CABLE CONNECTIONS CONSIDERATIONS FOR OFFSHORE WIND PLANTS

David Mueller

dmueller@enernex.com

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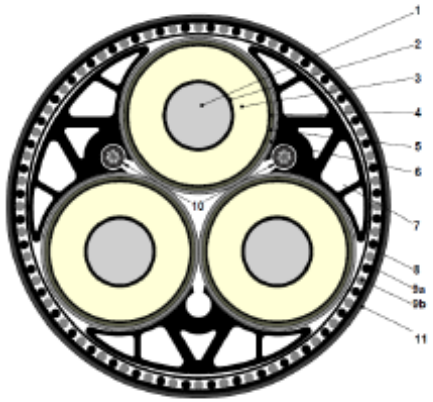
Offshore Wind Plant Electrical Systems

- *Large wind turbines*
- *Medium voltage collections systems (submarine cables)*
- *Medium voltage substation (sea platform)*
  - Collector feeder circuit breakers
  - Feeder circuit grounding transformers?
  - Gas insulated switchgear (GIS)?
  - Main GSU transformer(s)
  - Relay control house
  - Reactive power compensation (onshore?)
- *HV Transmission Connection*
  - Offshore/beach/onshore

HV AC Cable

- *HV AC Cable Characteristic*
- *Lower reactance than overhead lines*
- *Higher capacitance*
  - Voltage rise / compensating reactors
  - Switching transient considerations
  - Harmonics resonance



Overall Considerations for AC Connection to Shore versus HVDC

- *Power flow capability*
- *Voltage profile and management*
- *System cost*
- *DC system complexity*
- *Controls interaction with dc*
- *Harmonics resonance and transformer*
- *Energization sequence*
- *Transients considerations*
  - Switching
  - Faults

HVDC SylWin1 Offshore wind power to the power grid of the German mainland. Voltage-Sourced Converters with DC ratings of 864 MW, ±320 kV are used and the total cable length is 205 km. It is being built by the Siemens/ Prysmian consortium and was handed over to its owner, TenneT, in April 2015

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Hornsea 1 HVAC Versus HVDC

- *1.2 GW, Final turbine installed Oct 2019*
- *400/220 kV Killingholme Substation*
- *174 Siemens (7 MW) Turbines*
- *AC Offshore Cable*
- *140 km offshore, 60 km midpoint reactive compensation*

- *Project 2 (1.8 GW) 2022*
- *Project 3 (2.4 GW) 2025*

Anholt Wind Plant

- *Commissioned September 2013*
- *400 MW*
- *111 Siemens Turbines (3.6 MW each)*
- *220/33 kV*
- *25km Submarine + 56 km Land Cables*

- *EnerNex Transient Studies*
  - Determine switching transient overvoltages
  - Determine breaker ratings
  - Determine insulation withstand

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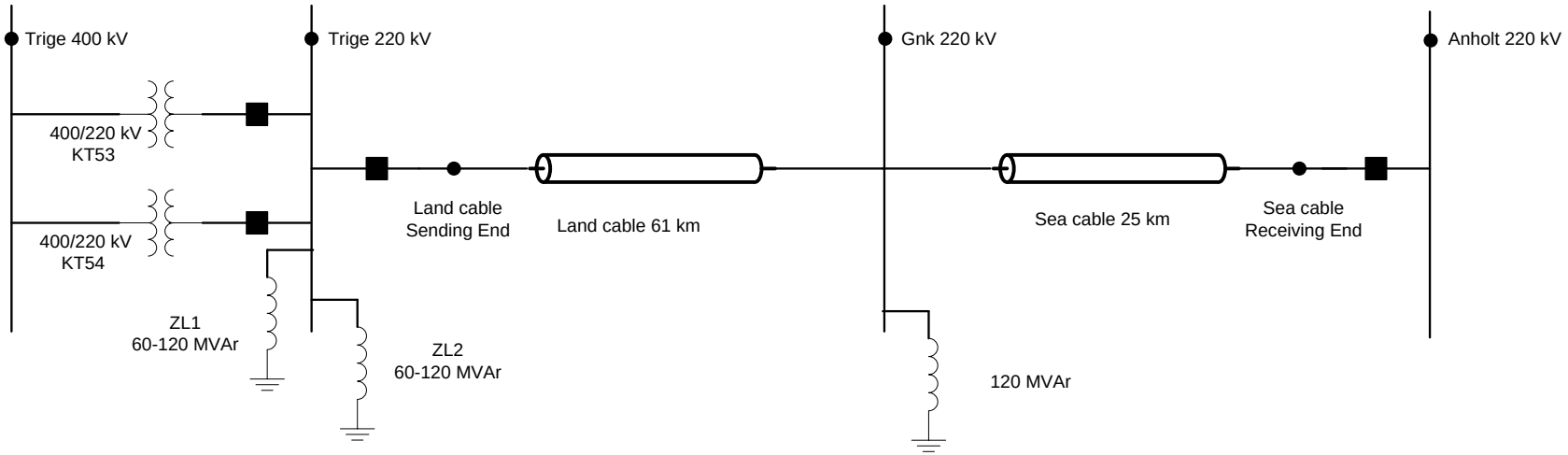
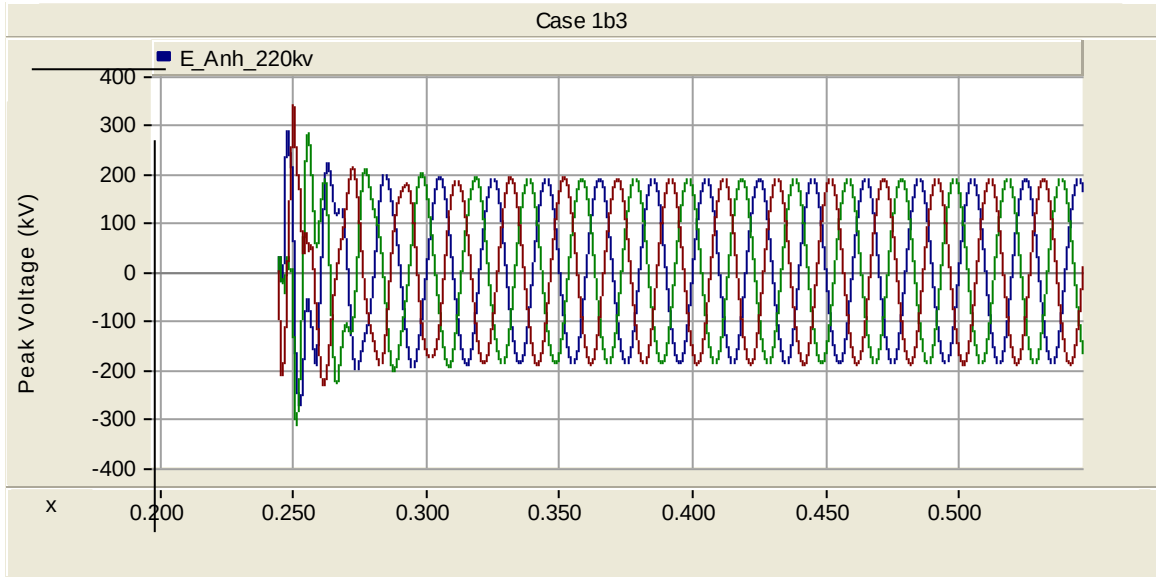
Transient Studies

- *Transient studies of offshore cables*
  - Determine switching transient overvoltages, switching sequences
  - Determine breaker ratings
  - Temporary overvoltage (TOV) considerations during faults
  - Determine insulation withstand

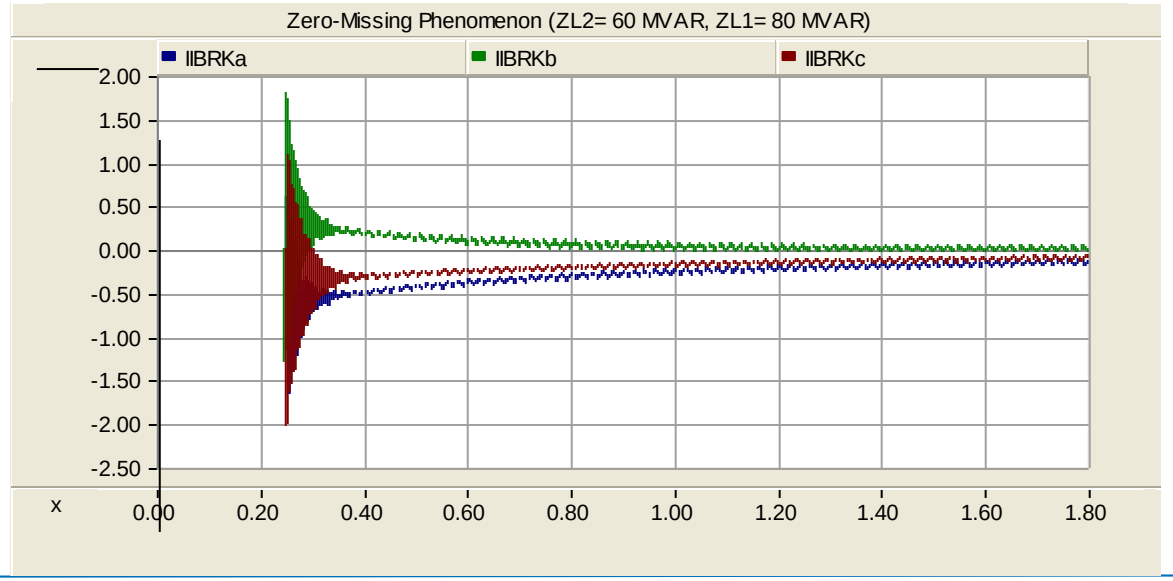


Anholt Transient Studies Results

- *Normal Cable Energizing Transient*



- *Cable Energizing into a Fault*



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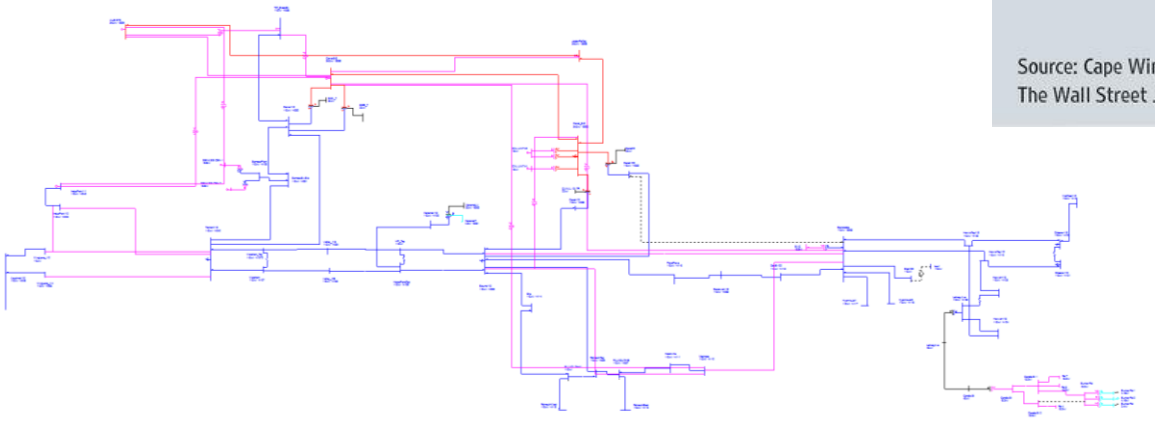
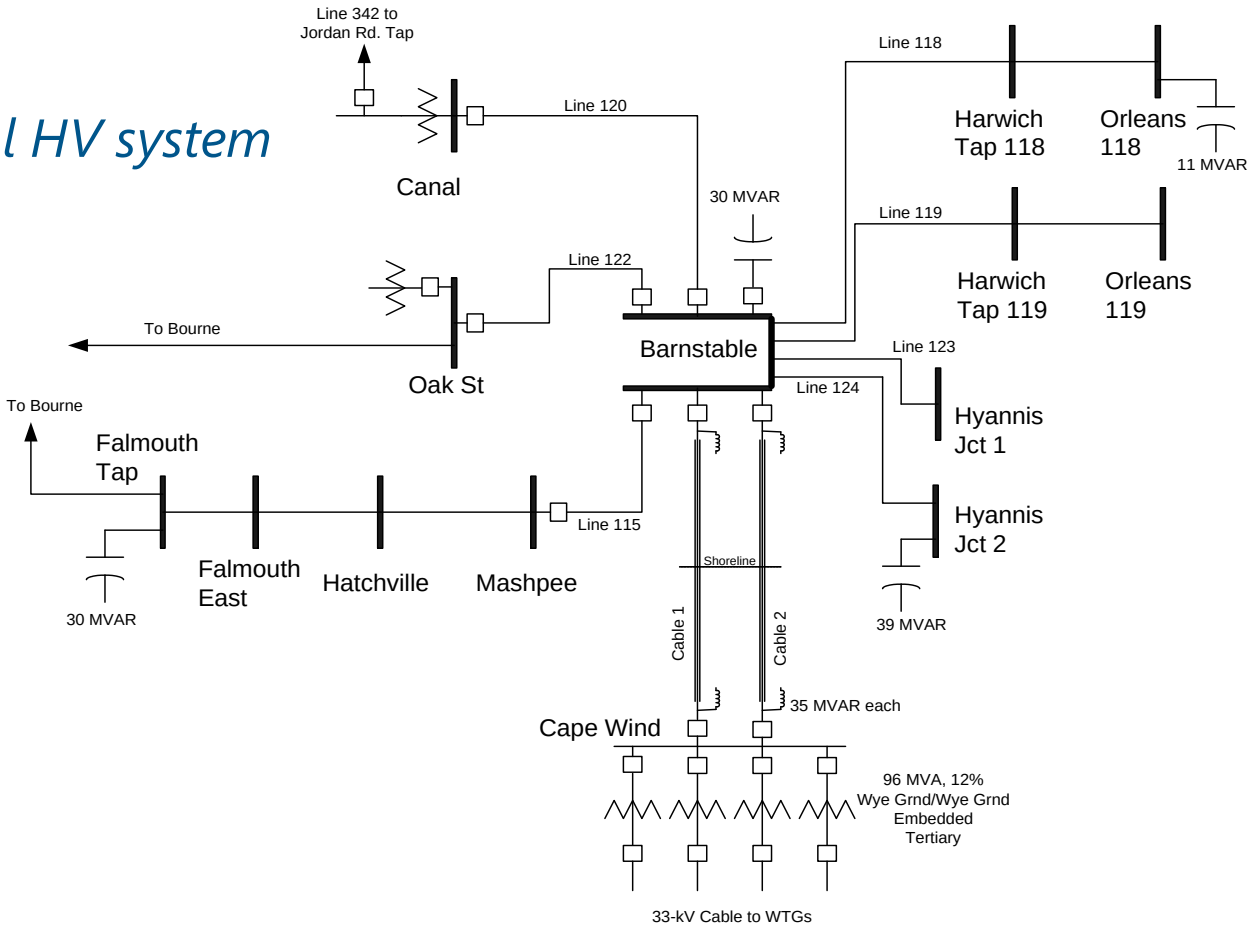
Cape Wind Harmonics Studies

- *115 kV Connection at Barnstable*
- *454 MW*
- *130 Turbines*
- *Nearby STATCOM in Operation*
- *115 kV Capacitor Banks*



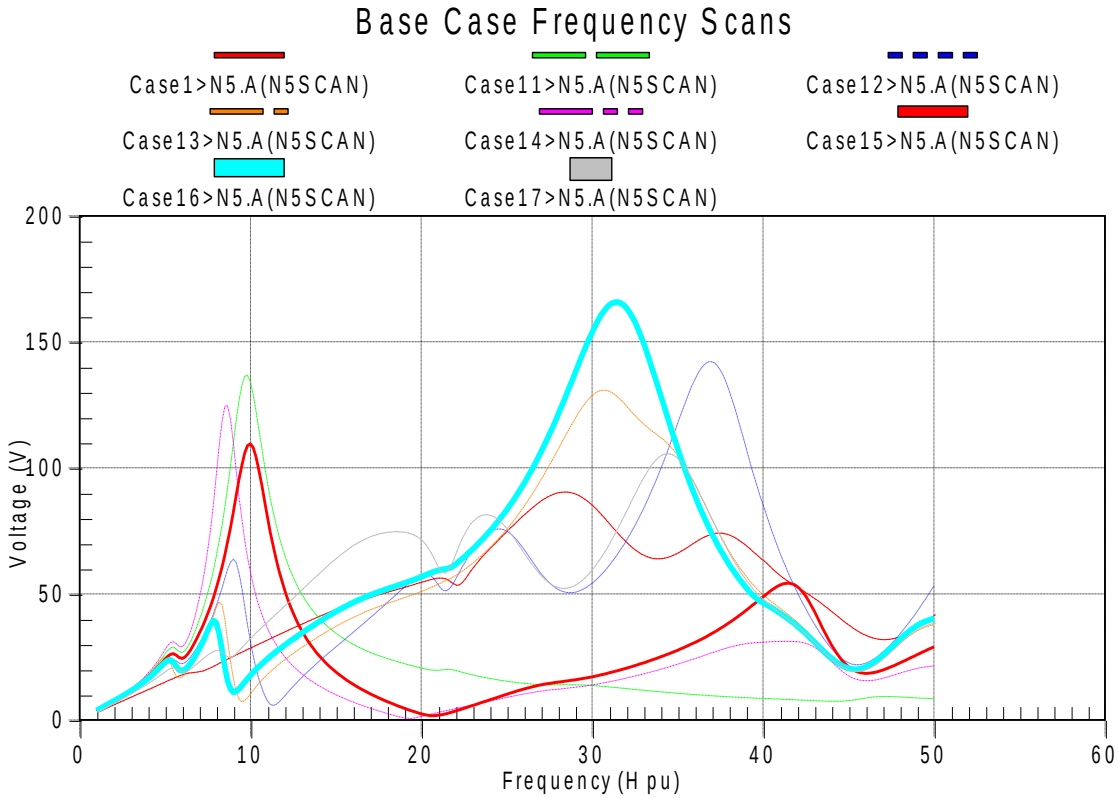
Harmonics Impacts

- *HV AC cable has high capacitance*
- *Harmonics resonance at HV system*
- *Filter likely required*
- *Interaction with the local HV system*



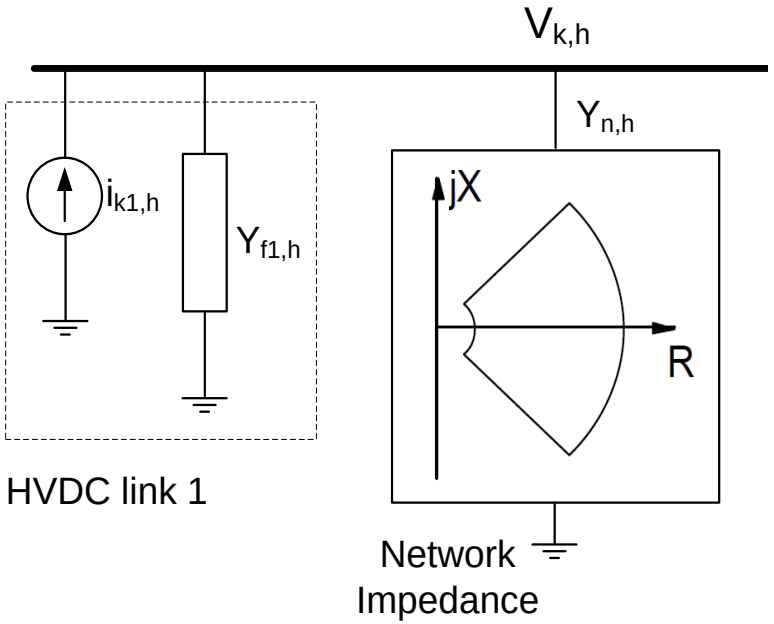
Harmonic Study Analysis

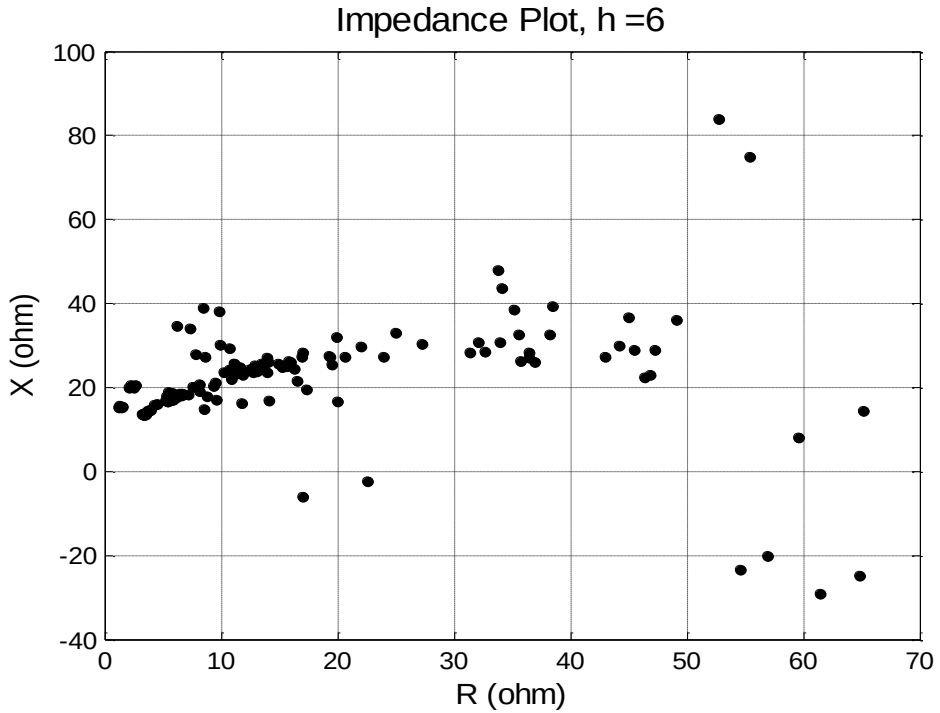
- *Frequency Scan Analysis*
- *Magnification of Background Harmonic Sources*



HV Grid Harmonics Interactions Studies

- *Harmonic filters likely required for AC or DC connections*
- *Harmonic interactions with the rest of the grid*
- *Grid network impedance for many (hundreds) of contingencies*





Summary

- *Designs are evolving*
- *HVDC for longer offshore runs*
- *Cost/complexity issues for HVDC*
- *Voltage Rise Issues for AC*
- *Switching Transient Issues*
- *Harmonics resonance at the HV interconnection*

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David Mueller

dmueller@enernex.com