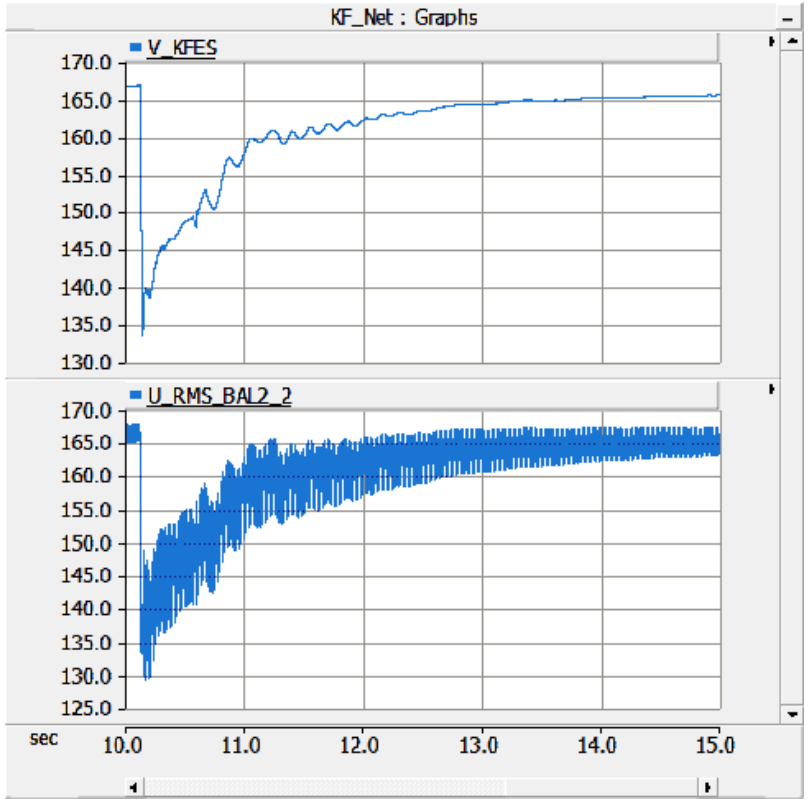
TRANSIENT STUDIES AND INFLUENCES FROM POWER CONVERTERS

Transformer energization – example from KF project

RMS voltage at KFE busbar during energization of KFE transformer (450 MVA)

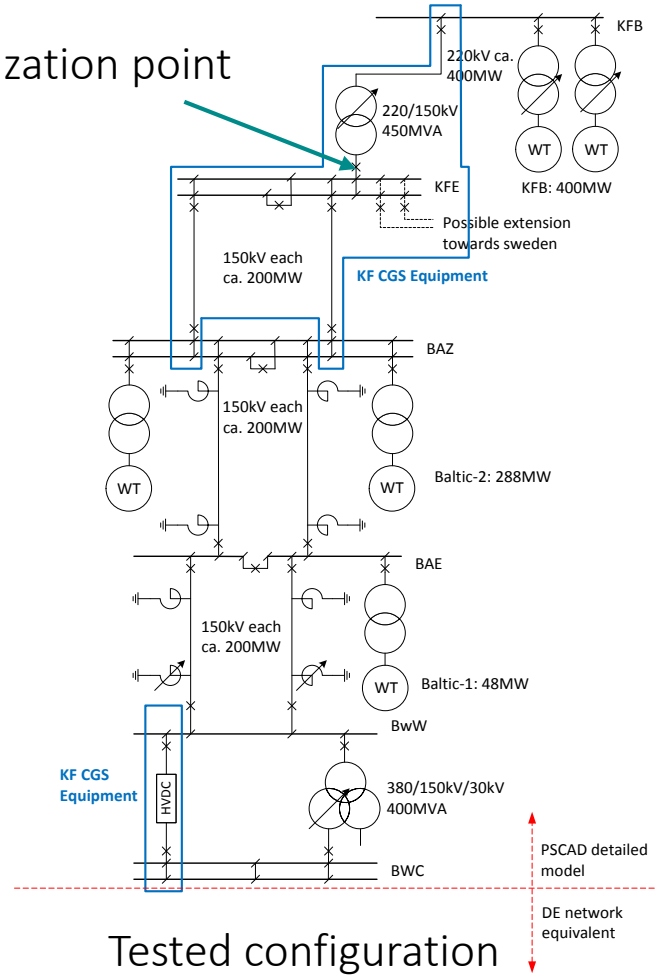


With BtB converter



Without BtB converter

Energization point

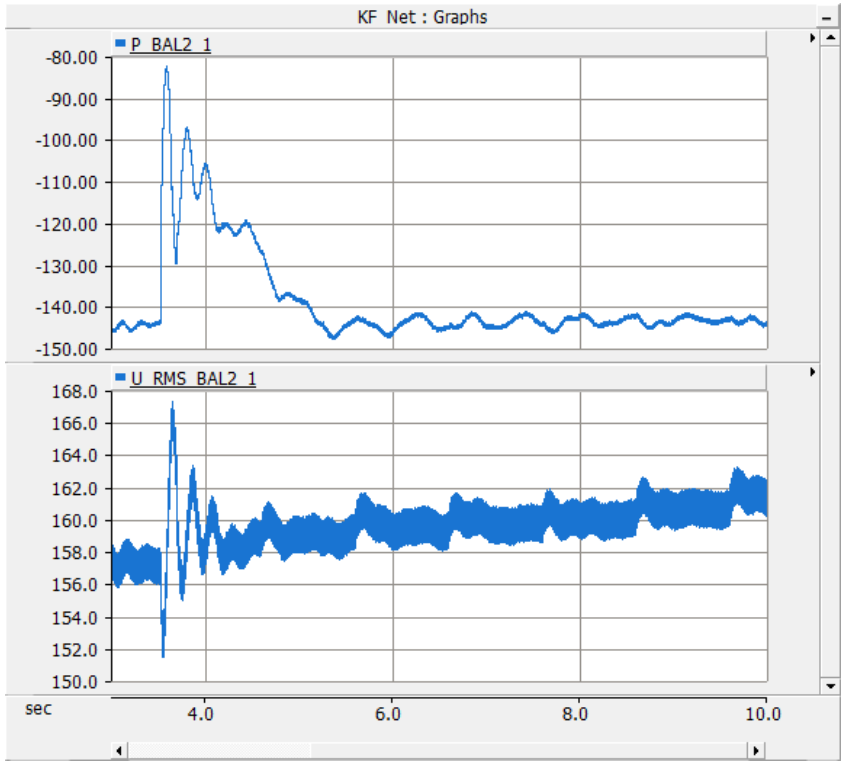


Tested configuration

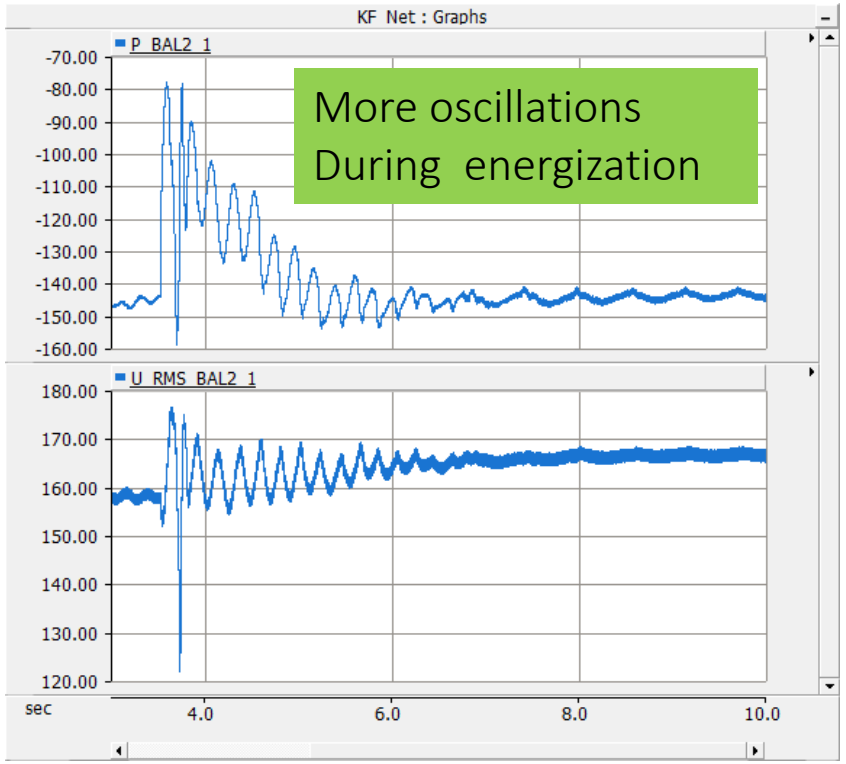
TRANSIENT STUDIES AND INFLUENCES FROM POWER CONVERTERS

Transformer energization – example from KF project

Active power and RMS voltage measured from BAL2 busbar

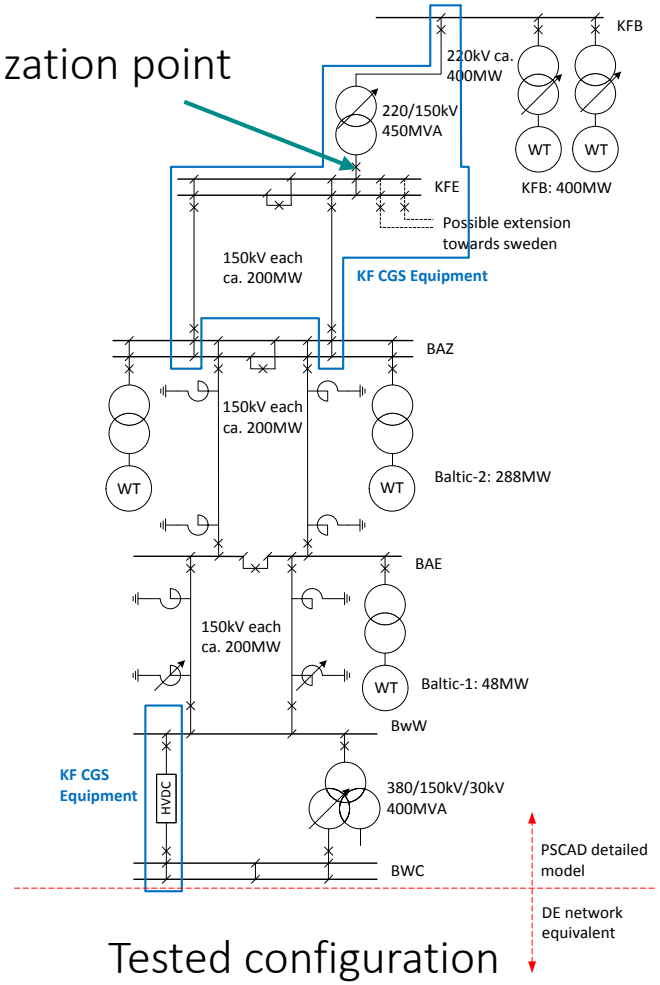


With BtB converter



Without BtB converter

Energization point



Tested configuration

TRANSIENT STUDIES AND INFLUENCES FROM POWER CONVERTERS

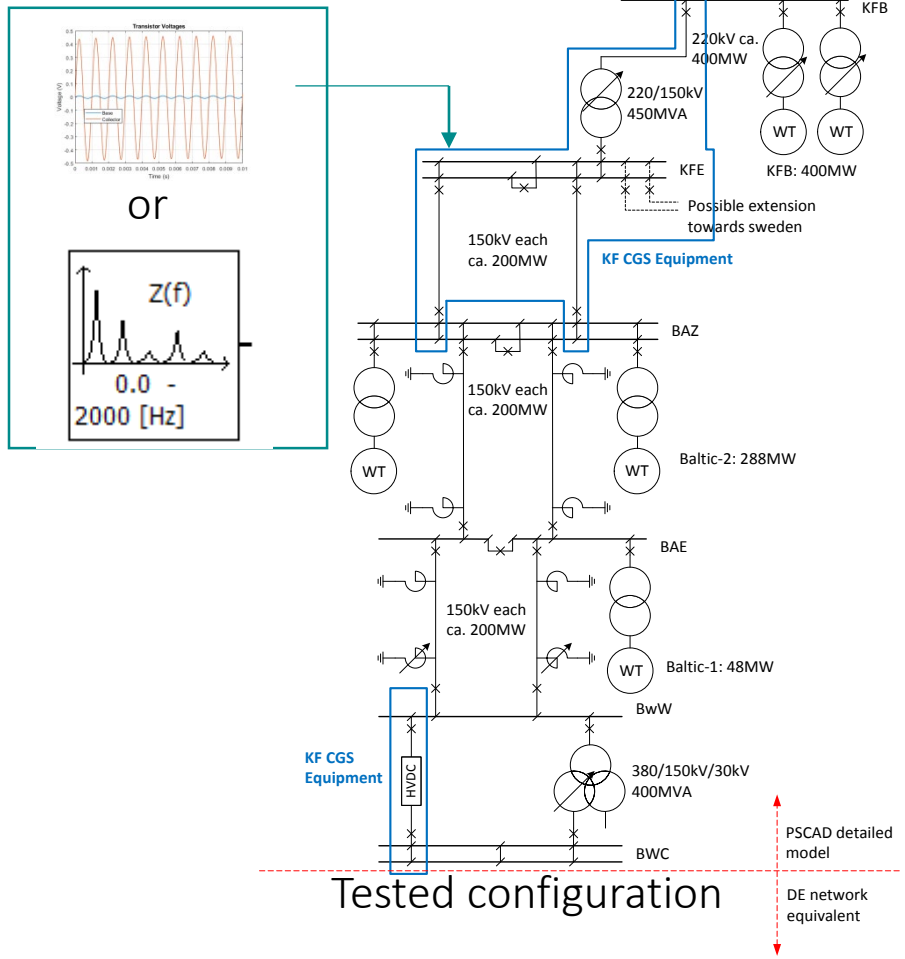
Transformer energization – example KF project

Methodology for verification

- Frequency scan from PSCAD to certain busbar, where components are to be energized.
- Small signal perturbation to whole grid

Results for discussion

- Resonance points around 100 Hz is shifted to another frequency or damped out as a frequency range is within a control bandwidth of power converters.
- Mostly, Power converters give a positive impact during transformer energizations, but there are also risks that resonance at even order harmonics can increase.



TRANSIENT STUDIES AND INFLUENCES FROM POWER CONVERTERS

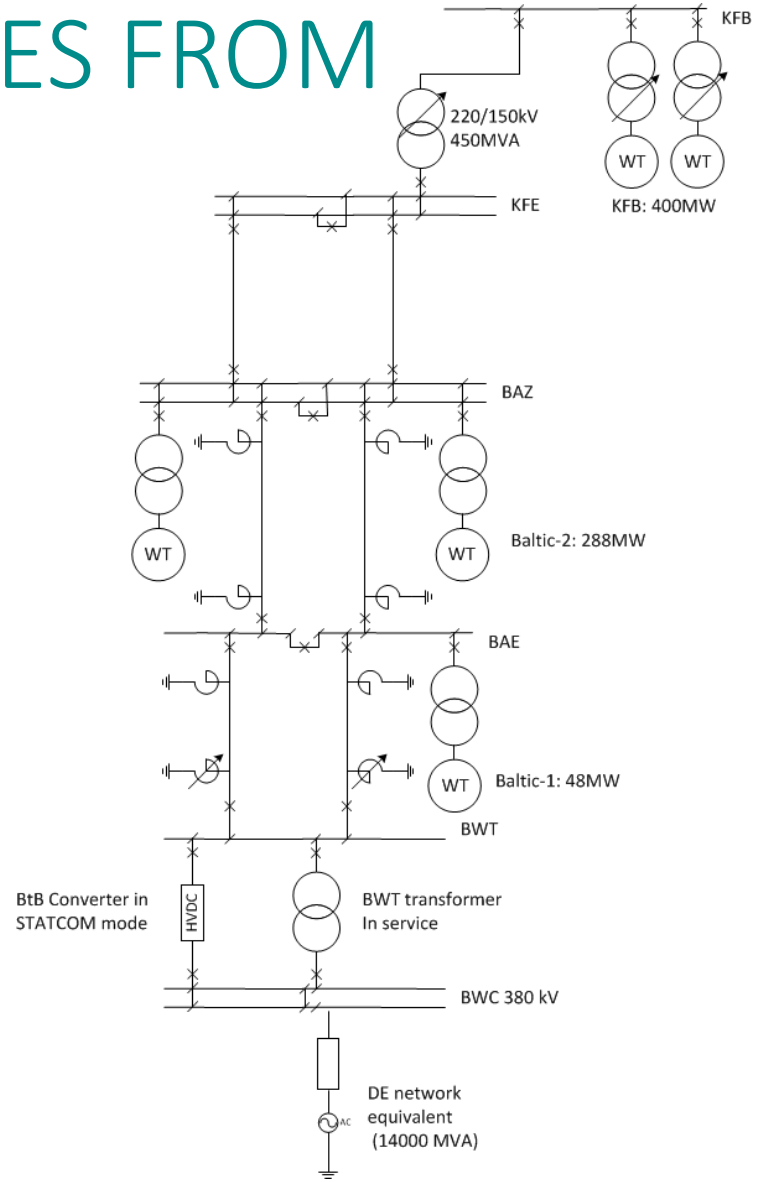
High frequency oscillations - Problem statement and conditions

Problem

- Unexpected harmonics at both high and low frequency are identified at the KFB busbar.

Scenario for simulation

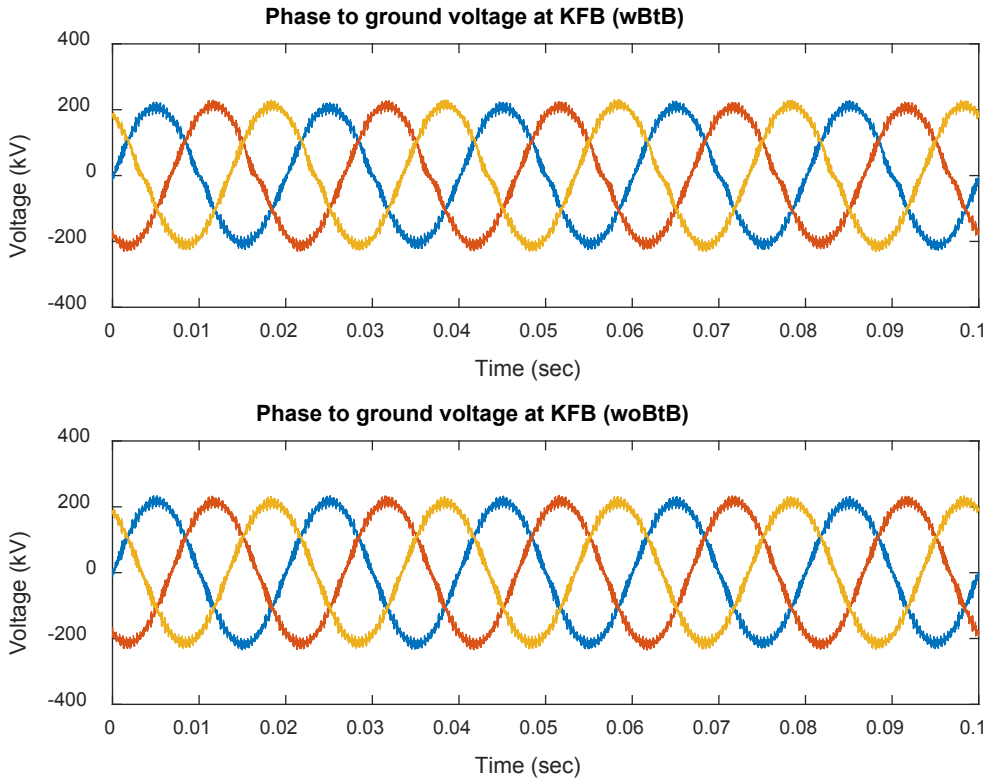
- No AC-connection to Denmark
- Back-to-back (BtB) converter is in STATCOM mode **or not connected**
- The BWT Transformer is in Service.
- BAL1/2 and KFB are connected to the grid with **zero wind power production**.
- German side grid is considered as **strong grid conditions** (14000 MVA)



TRANSIENT STUDIES AND INFLUENCES FROM POWER CONVERTERS

Simulation cases and results – steady state harmonics

- Since KFB wind farms are connected with a long cable from german grid side, the wind farms are actually connected with very weak grid.
- Impedance interaction occured at high frequency range above 1kHz between the wind farms and the rest of grid.
- The oscillations persist as steady state harmonics during normal operation.



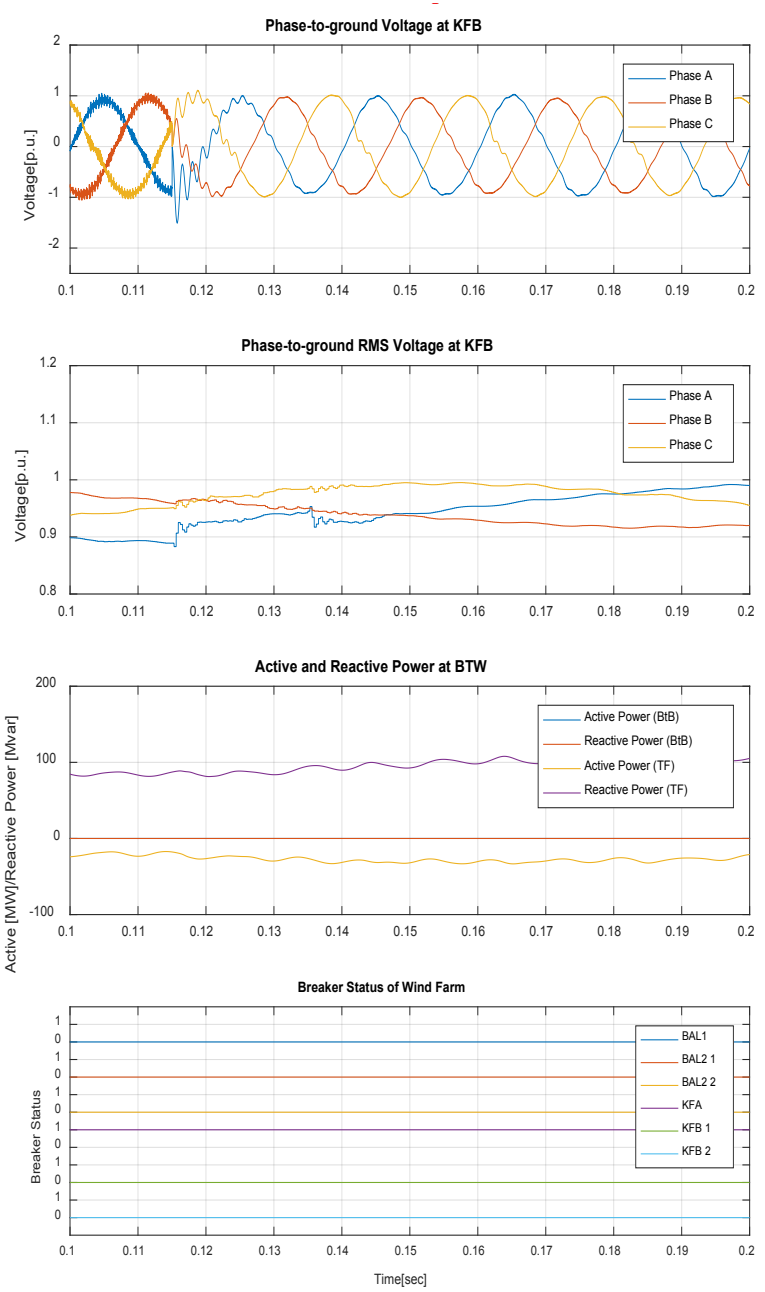
TRANSIENT STUDIES AND INFLUENCES FROM POWER CONVERTERS

Simulation cases and results – Transient behavior

Scenario for simulation (whole KF model)

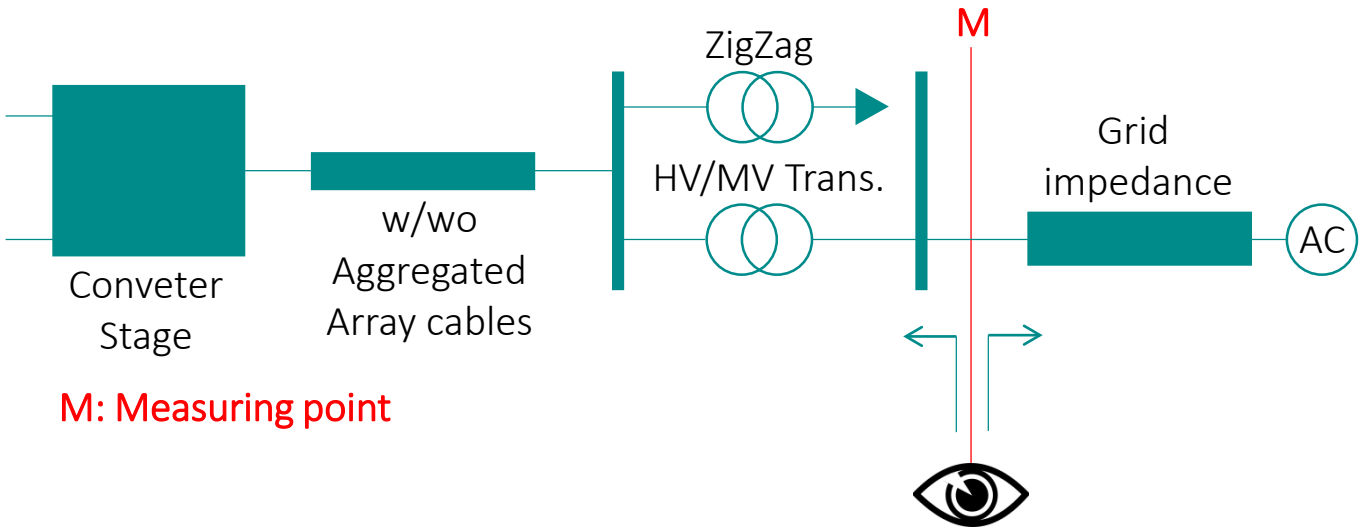
- No AC-connection to Denmark
- No matter Back-to-back (BtB) converter is in STATCOM mode **or not connected.**
- BWT Transformer is in Service.
- BAL1/2 and KFB is connected to the grid with **zero / full wind power production**.
- German side grid is considered as **strong grid conditions** (14000 MVA)
- The Cable between the KFA and the KFB is energized at 0.115 sec.

Interaction point is shifted to another frequency after the energization of cable from the point of interest.



TRANSIENT STUDIES AND INFLUENCES FROM POWER CONVERTERS

Experience from KF transient studies to mitigate high frequency related issues.



Energinet performed small signal perturbations for detail analysis to analyze a root cause of oscillation observed from KF transient related studies.

- Most of oscillations in high frequency (>500 Hz) disappeared after we consider detail array cable models between wind turbines.
- However, low frequency oscillations (<200 Hz) persists or just shifted, or amplified through “array cables”

CONCLUSION

- Principal transient behaviors in Kriegers Flak project are presented, where power electronic devices give “positive effects” in terms of any energization procedure occurred in the grid.
- However, there are also some risks to be careful about. The sub-synchronous oscillations or long transient time , for example, could occur due to negative resistance or interaction between grid impedances and power electronic devices.
- Measuring the impedance profile and their validations of “Black box model” through simulations are going to be really important in perspective of TSO (Transmission System Operator).

QUESTIONS