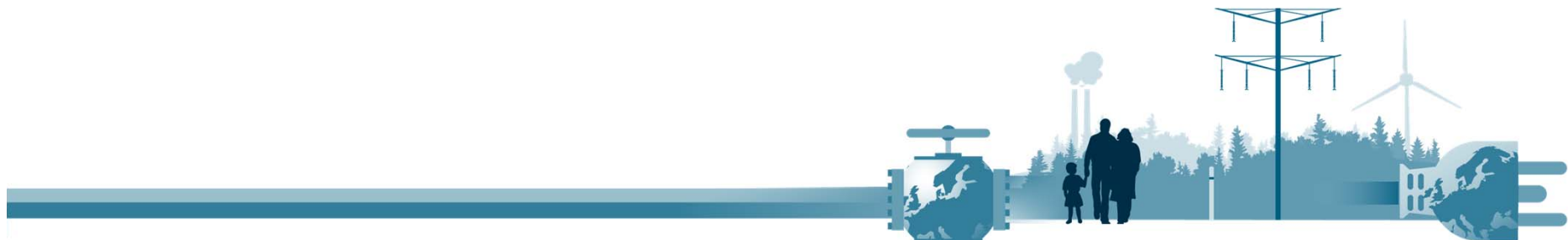


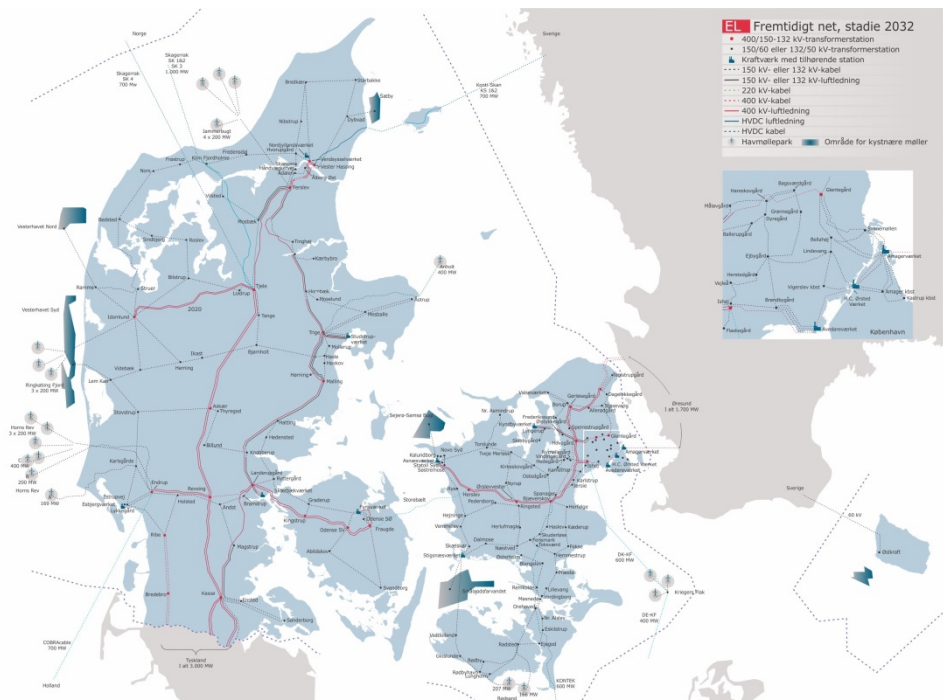
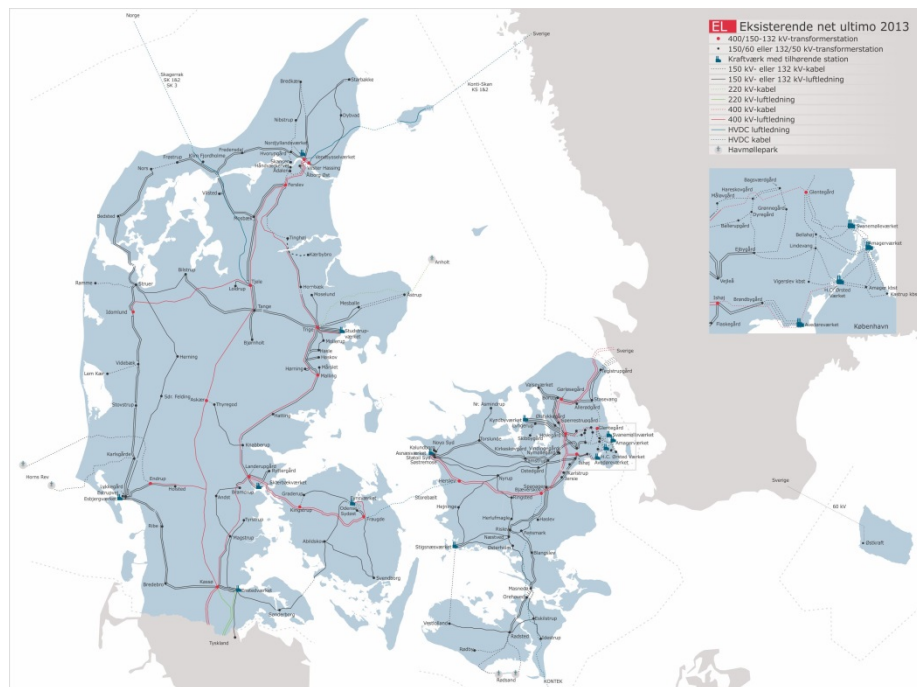
Harmonic Assessment in a Modern Transmission Network

HARMONY Symposium August 2015

Christian Flytkjær Jensen Energinet.dk



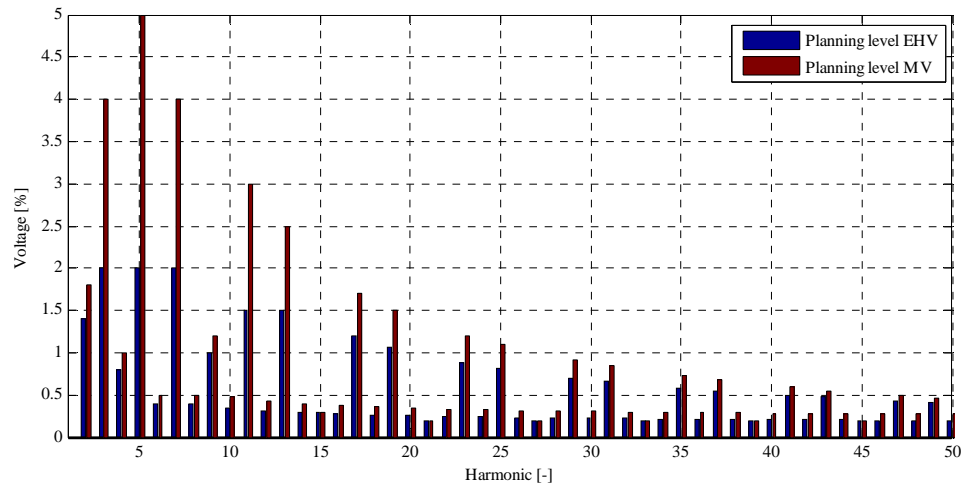
Harmonic Coordination at transmission level



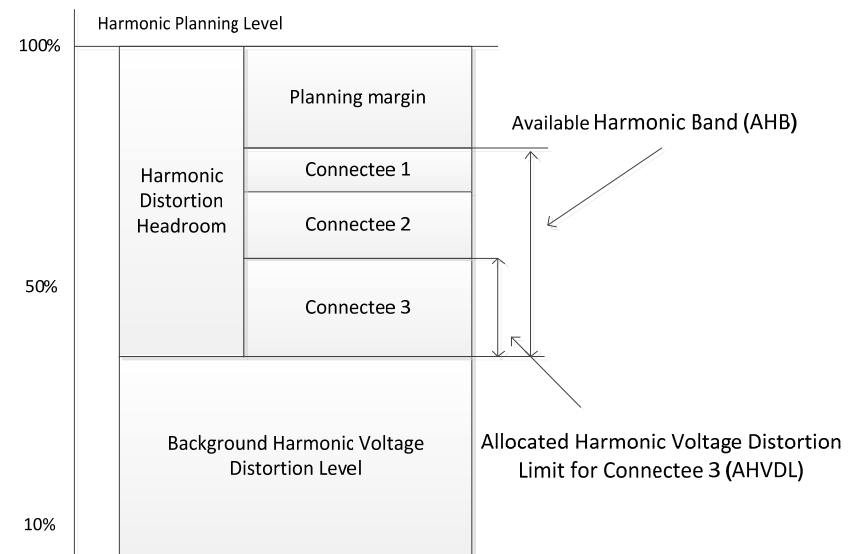
Harmonic Coordination at transmission level



Harmonic Coordination at transmission level – the planning level



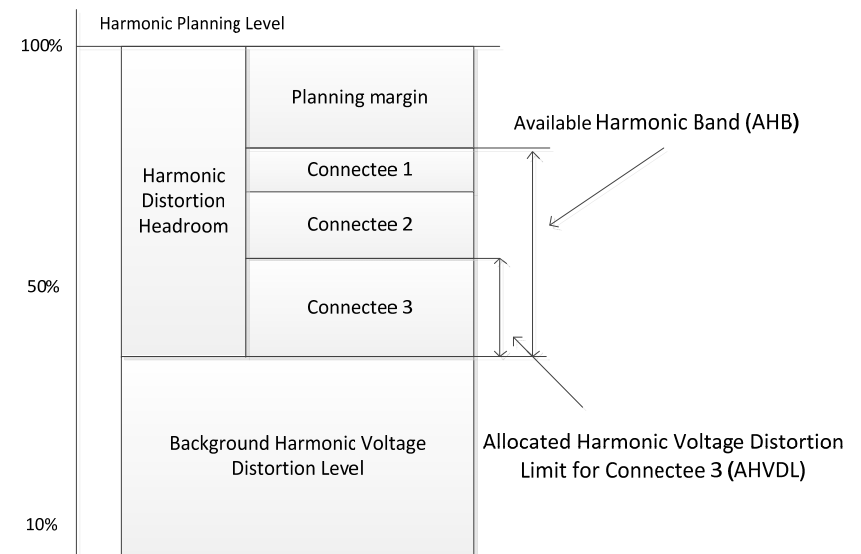
MV and EHV planning levels according to IEC-61000-3-6.
THD_v at MV is restricted to 6% and 3% at MV and HV



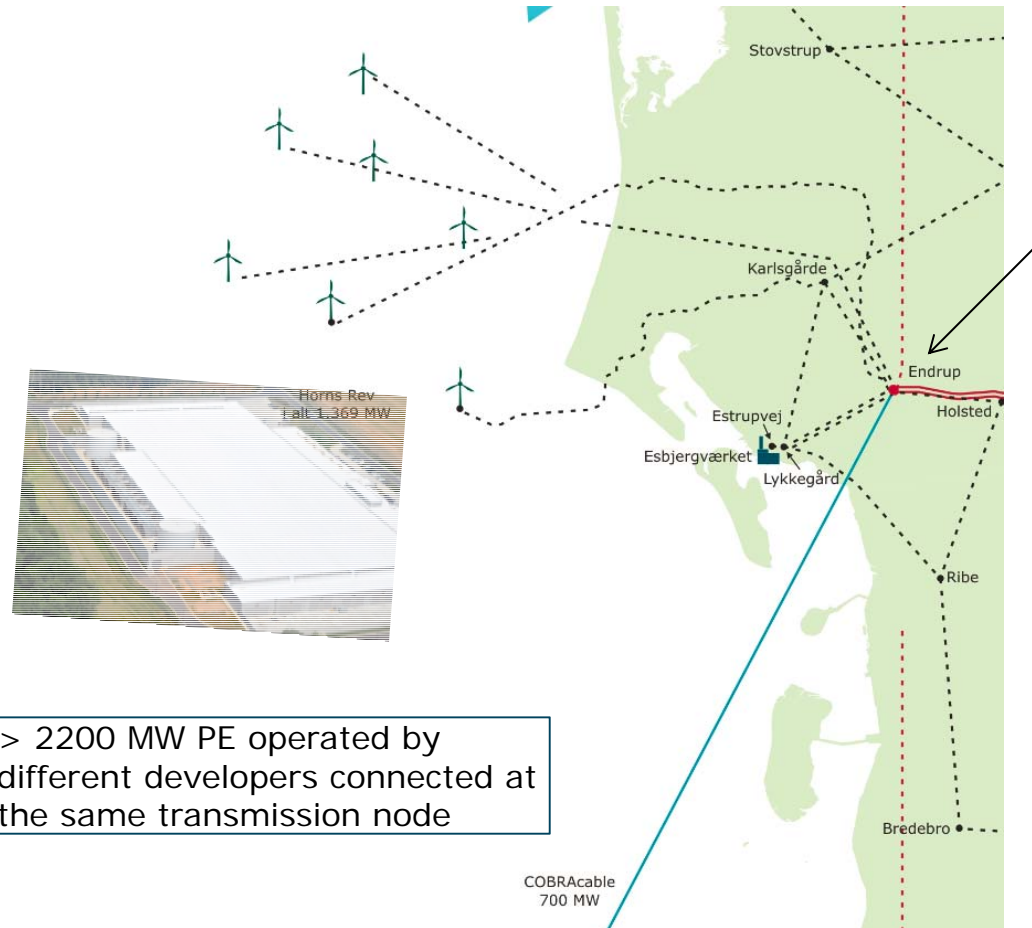
Harmonic Coordination at transmission level – the planning level

The responsibility of the TSO is:

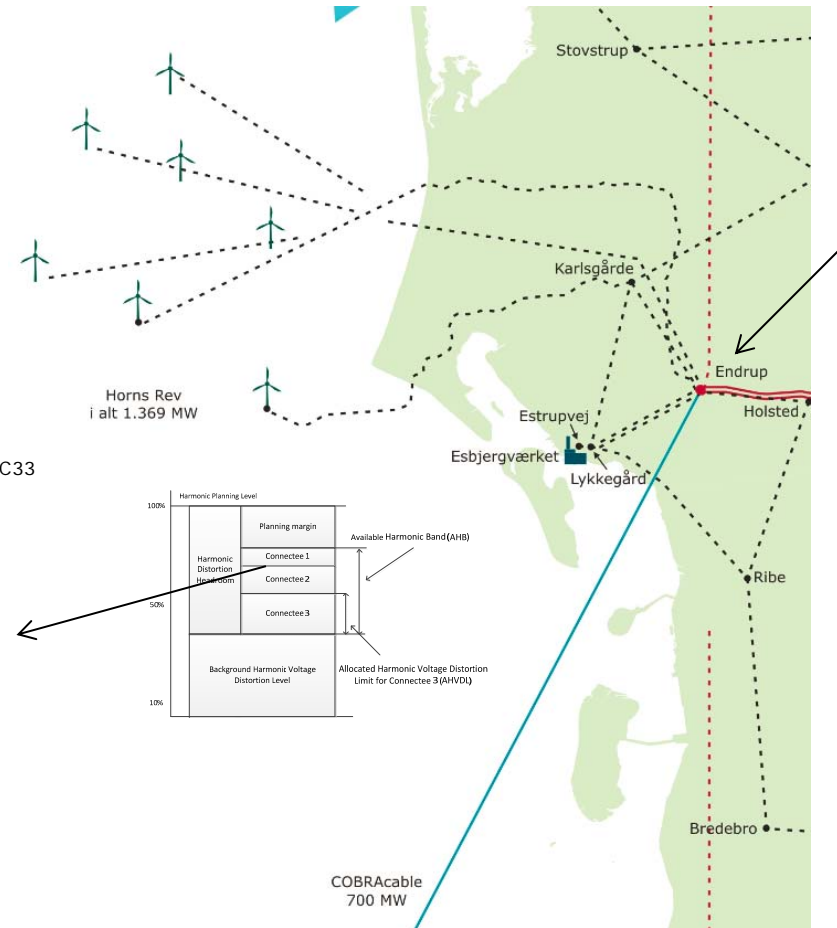
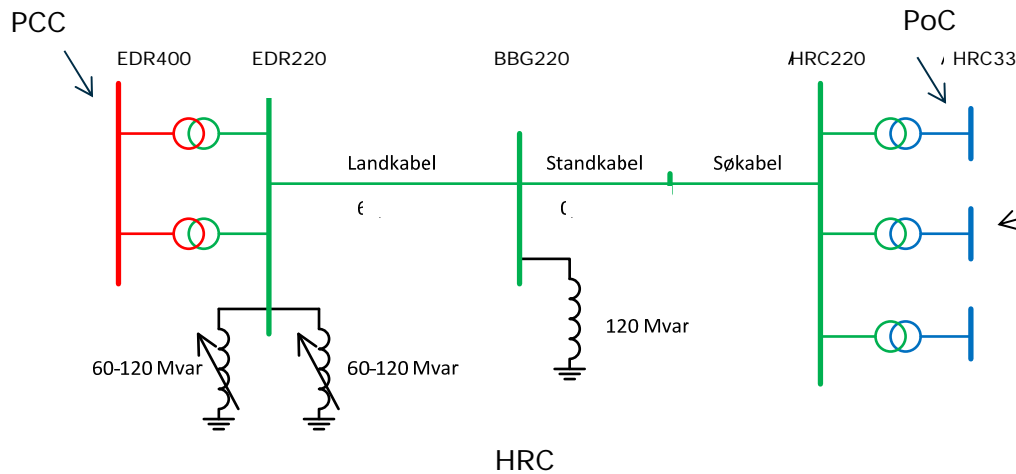
1. Ensure that the harmonic voltage distortion level is below the planning level at all nodes where customers are connected
2. Allocate each connectee as much of the planning level as possible



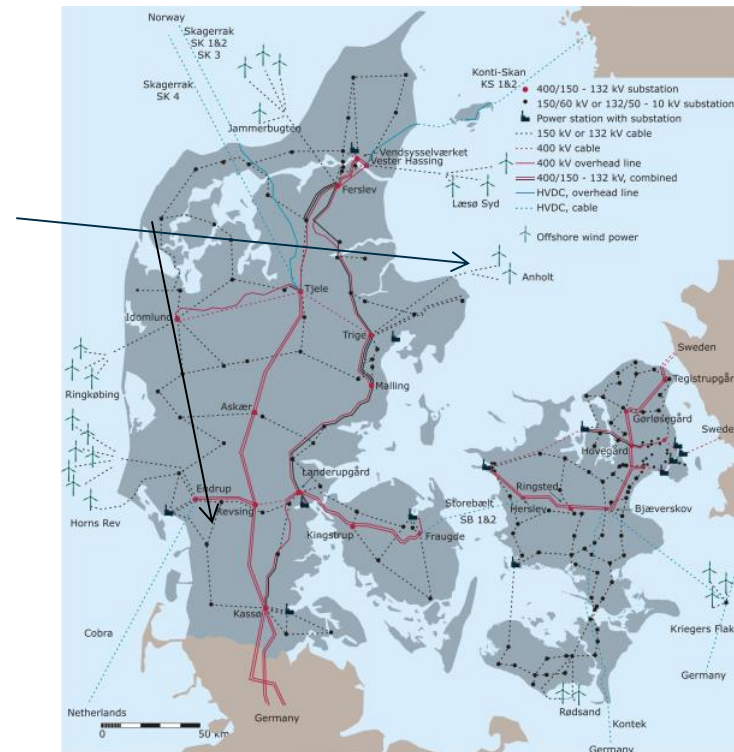
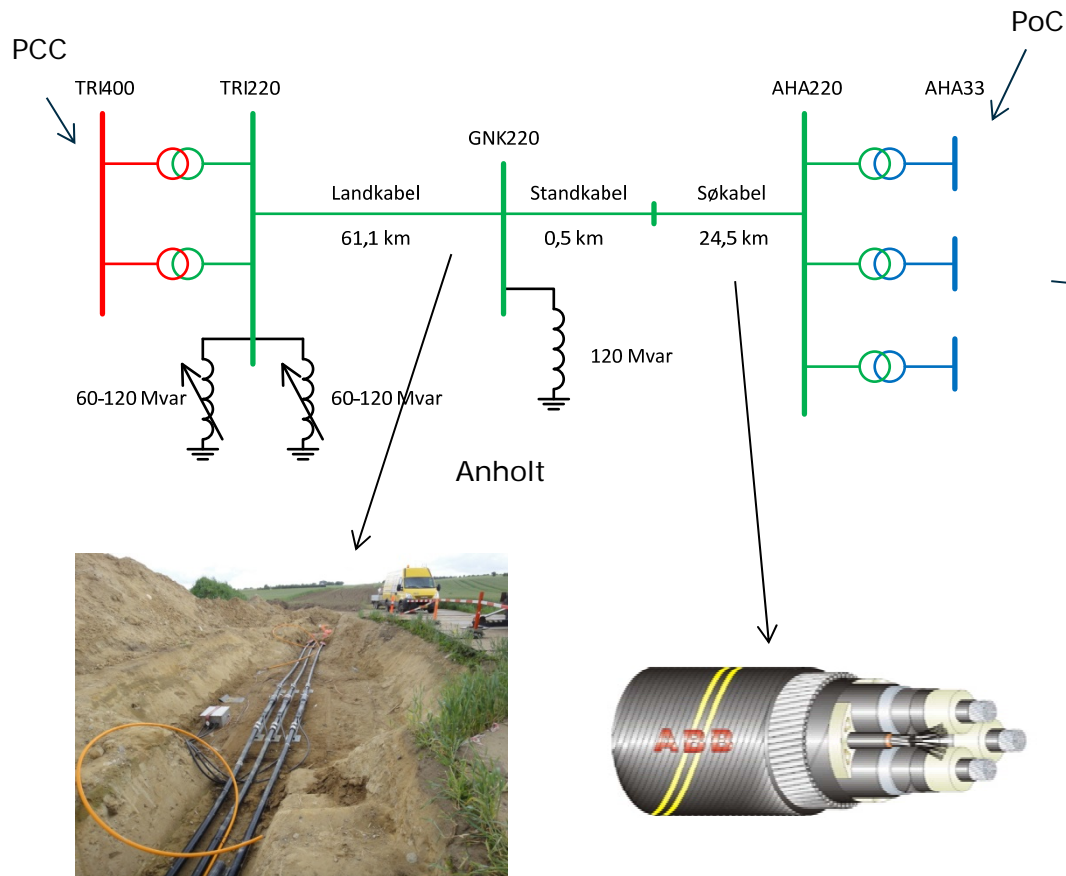
Harmonic Coordination at transmission level – a complicated task



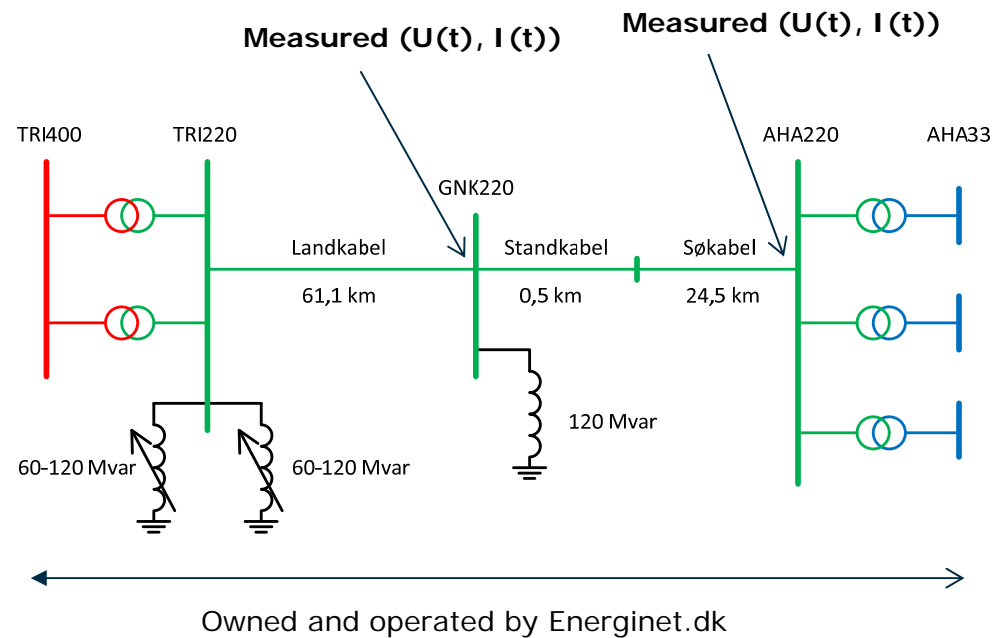
Harmonic Coordination at transmission level – a complicated task



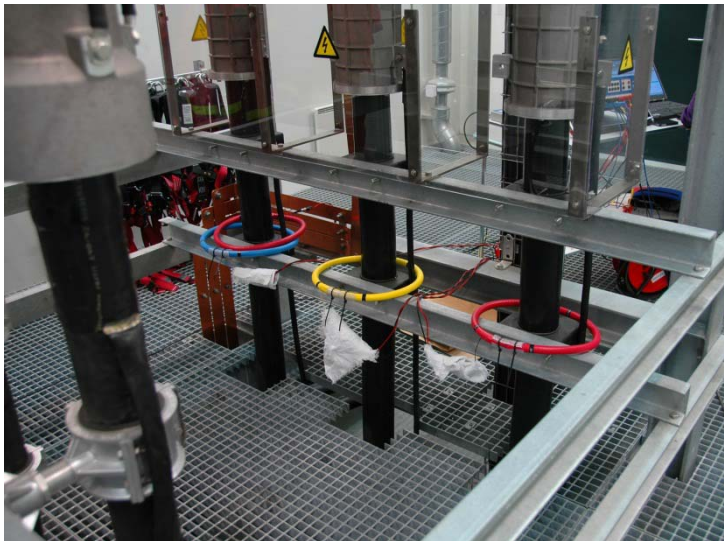
Power quality issues on Anholt



Power quality issues on Anholt



Power quality issues on Anholt

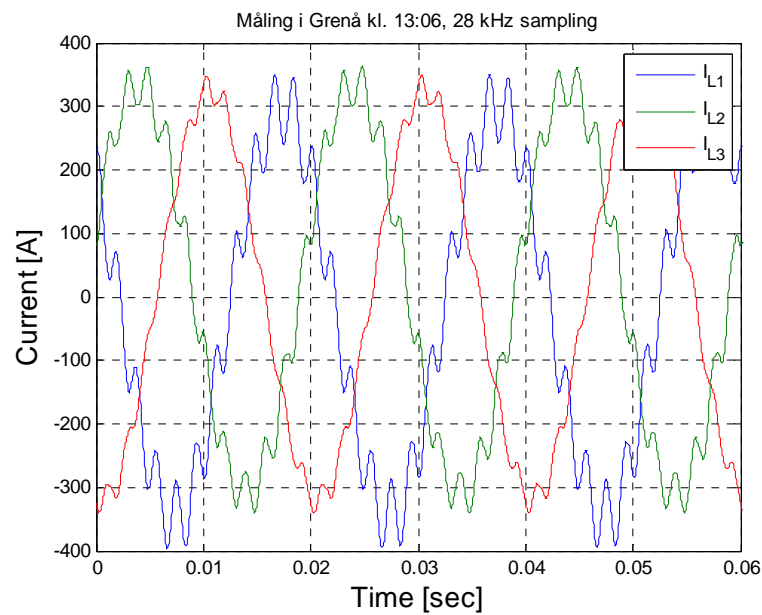


Grenå

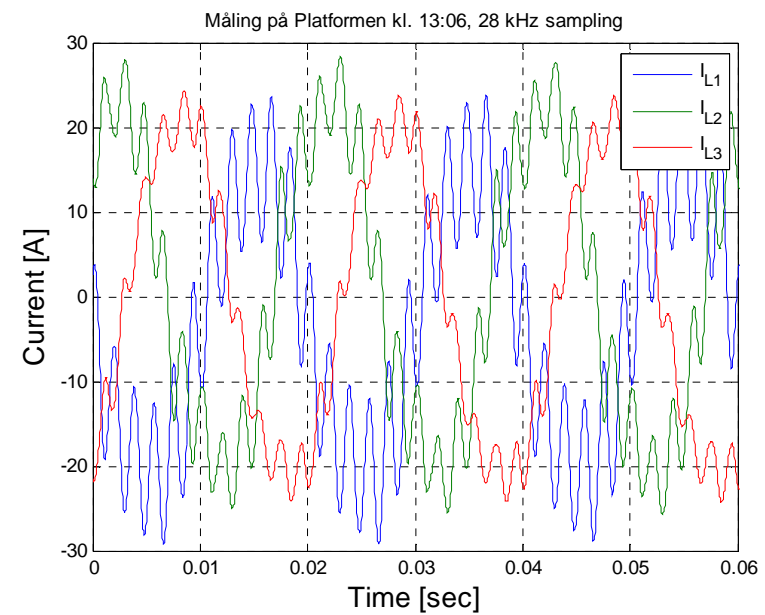


Anholt

Power quality issues on Anholt

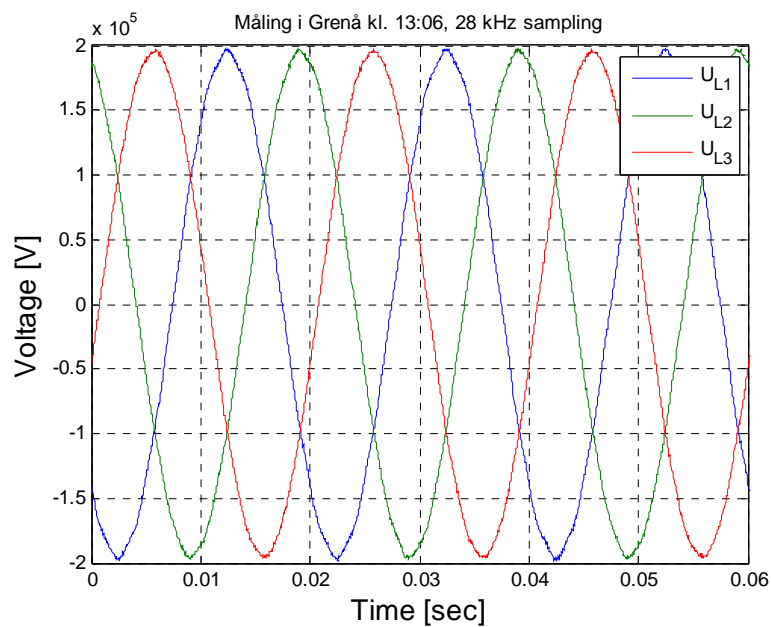


Grenå 220 kV – måling på søkablet

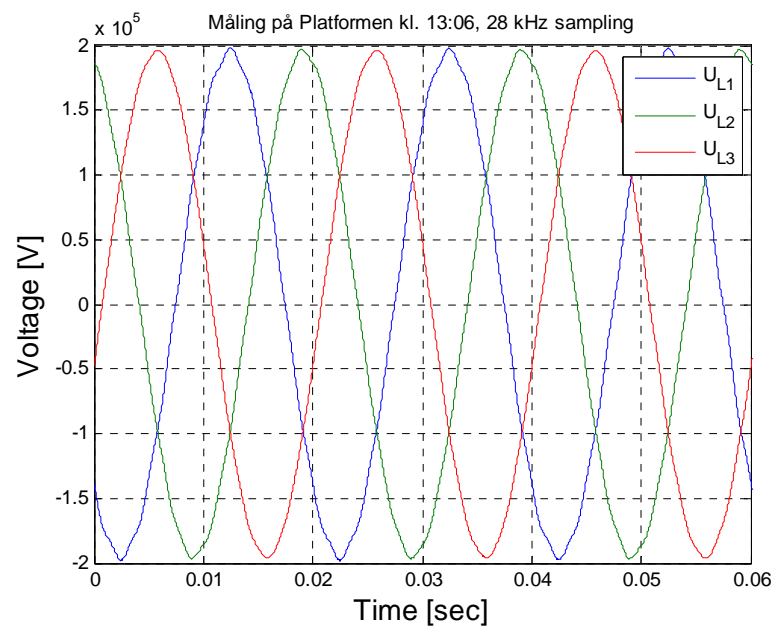


Anholt 220 kV – måling på søkablet

Power quality issues on Anholt

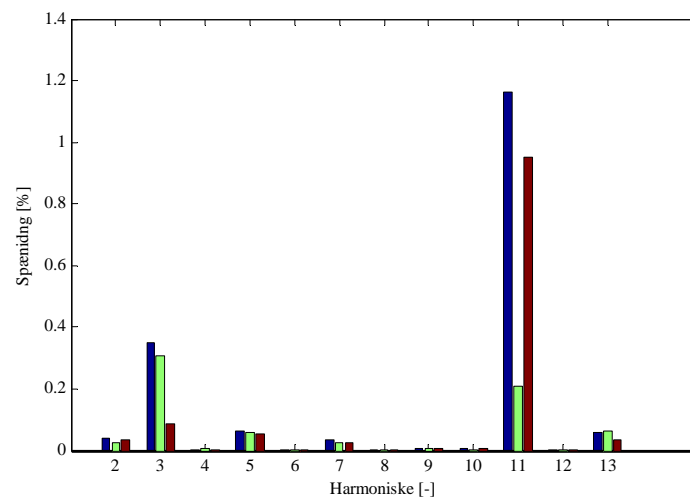
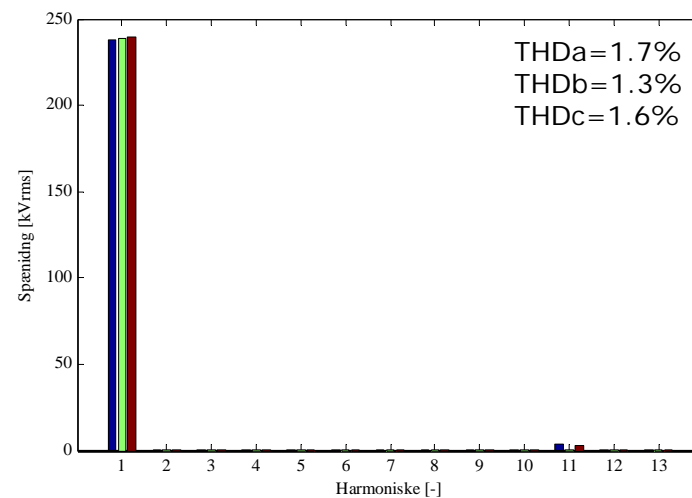
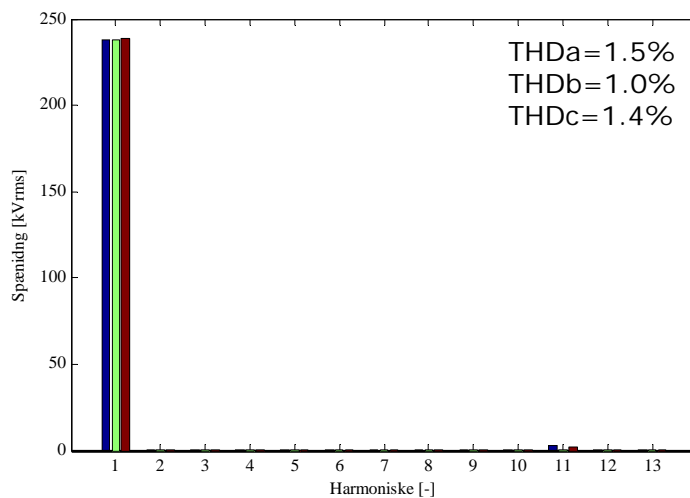


Grenå 220 kV

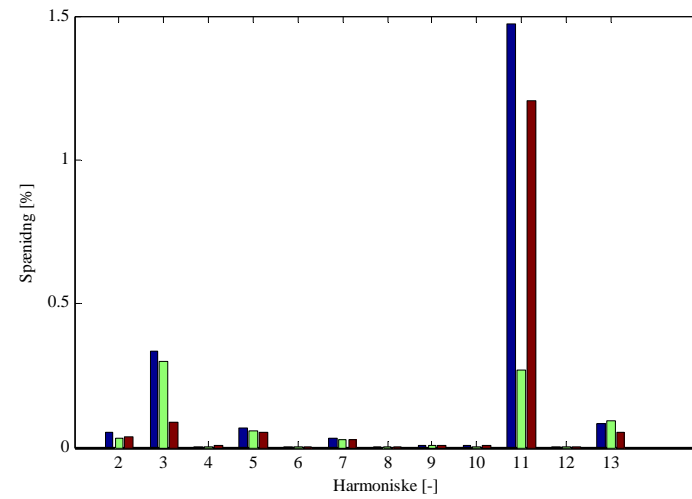


Anholt 220 kV

Power quality issues on Anholt



Grenå 220 kV



Anholt 220 kV

Measuring challenges



Wound GIS voltage transformers class 0.2

Measuring challenges

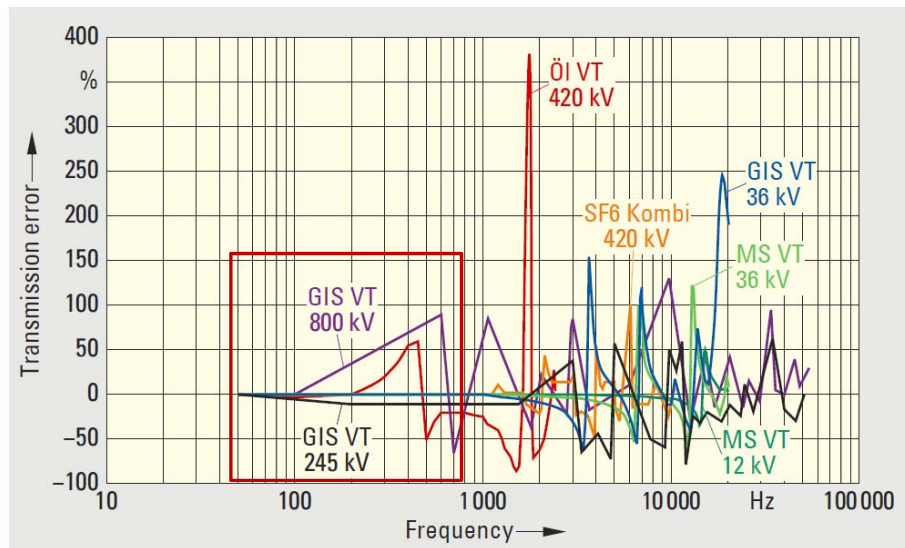
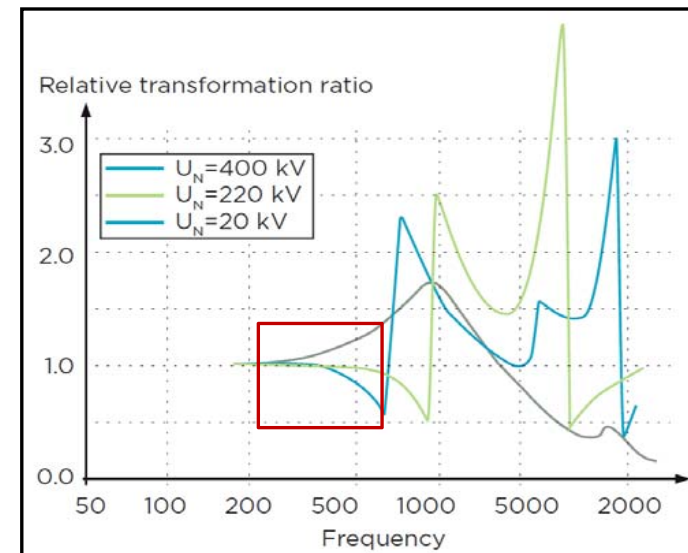


Fig. 1. Transmission errors with various different inductive instrument transformer types



Measuring challenges

Table 4-1: Suitability of IVTs for harmonic measurements at different voltage levels

	Voltage level	2 nd - 7 th Harmonic	8 th - 20 th Harmonic	21 st - 50 th Harmonic
MV	10 kV	Yes	Yes	Yes
	20 kV	Yes	Yes	Uncertain
	30 kV	Yes	No	No
HV	60 kV	Yes	Yes	Uncertain
	110 kV	Yes	Uncertain	No
EHV	≥ 220 kV	Uncertain	No	No



Measuring challenges

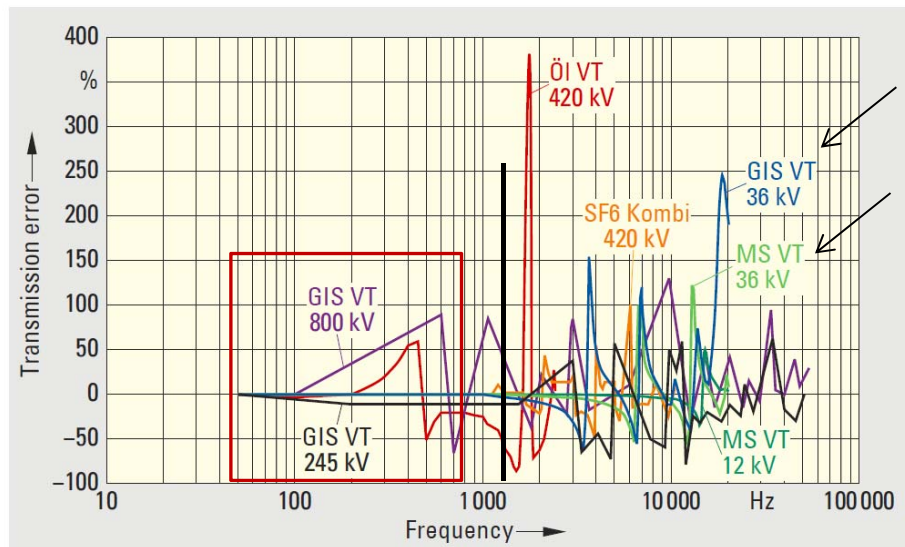
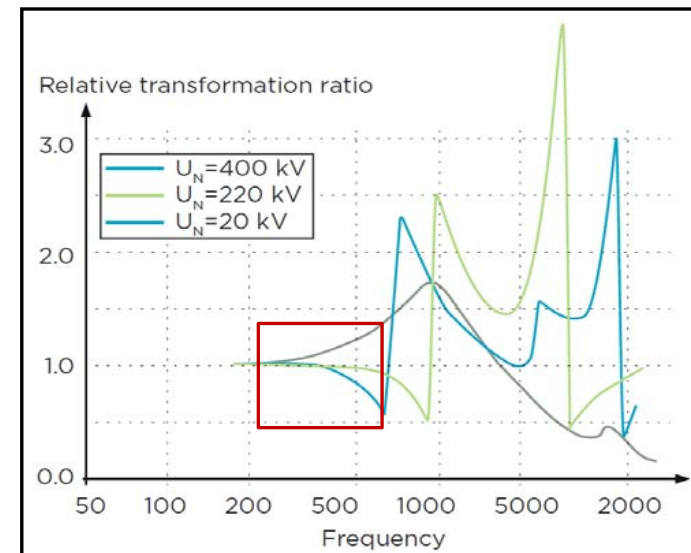
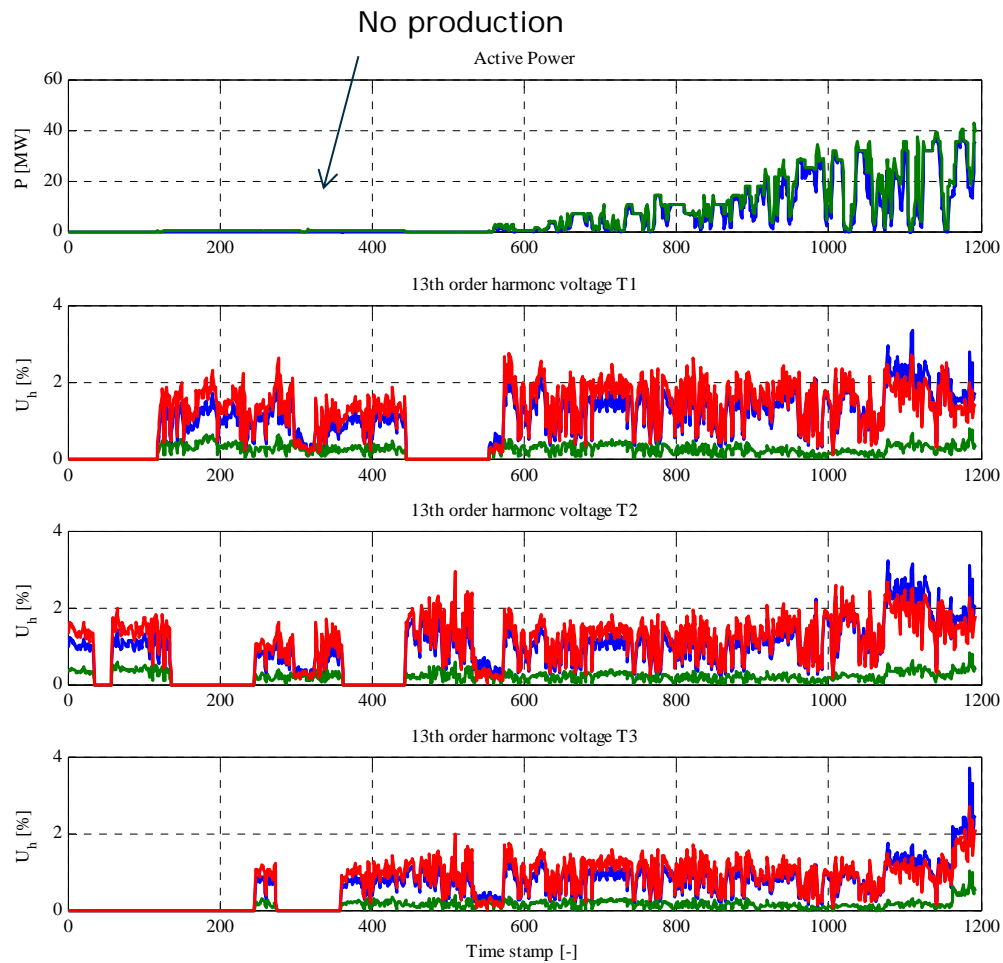


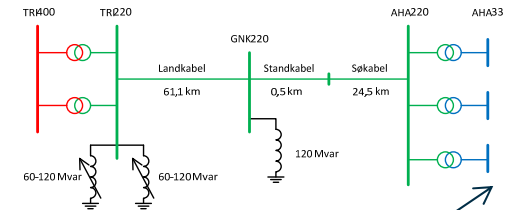
Fig. 1. Transmission errors with various different inductive instrument transformer types



Harmonic distortion at the PoC

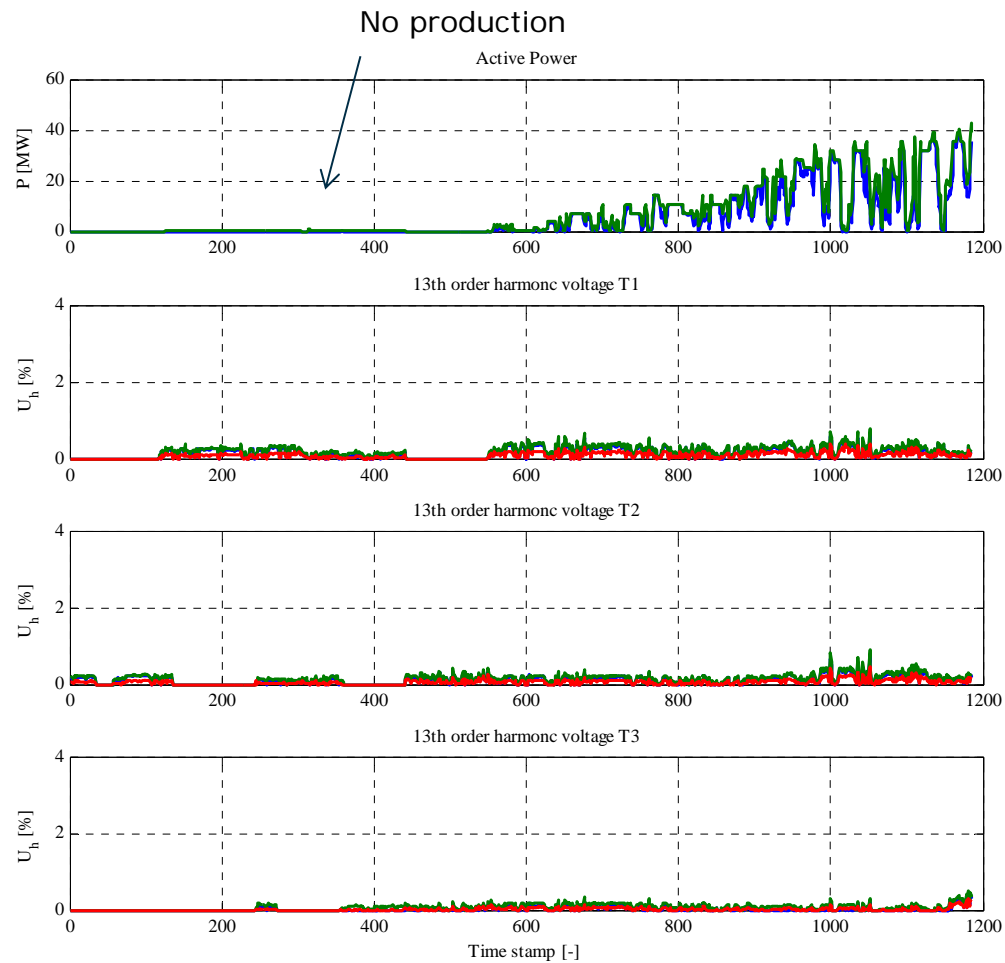


11th order harmonic at 33 kV level

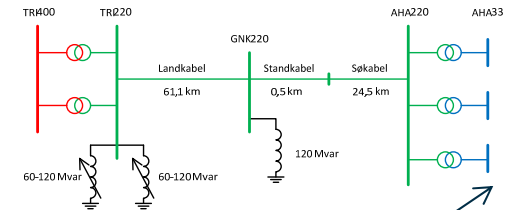


Poor correlation of harmonic voltage level to production

Harmonic distortion at the PoC



13th order harmonic at 33 kV level



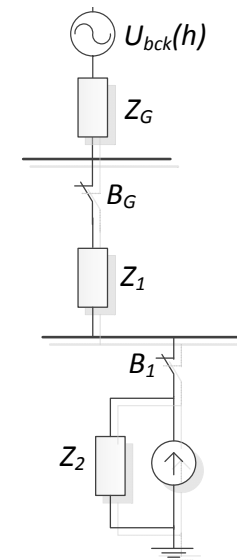
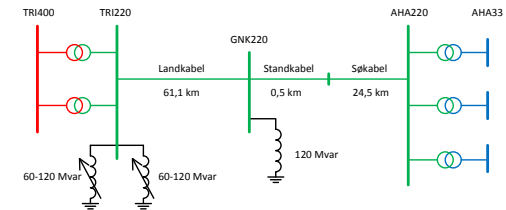
Poor correlation of harmonic voltage level to production

Additional Harmonic Contribution (AHC)

The Harmonic Voltage Distortion Level at the PoC for the h^{th} harmonic can be calculated as:

$$U_{HVDL_{PoC}}(h) = G(h) \cdot U_{bck}(h) + I(h) \cdot Z_{tot}$$

where $G(h)$ is an amplification factor (gain factor) from 400 kV busbar to the PoC and Z_{tot} is the combined impedance seen by the current source $i(h)$.

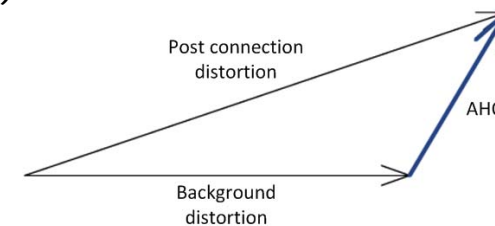
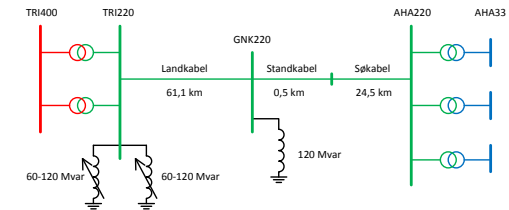


Additional Harmonic Contribution (AHC)

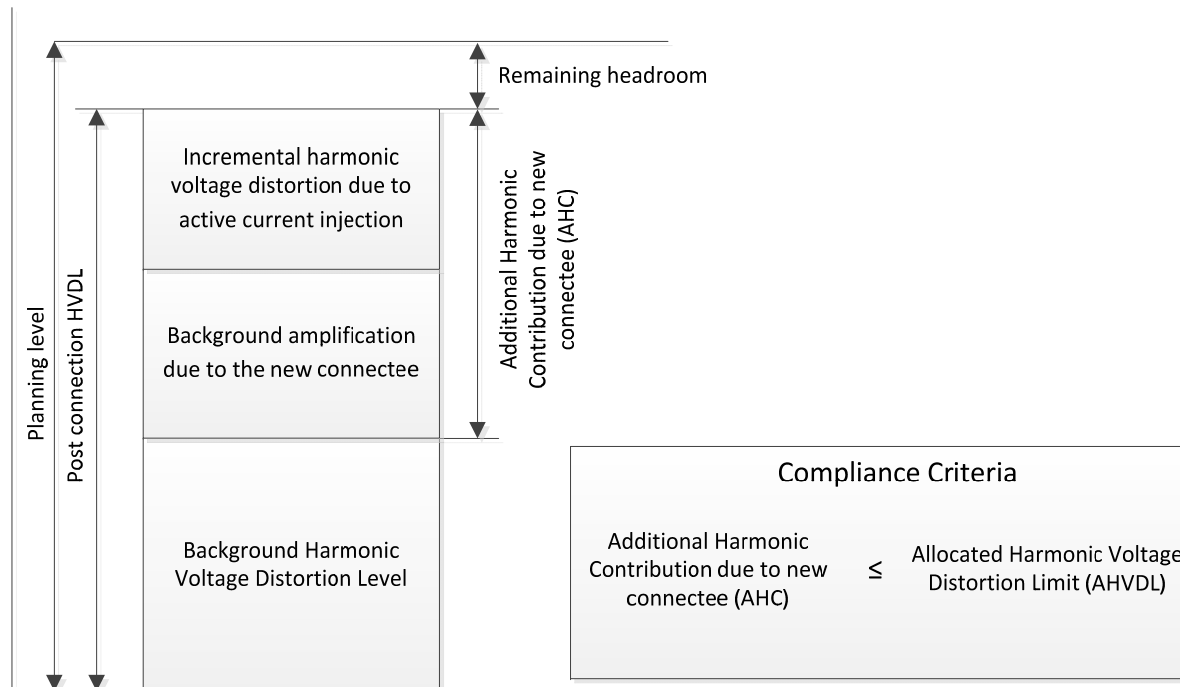
Additional Harmonic Contribution (AHC)

The Additional Harmonic Contribution is defined as the total increase in the magnitude of the Harmonic Voltage Distortion Level (HVDL) due to connection of the Plant to the Transmission System. The AHC includes the increase in HVDL due to:

1. Additional harmonic distortion due to harmonic voltages or currents generated and emitted by the Plant.
2. Amplification of the background harmonic voltage distortion level at the PoC caused by an interaction between the Plant's and the Transmission System's harmonic impedances (for instance due to resonance)



Additional Harmonic Contribution (AHC)



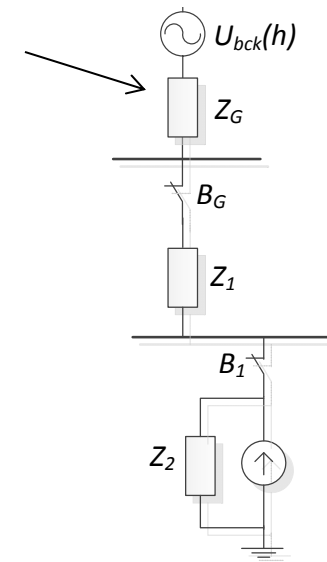
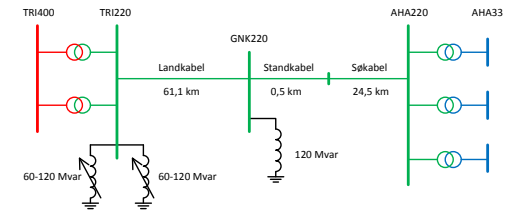
$$U(h)_{AHC} = (G(h) - 1) \cdot U_{bck}(h) + I_h \cdot Z_{tot}$$

Factors influencing the AHC – grid impedance

The Harmonic Voltage Distortion Level at the PoC for the h^{th} harmonic can be calculated as:

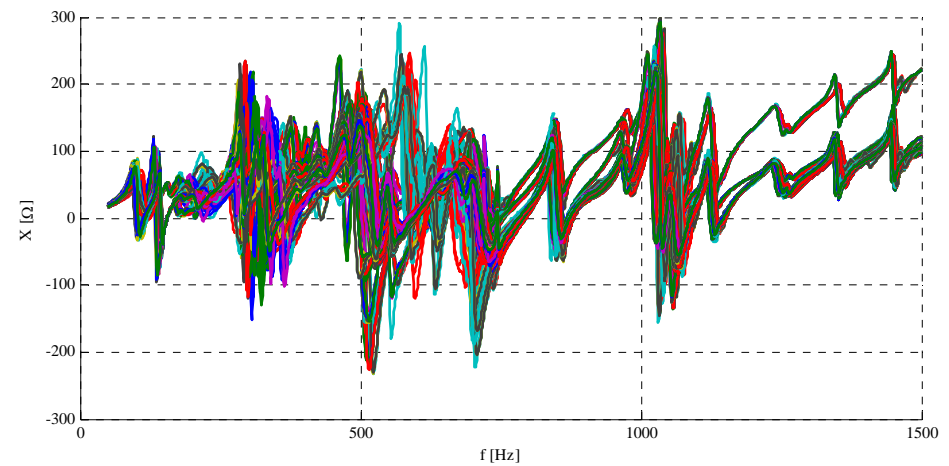
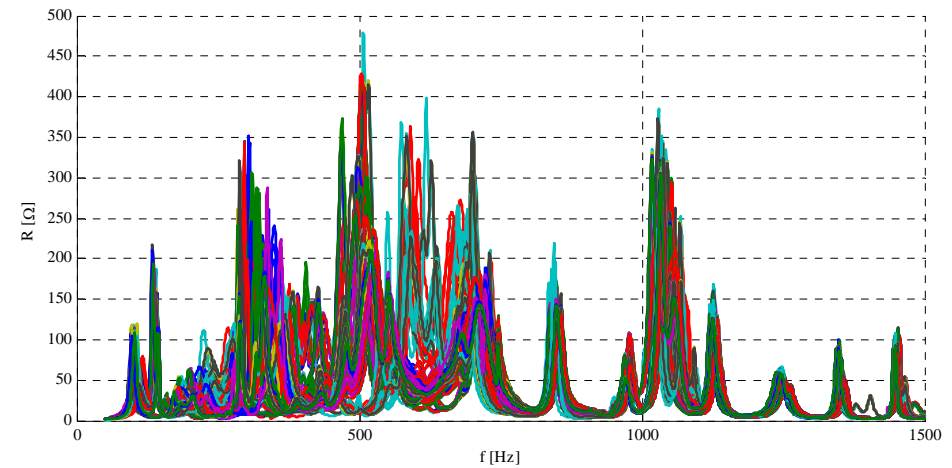
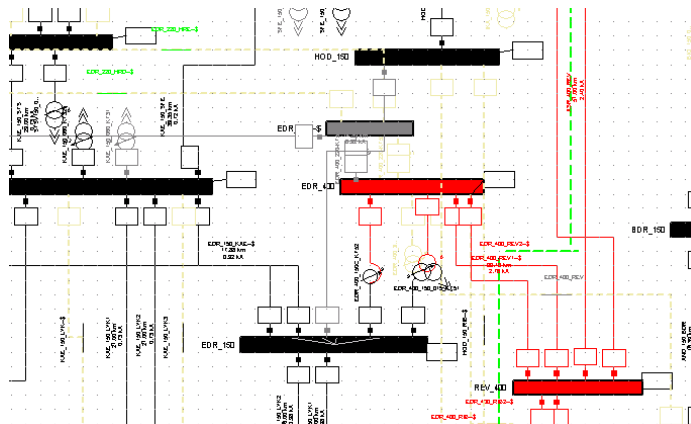
$$U_{HV D L_{PoC}}(h) = G(h) \cdot U_{bck}(h) + I(h) \cdot Z_{tot}$$

where $G(h)$ is an amplification factor (gain factor) from 400 kV busbar to the PoC and Z_{tot} is the combined impedance seen by the current source $i(h)$.



Factors influencing the AHC – grid impedance

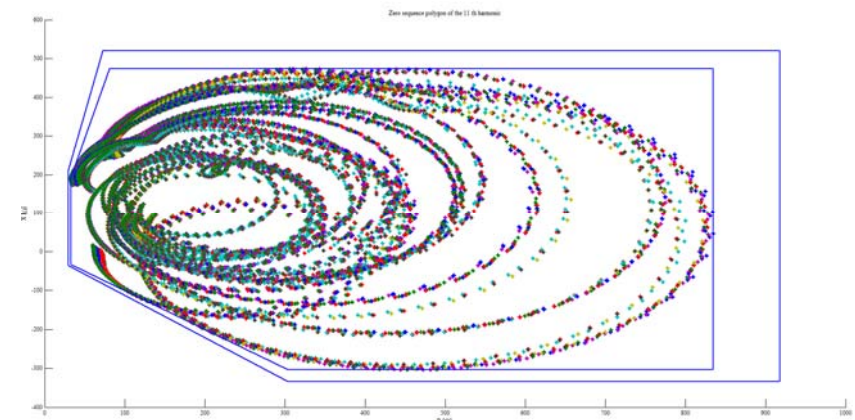
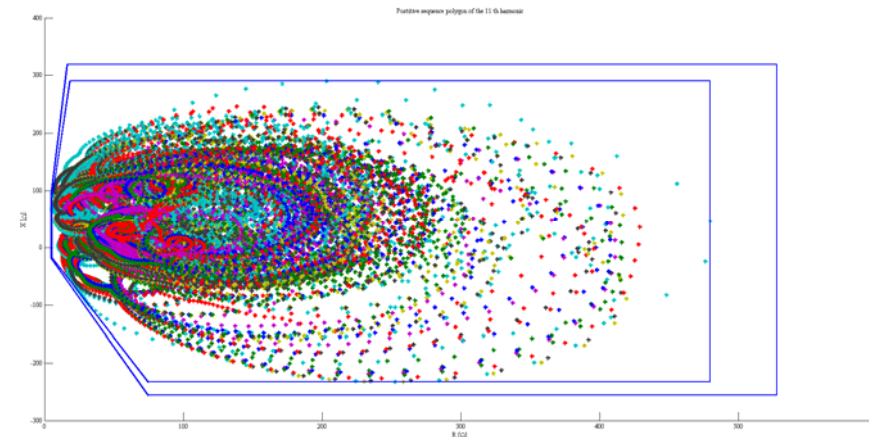
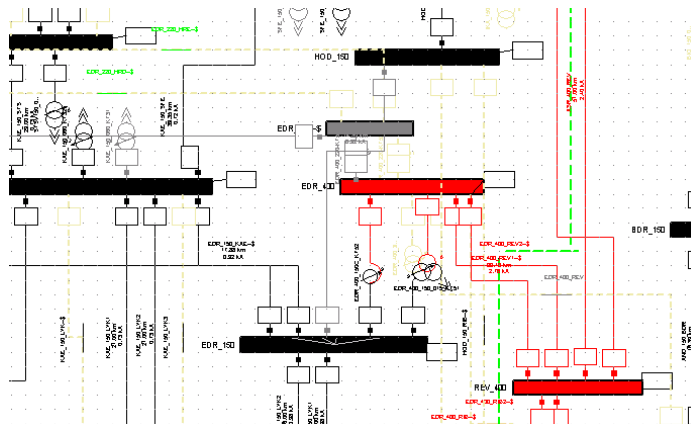
- Grid impedance depends on:
 - Loading
 - Dispatch
 - Grid configuration (n-1, n-2,..)
 - Passive filter coupling
 - ...



R1 vs X1 under 364 system conditions @ 400 kV

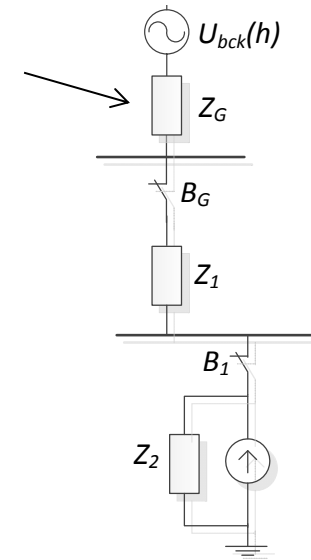
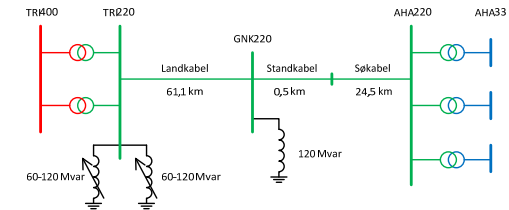
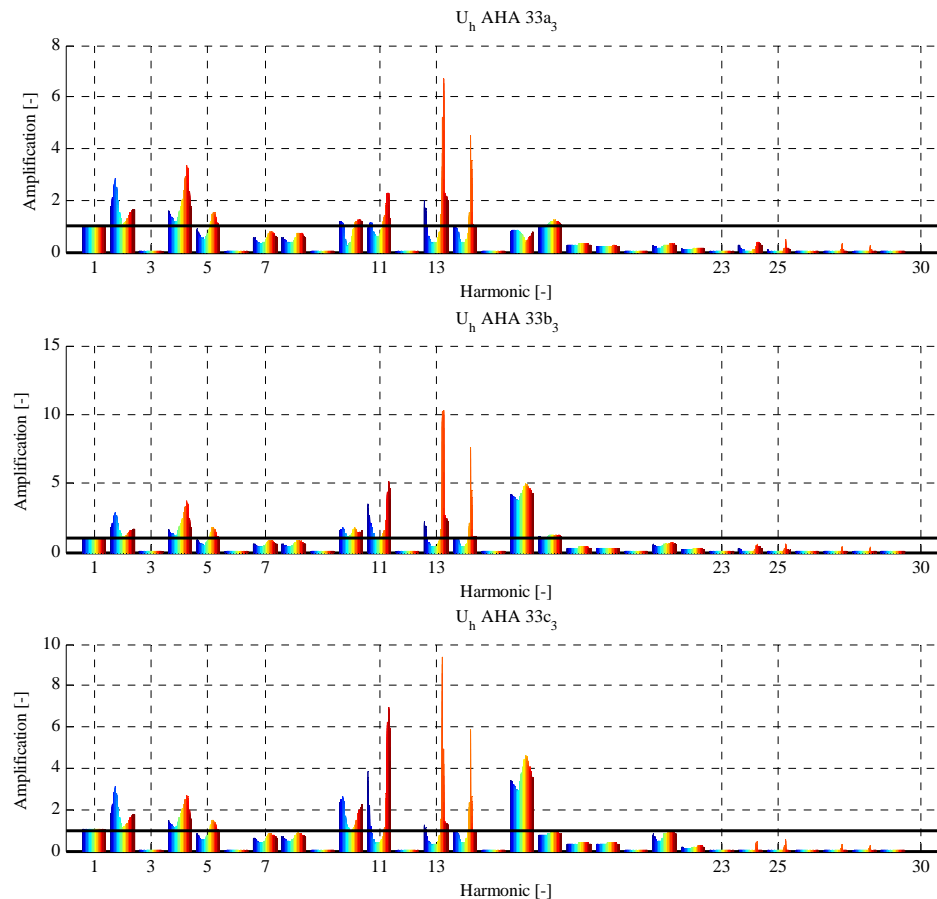
Factors influencing the AHC – grid impedance

- Grid impedance depends on:
 - Loading
 - Dispatch
 - Grid configuration (n-1, n-2,...)
 - Passive filter coupling
 - ...



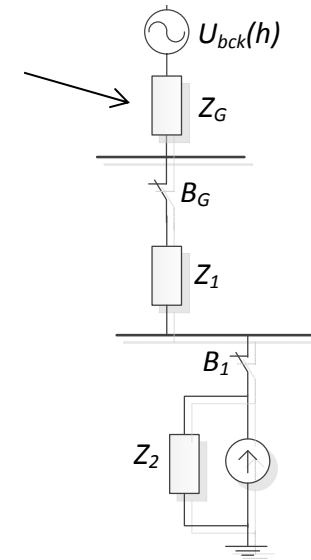
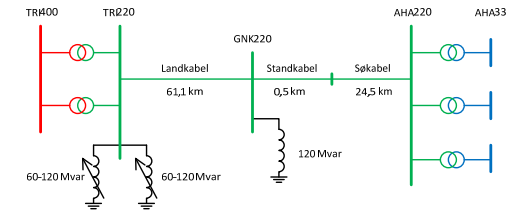
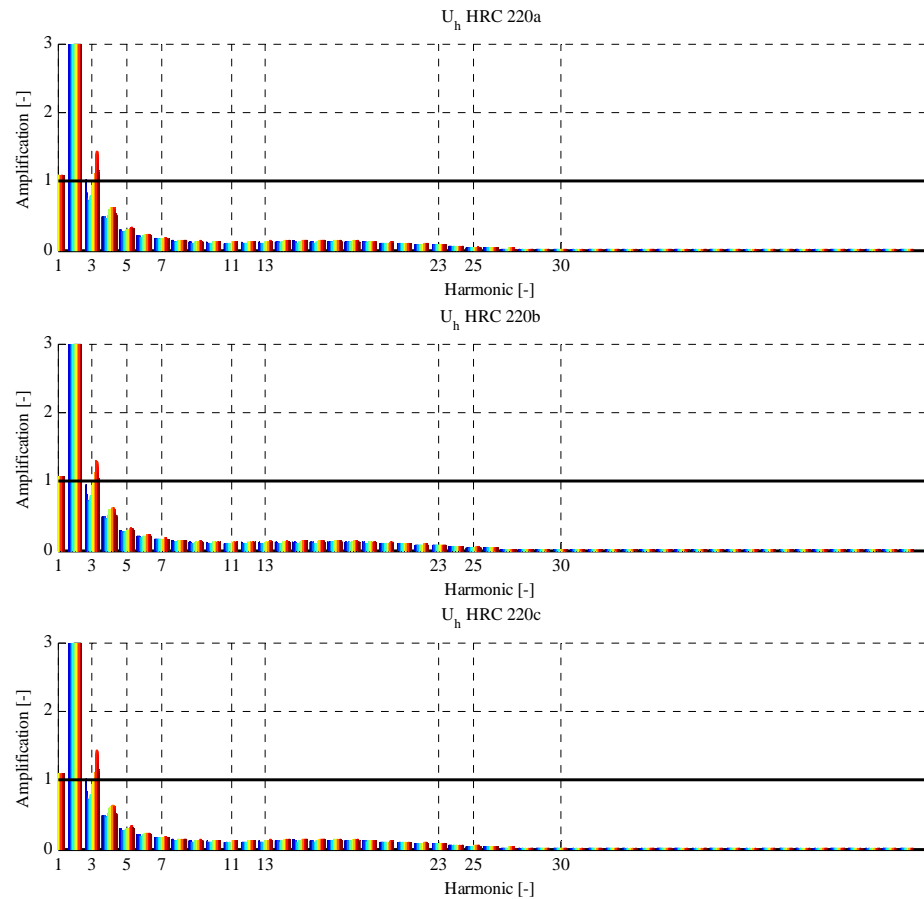
R1 vs X1 and R0 vs X0 for 364 system conditions at the 11th harmonic $f \pm 10\%$ with polygons

Factors influencing the AHC – grid impedance



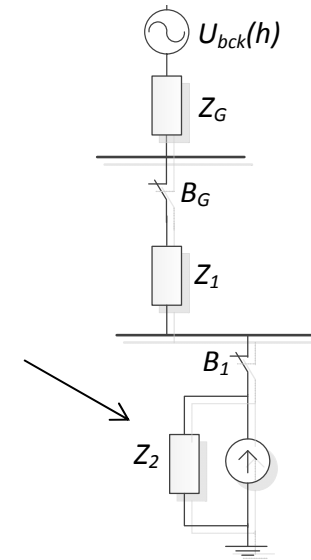
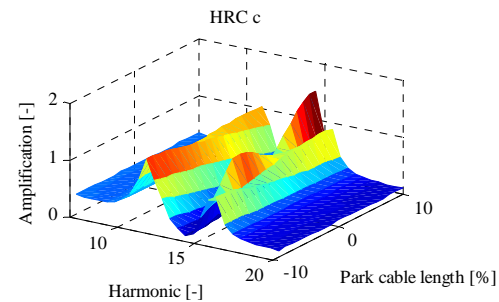
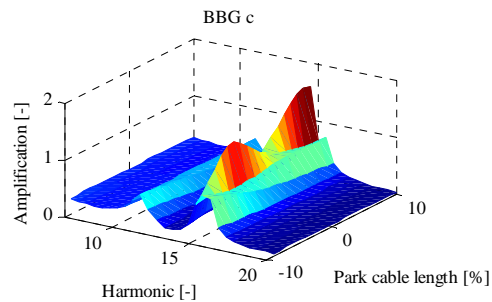
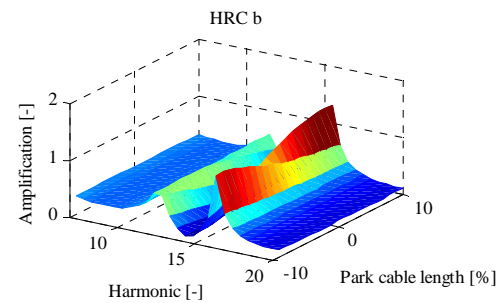
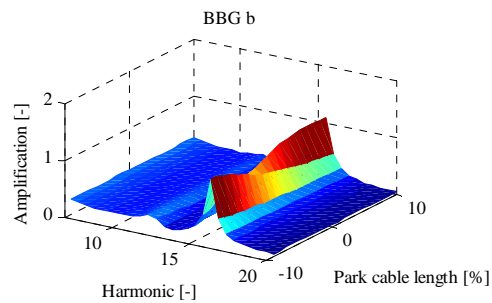
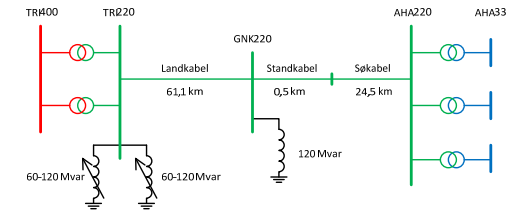
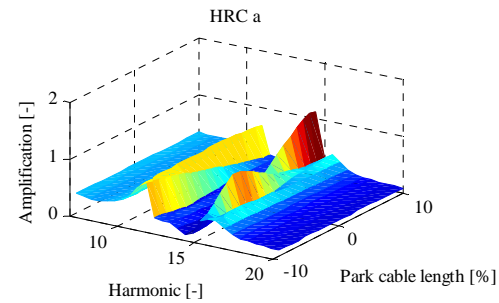
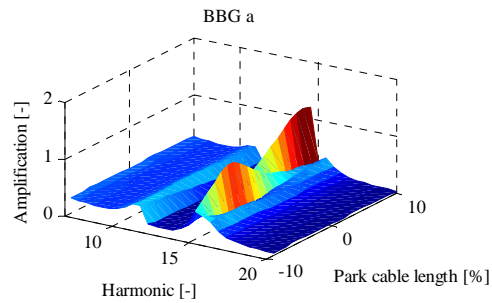
Positive sequence amplification factor as function of harmonic frequency and Z_G

Factors influencing the AHC – grid impedance

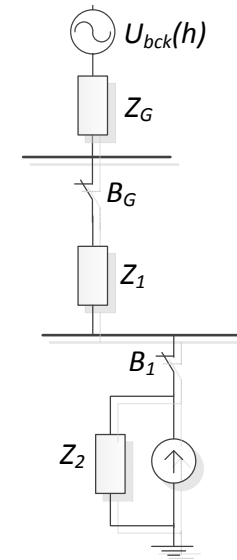
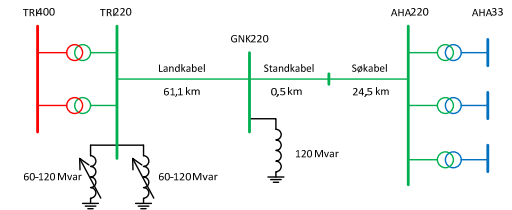
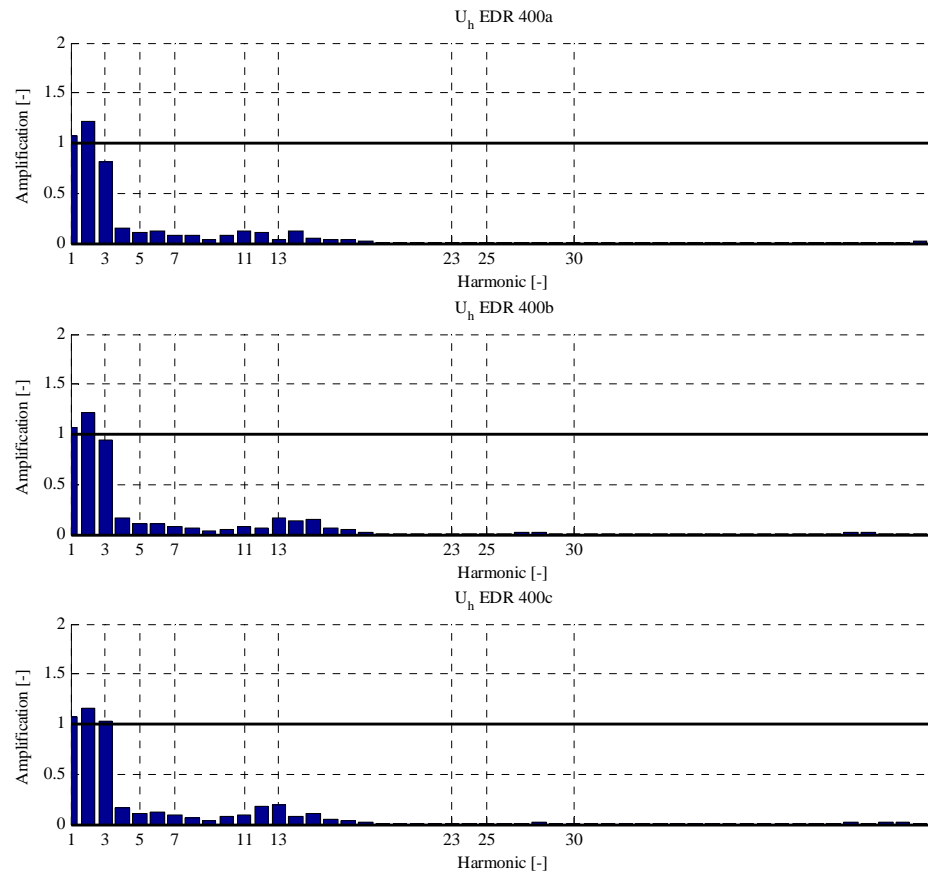


Zero sequence amplification factor as function of harmonic frequency and Z_G

Factors influencing the AHC – array system

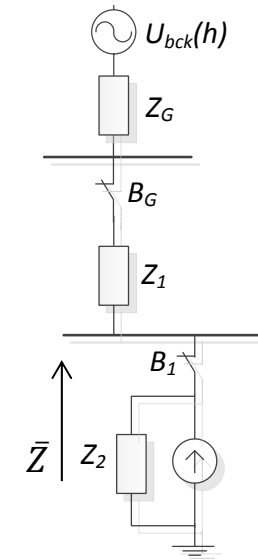
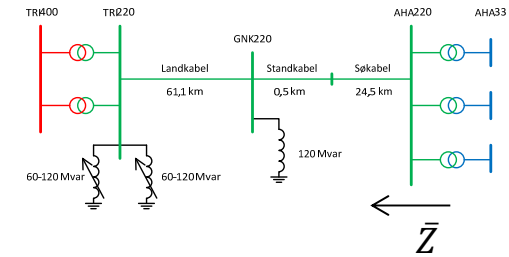
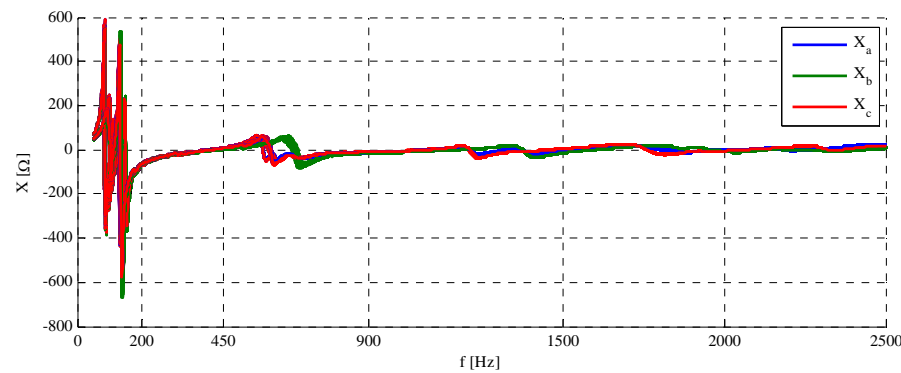
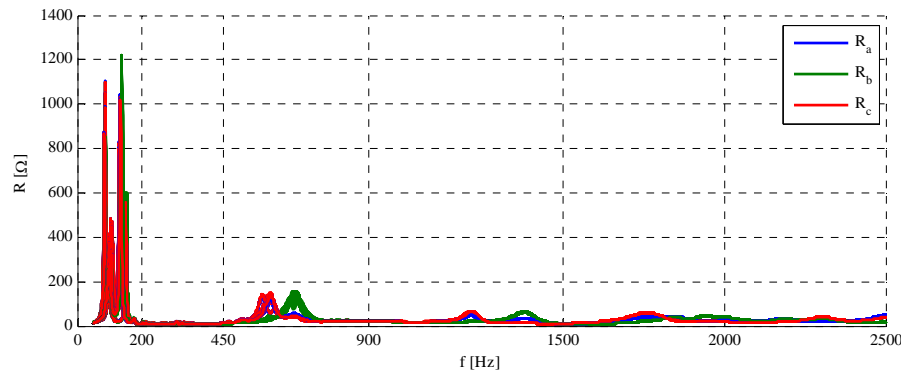


PoC to PCC amplification factors



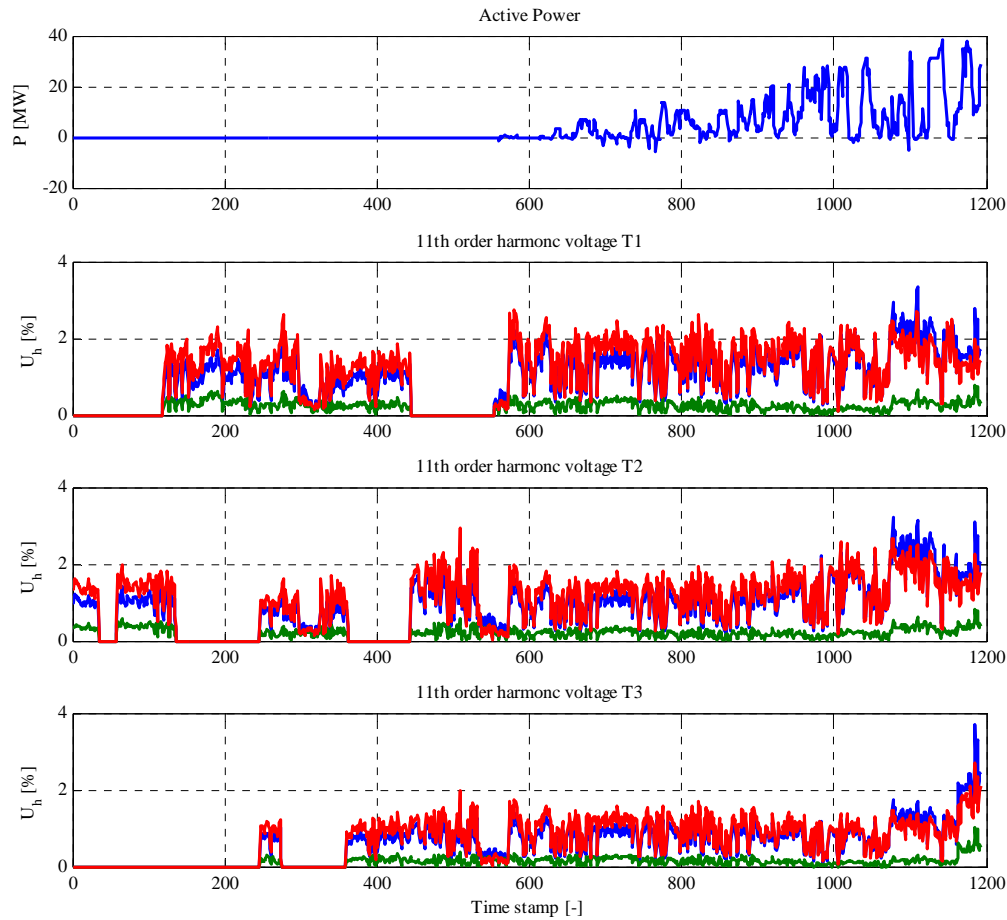
Positive sequence amplification factor from PoC to PCC as function of harmonic frequency

PoC to PCC amplification factors

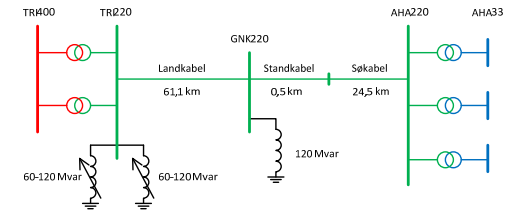


Phase resistive and reactive components of the frequency dependent impedance seen from the off-shore platform under changing configurations in the 400 kV grid.

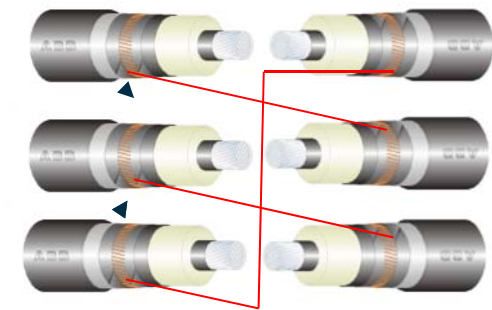
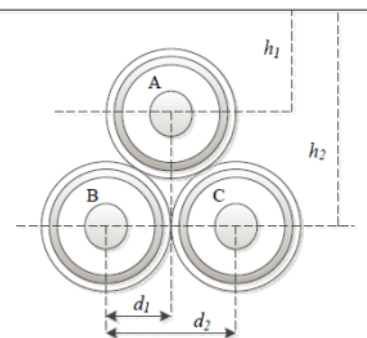
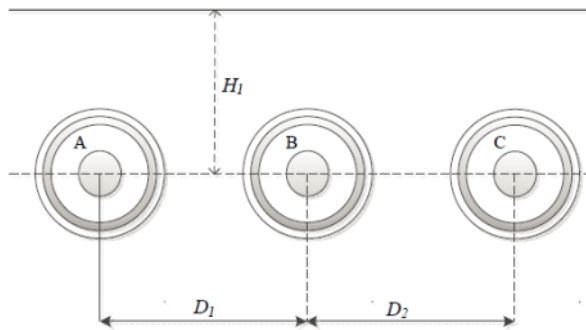
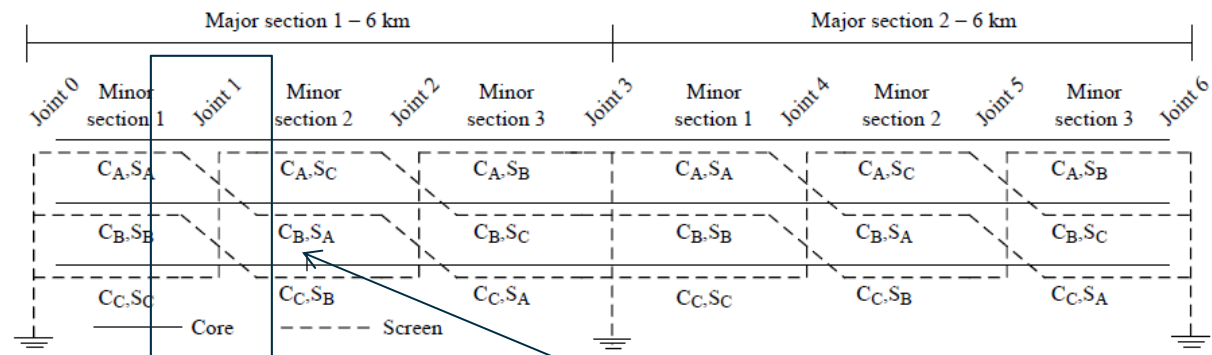
Transmission level harmonic modelling



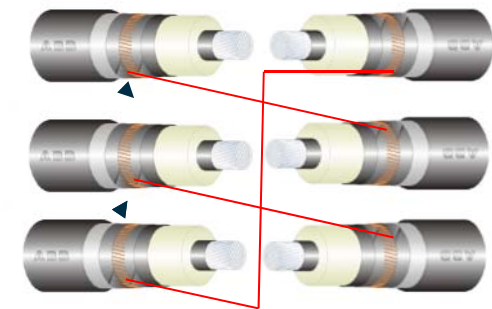
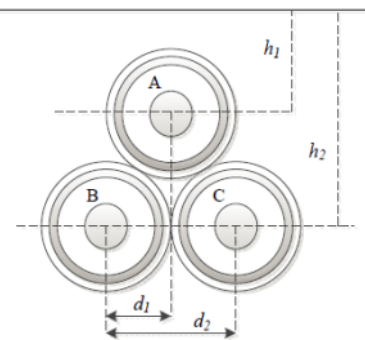
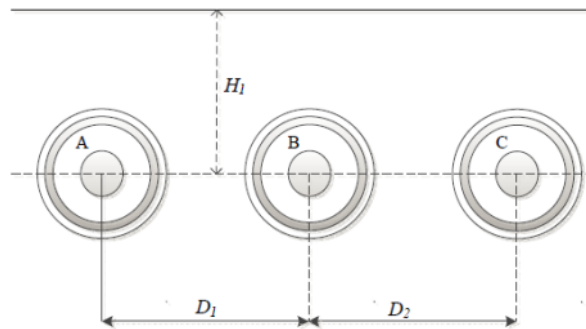
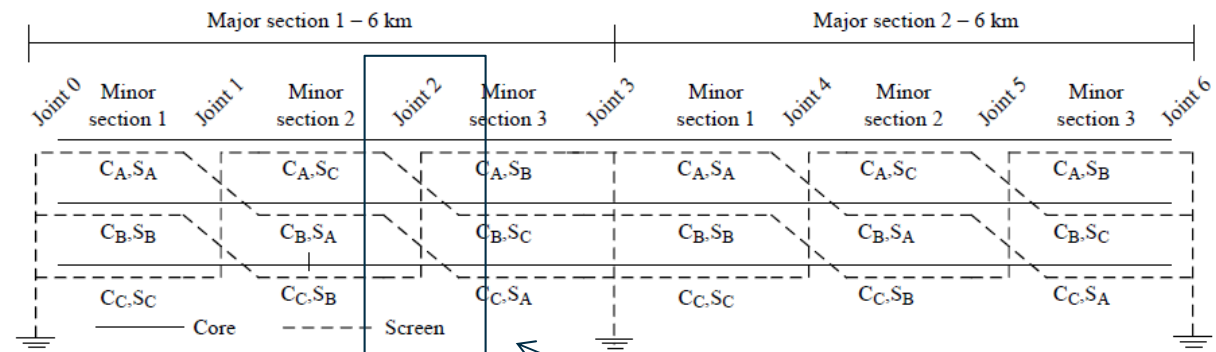
11th order harmonic at 33 kV level



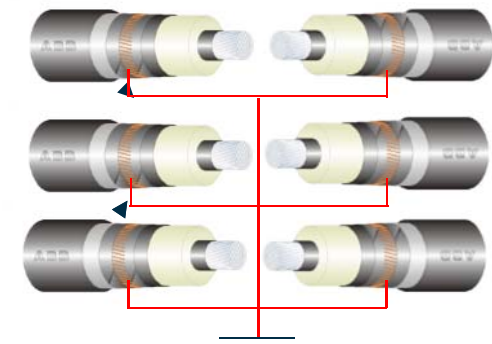
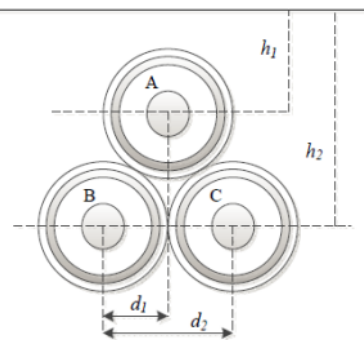
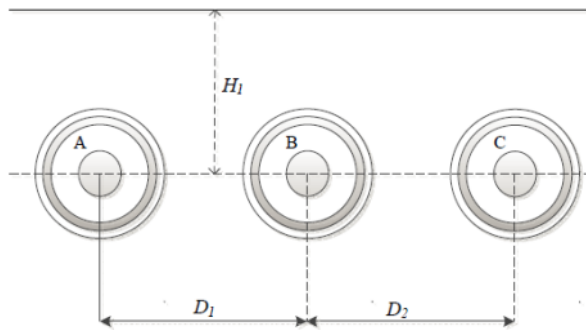
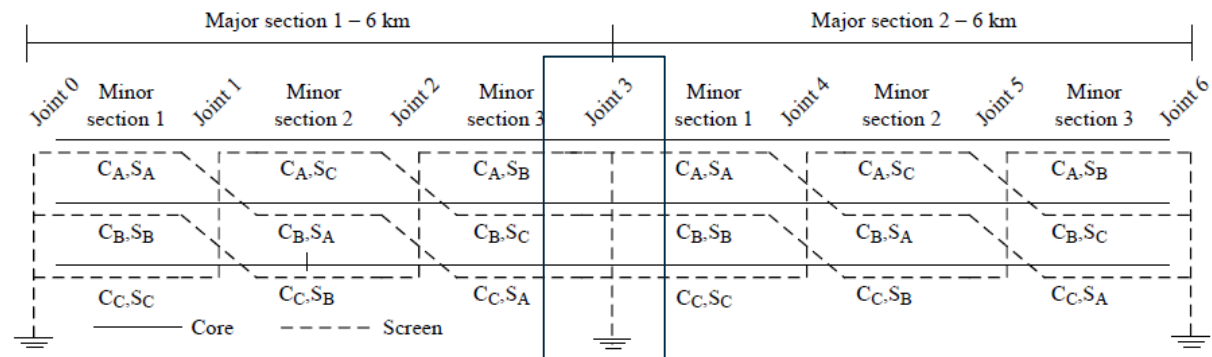
What is a Crossbonded Cable System?



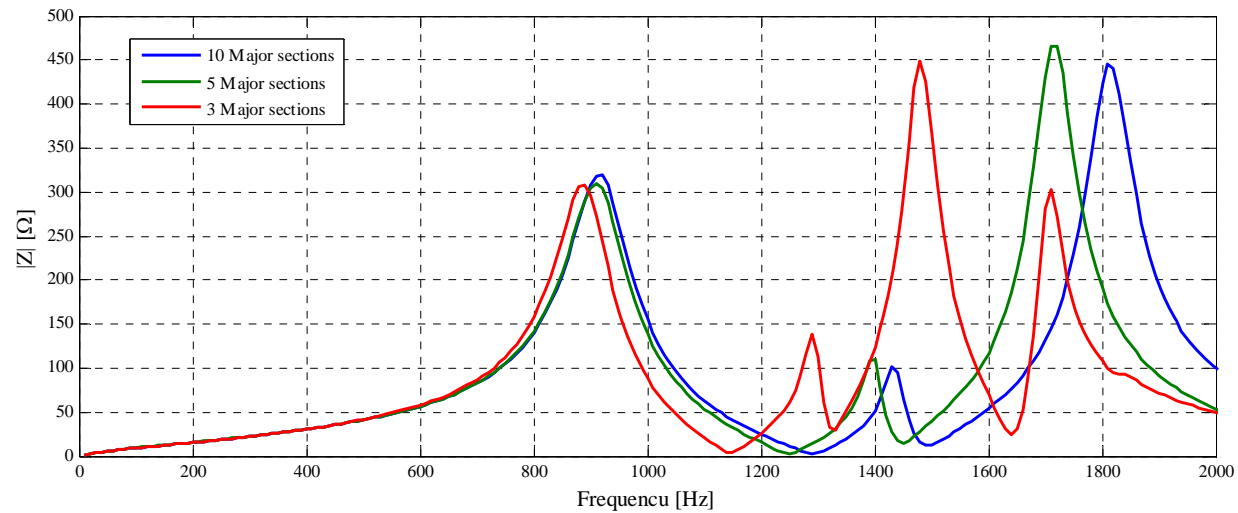
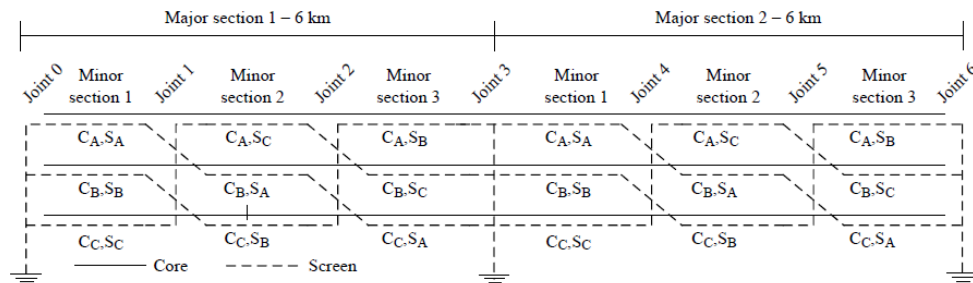
What is a Crossbonded Cable System?



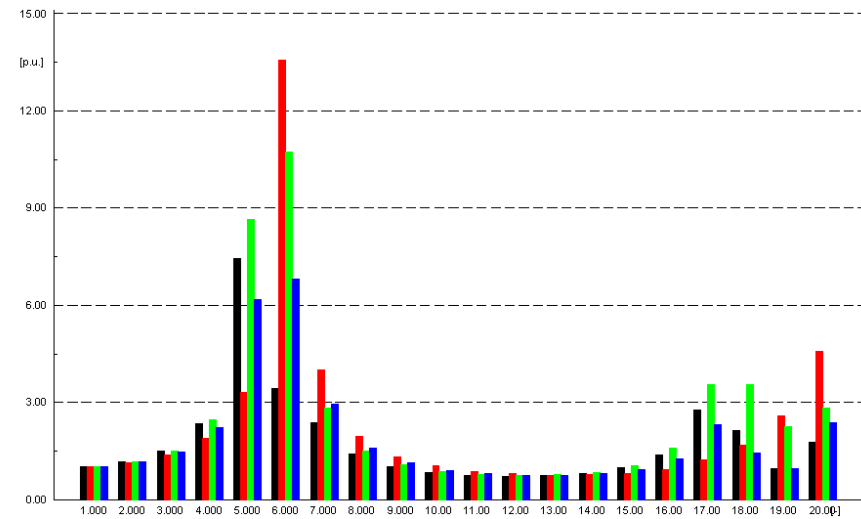
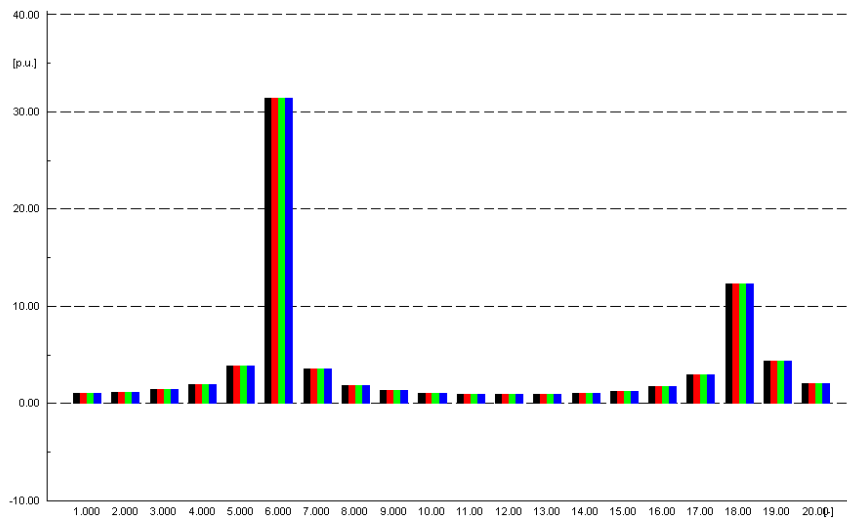
What is a Crossbonded Cable System?



Transmission level harmonic modelling



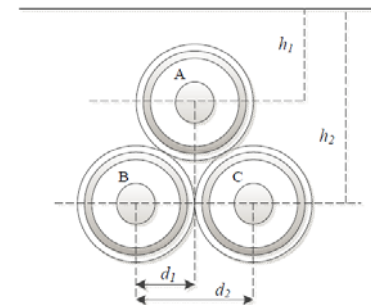
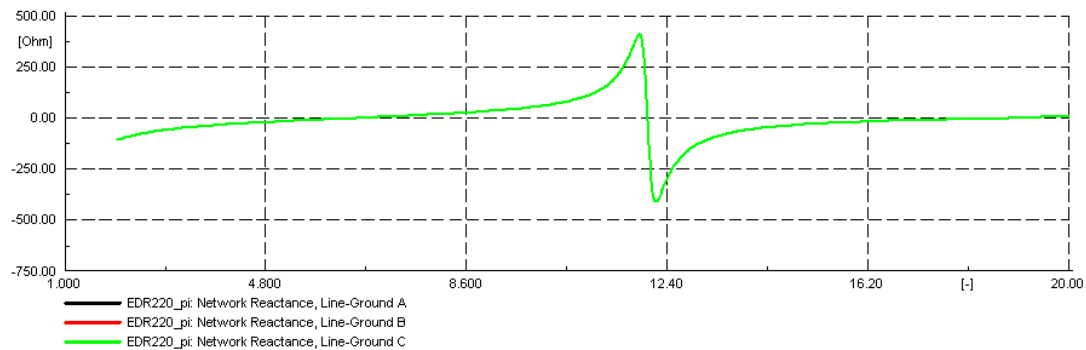
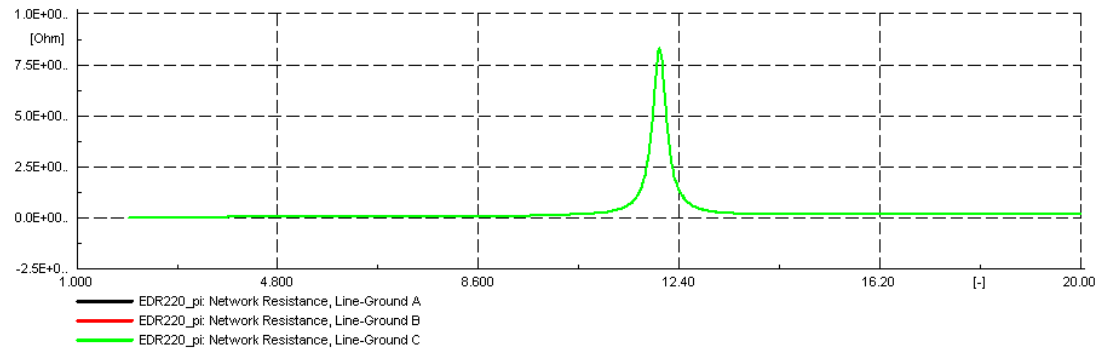
Transmission level harmonic modelling



$$Z_{012}(h) = \begin{bmatrix} Z_0(h) & 0 & 0 \\ 0 & Z_1(h) & 0 \\ 0 & 0 & Z_2(h) \end{bmatrix}$$

$$Z_{012}(h) = \begin{bmatrix} Z_{00}(h) & Z_{01}(h) & Z_{02}(h) \\ Z_{10}(h) & Z_{11}(h) & Z_{12}(h) \\ Z_{20}(h) & Z_{21}(h) & Z_{22}(h) \end{bmatrix}$$

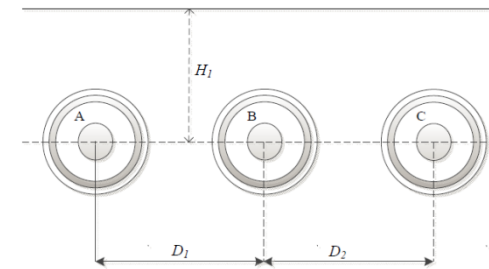
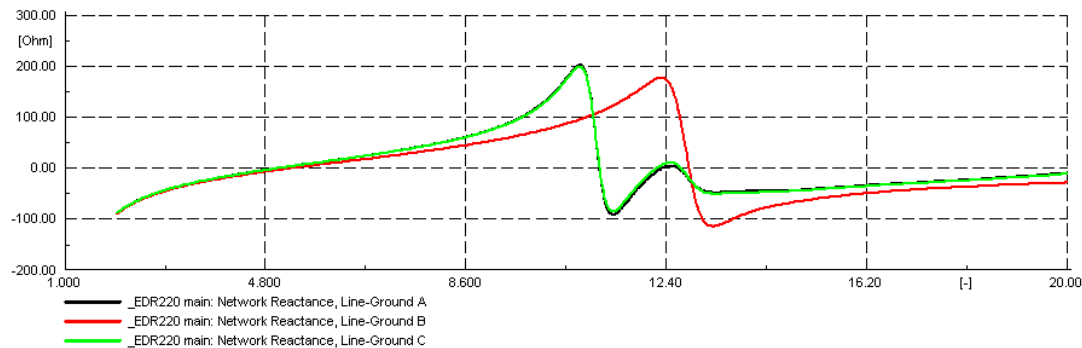
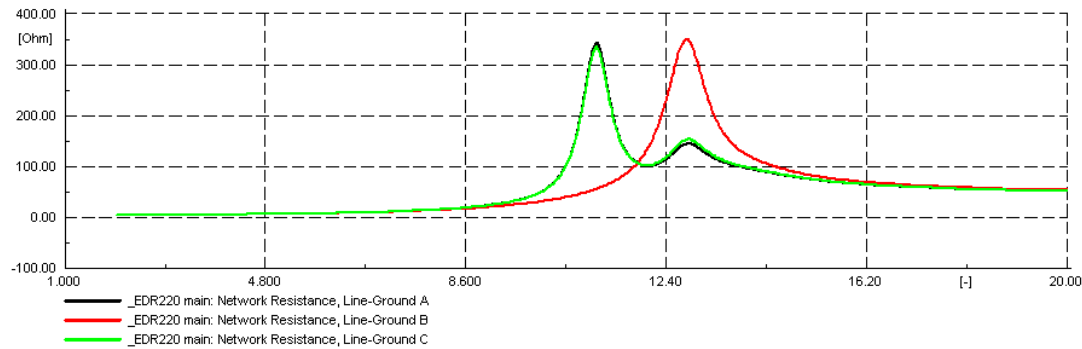
Transmission level harmonic modelling



$$\mathbf{Z}_{012}(h) = \begin{bmatrix} \mathbf{Z}_0(h) & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{Z}_1(h) & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{Z}_2(h) \end{bmatrix}$$

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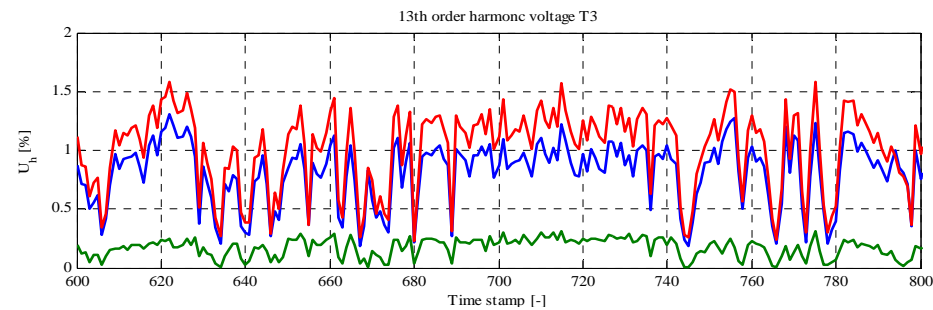
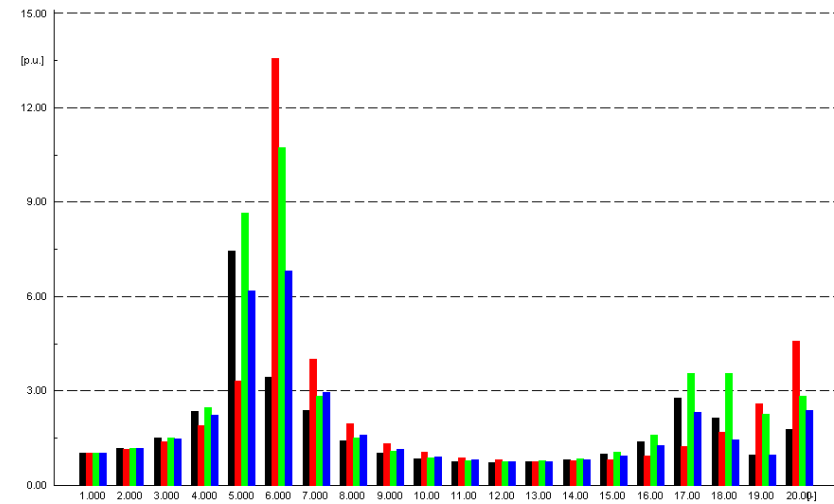
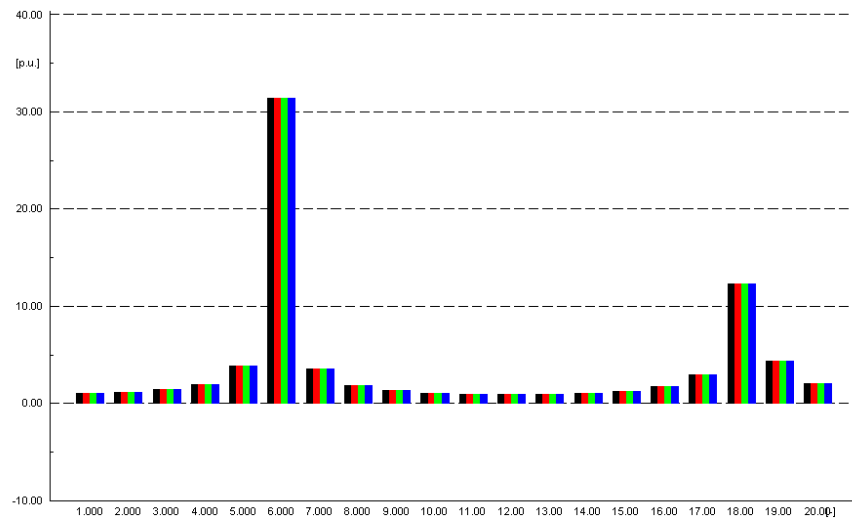
Transmission level harmonic modelling



$$Z_{012}(h) = \begin{bmatrix} Z_0(h) & 0 & 0 \\ 0 & Z_1(h) & 0 \\ 0 & 0 & Z_2(h) \end{bmatrix}$$

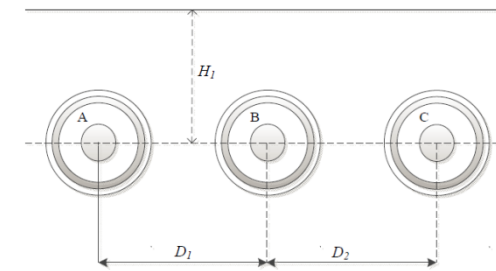
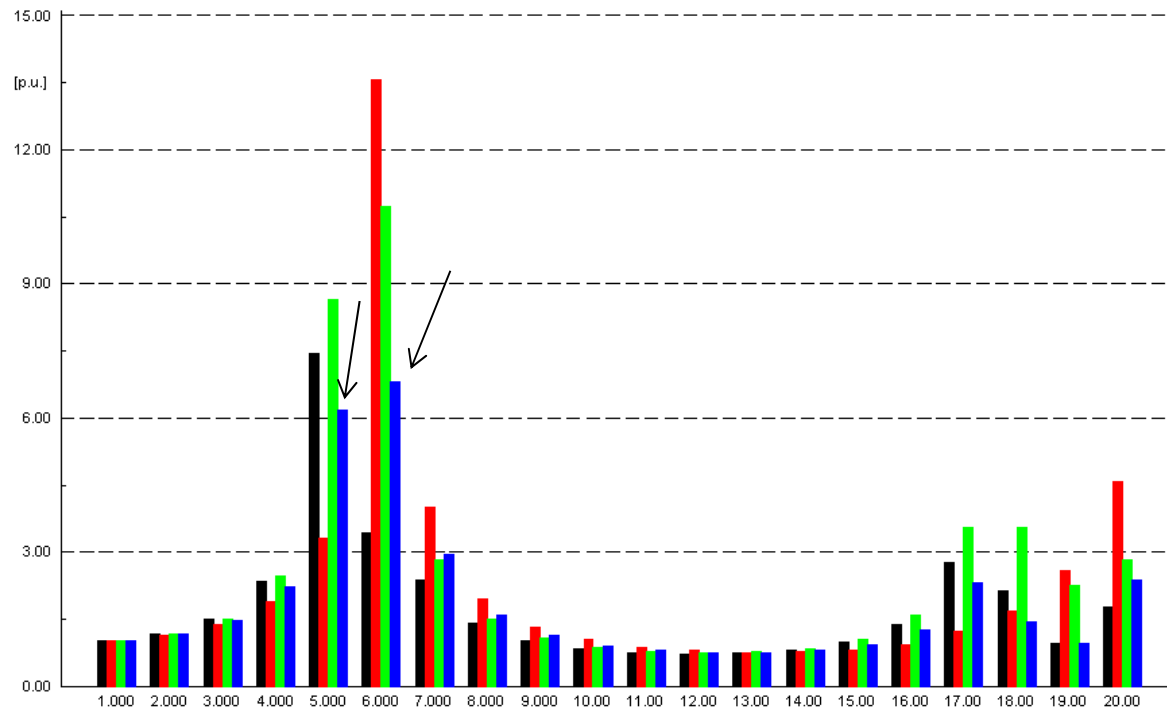
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Transmission level harmonic modelling



- _HRC220: Line-Ground Voltage, Magnitude A
- _HRC220: Line-Ground Voltage, Magnitude B
- _HRC220: Line-Ground Voltage, Magnitude C
- _HRC220: Positive-Sequence Voltage, Magnitude

Transmission level harmonic modelling



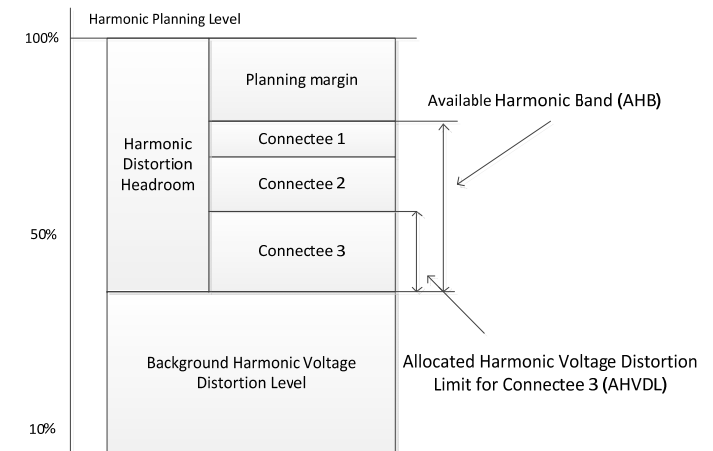
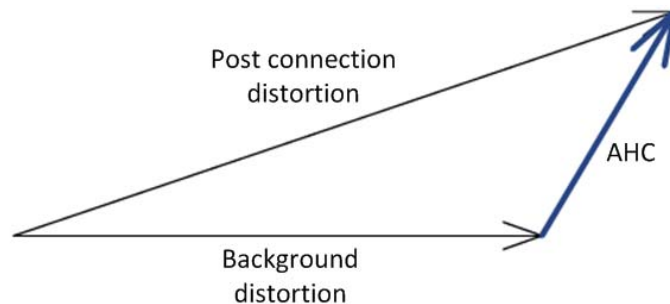
- _HRC220: Line-Ground Voltage, Magnitude A
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- _HRC220: Positive-Sequence Voltage, Magnitude

Harmonic Coordination at transmission level

Difficulties in obtaining representative AHC values lead to:

- A conservative limit for each connectee is given
- Complicated high voltage level harmonic coordination

-> AHC must be evaluated as a harmonic phasor for compliance evaluation

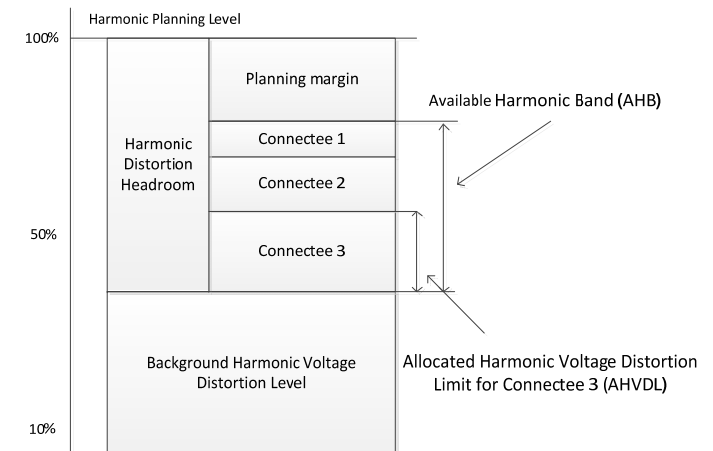
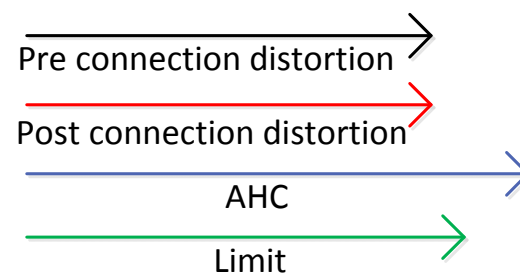
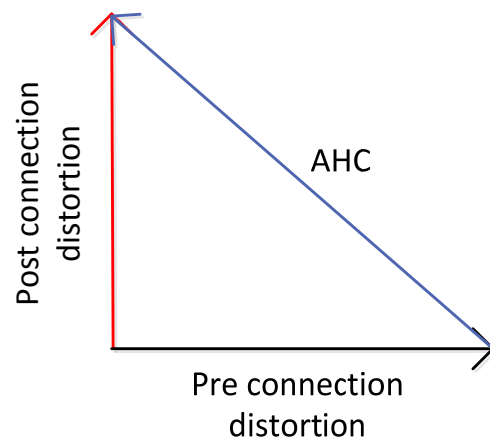


Harmonic Coordination at transmission level

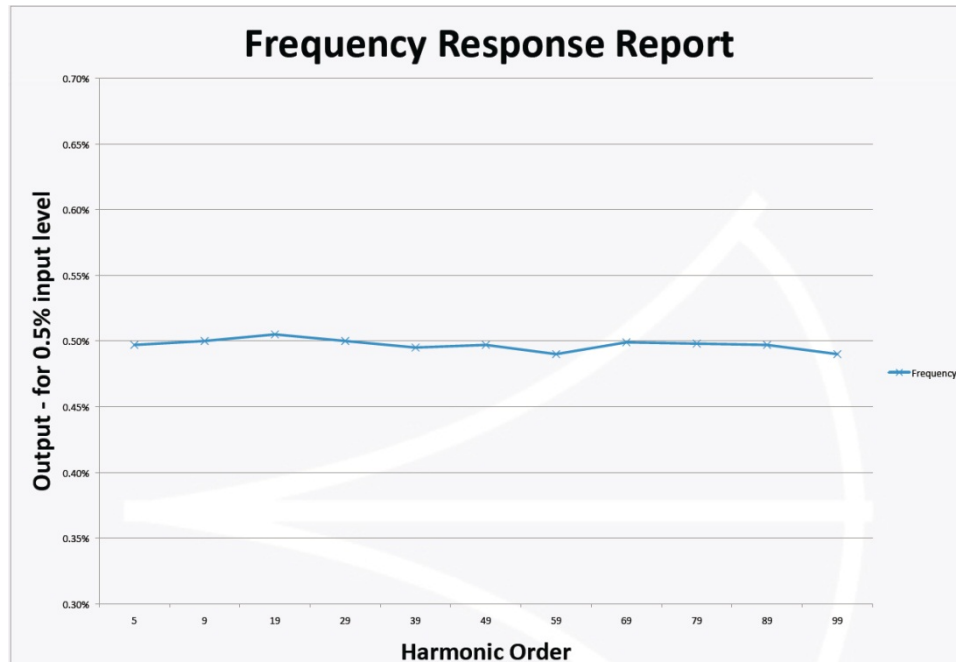
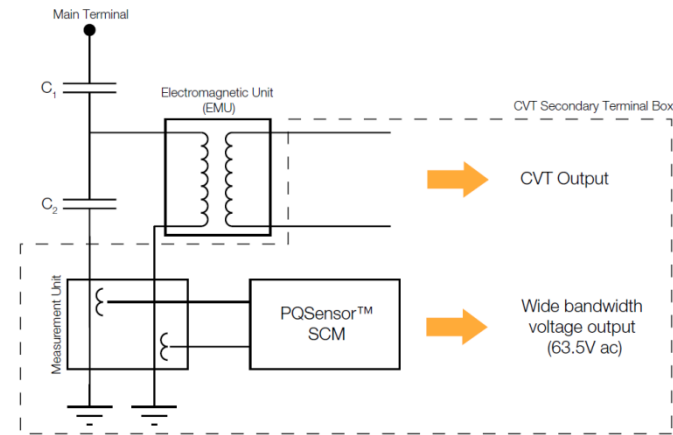
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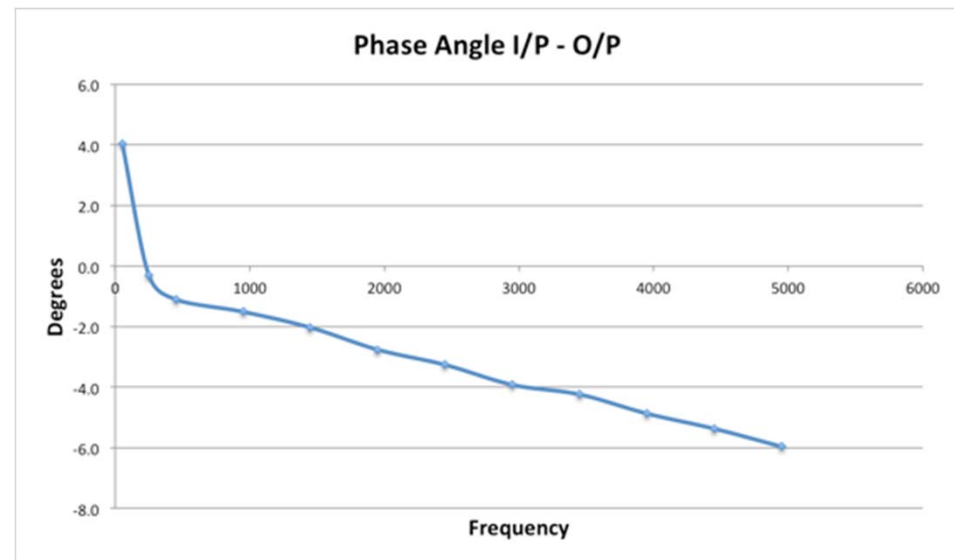
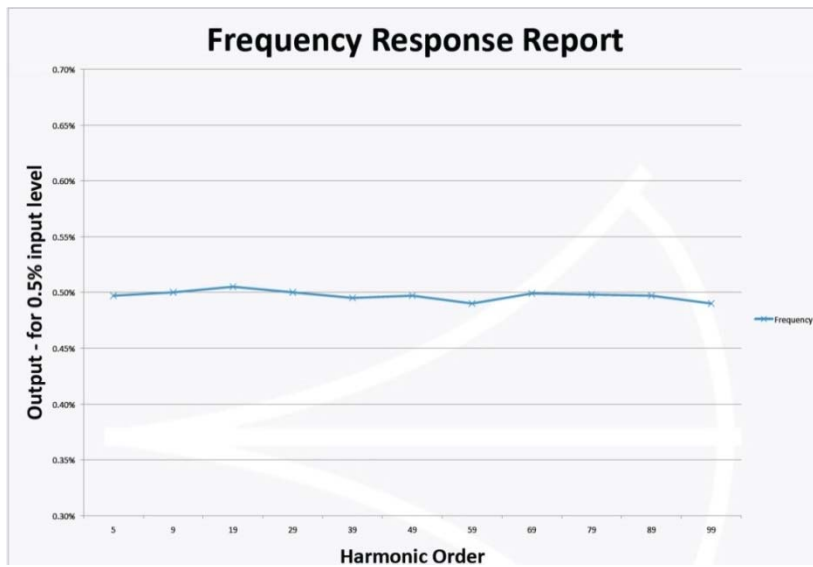
-> AHC must be evaluated as a harmonic phasor for compliance evaluation



The PQ-sensor for CVTs



The PQ-sensor for CVTs

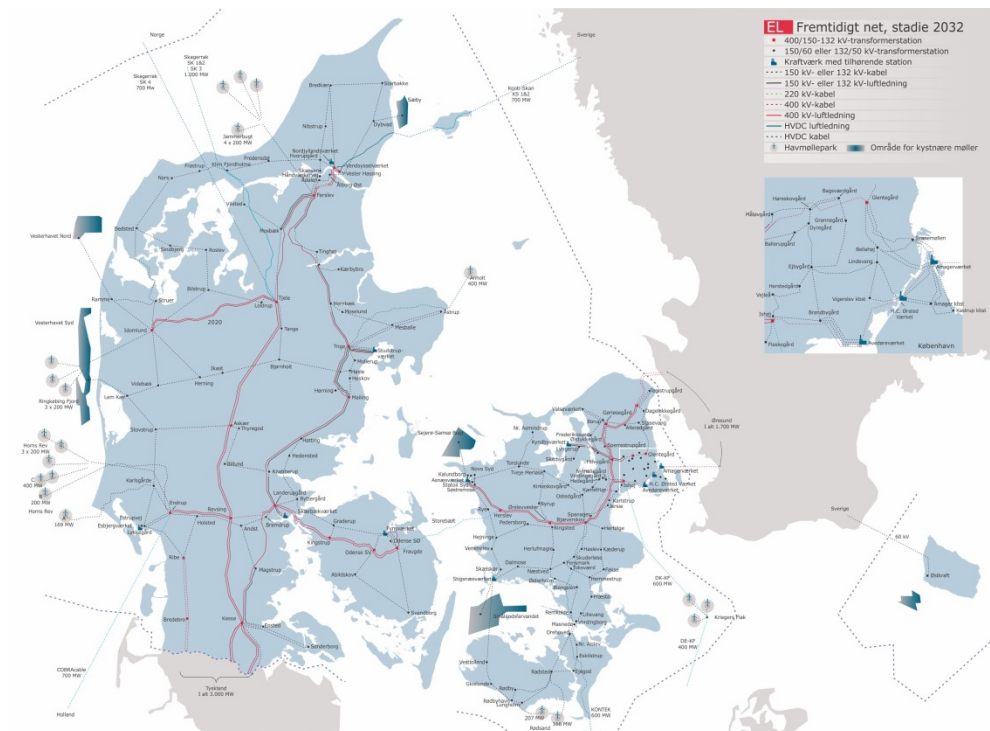


- Harmonic phasors can be determined correctly (AHC)
- The harmonic sequence components can hence be determined

The first Danish WA PQ-measuring system

Program covers:

- All 400 kV substations
- All 220 kV substations
- Selected 132 kV and 150 kV substations



The first Danish WA PQ-measuring system

Research goals:

- Determine the main source(s) of harmonic distortion in the Danish transmission system
- Reduce emission at the source

