16.7 Hz - The Missing Link?

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Elektrische Anlagen und Netze
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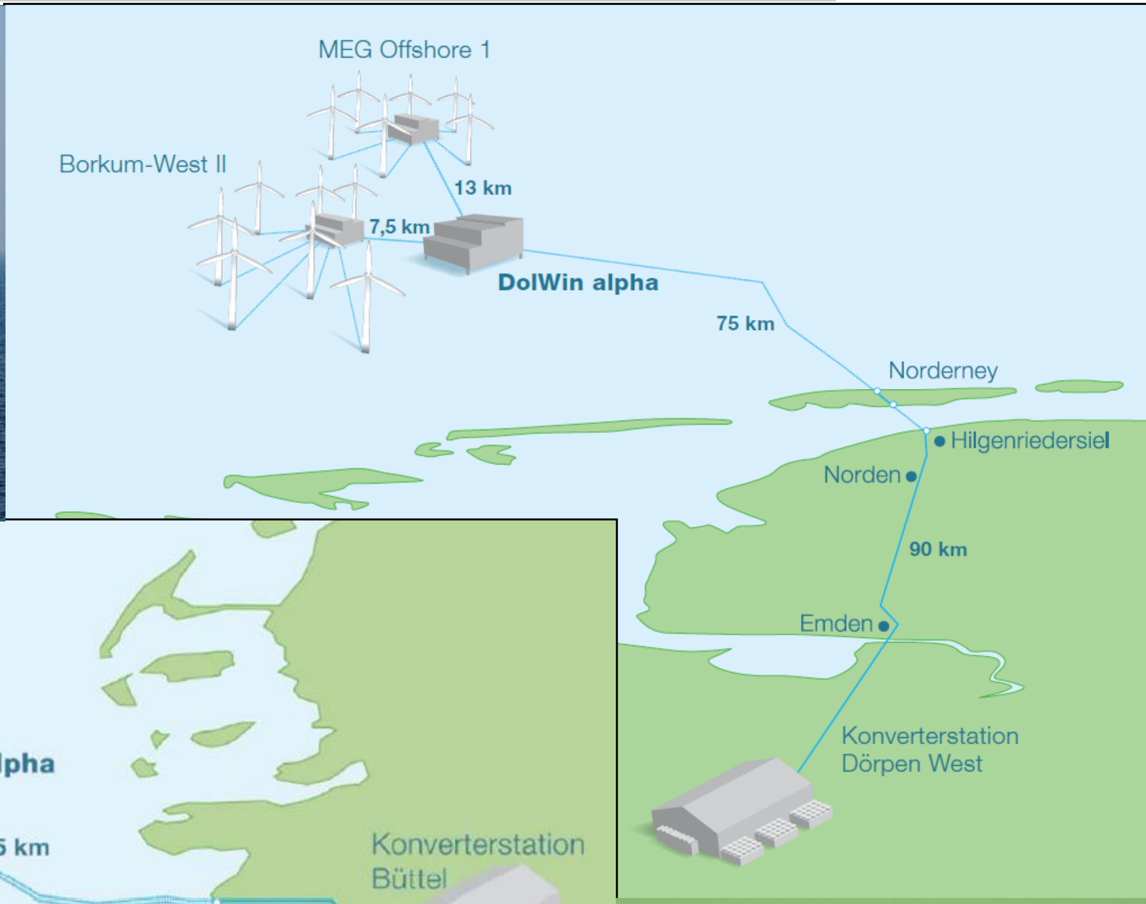
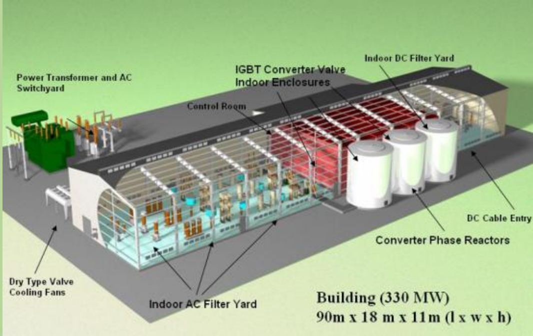
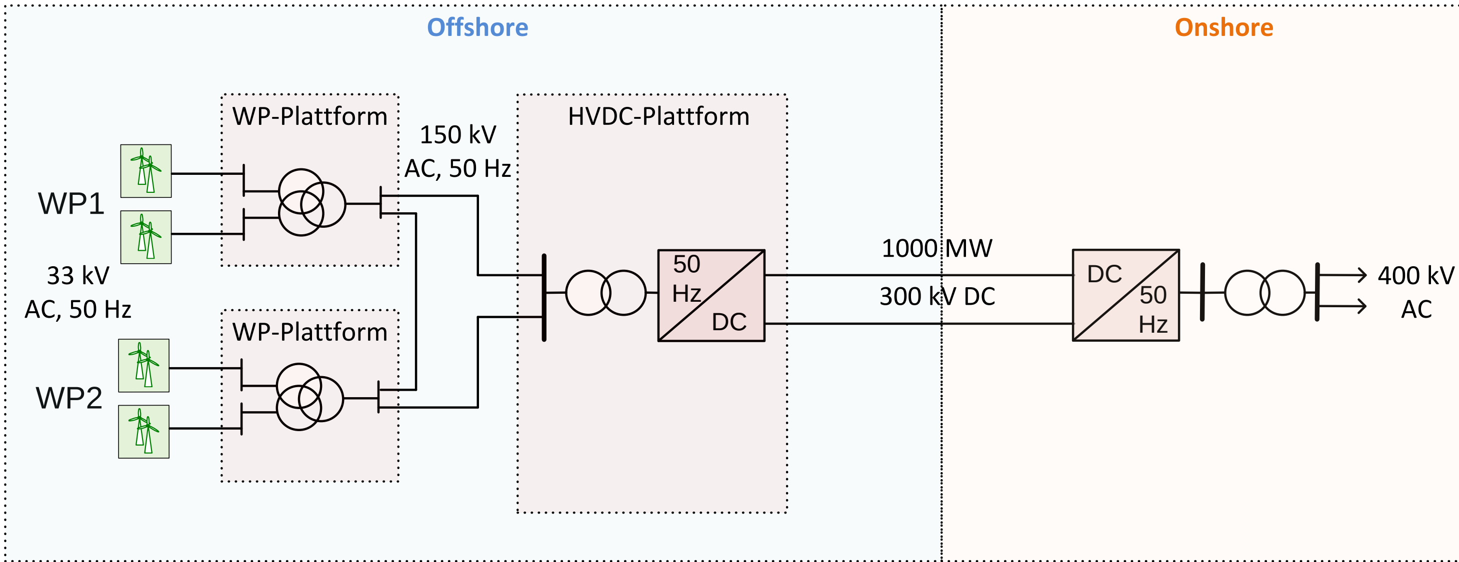
Current Concept



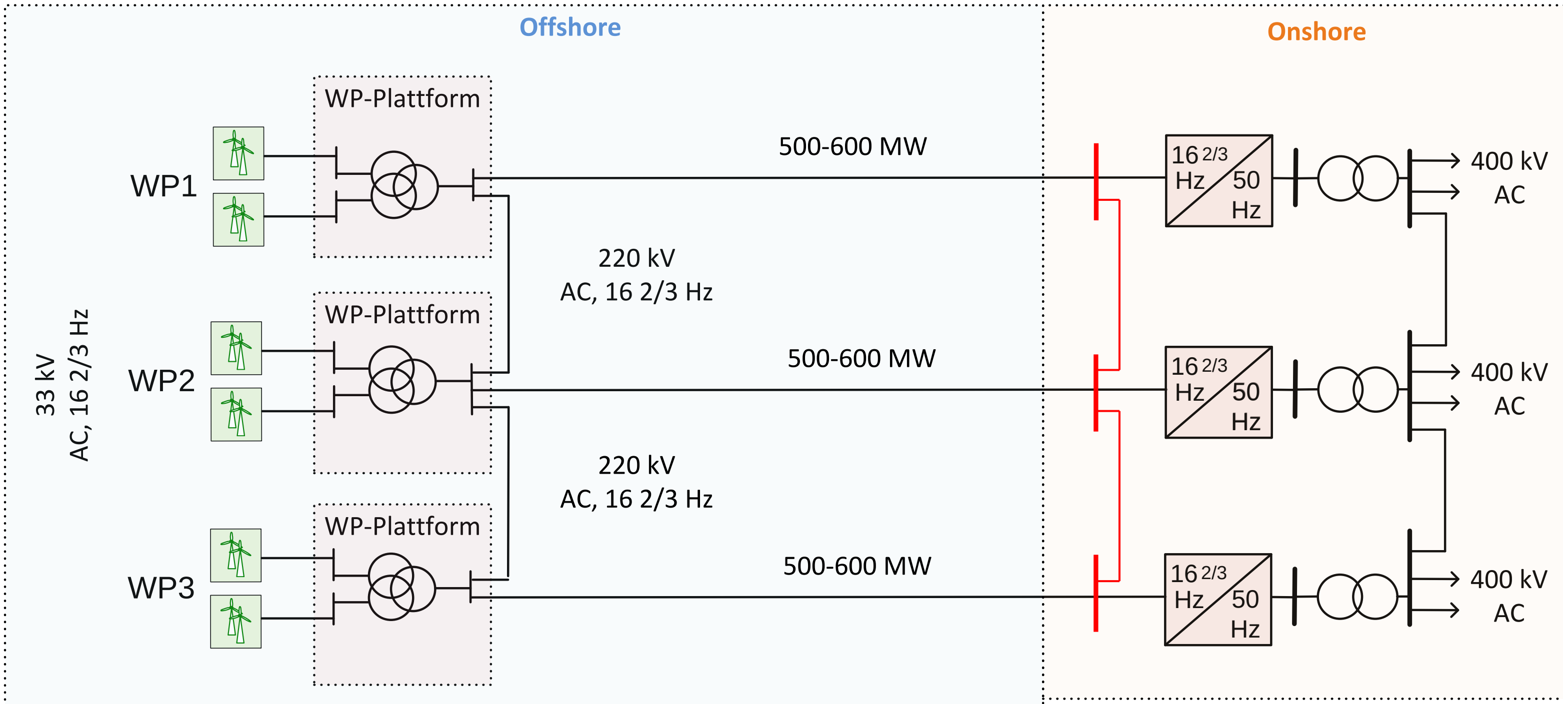


Current Concept



- Separate platform for each wind farm plus one additional HVDC Platform, both offshore
- 150 kV AC for wind farm connections ➔ voltage too low for considerable power transmission
- Converter technique is located offshore ➔ reliability concerns

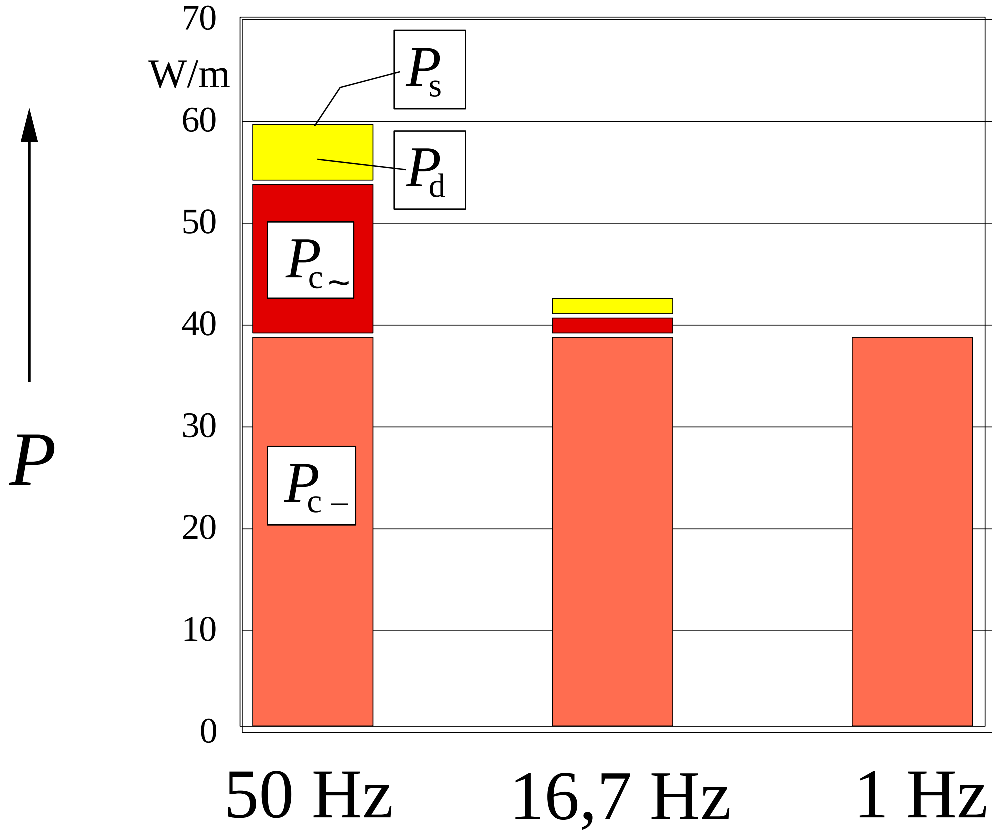
Alternative Concept 16⅔ Hz



- 220 kV AC cable for power transmission to onshore
- 220 kV AC suitable for a mashed North Sea grid
- Separate platform for each wind farm but no need for HVDC platform
- No converter offshore

Cable Losses at Low Frequency

Losses at I_{n_50Hz}=2483 A



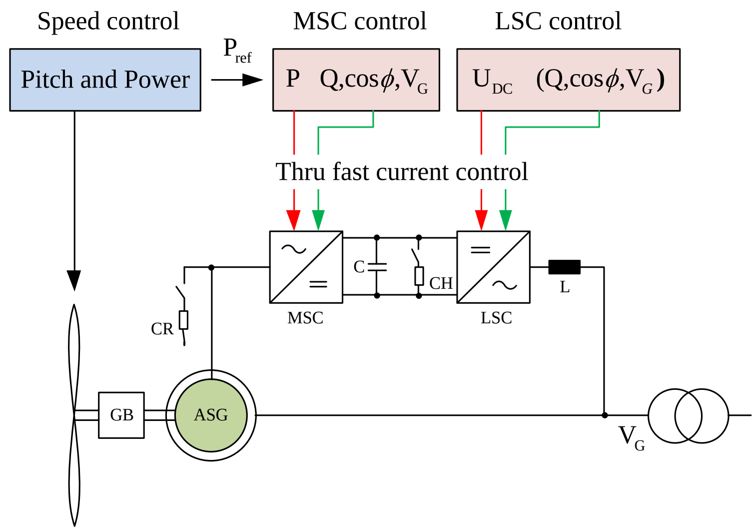
Alternative Concept 16⅔ Hz

Converter onshore:

- Converter is not separated in offshore and onshore but back-to-back
- Not affected by sea climate
- Maintenance fast and to lower costs possible
- Mashed offshore grid easy to establish

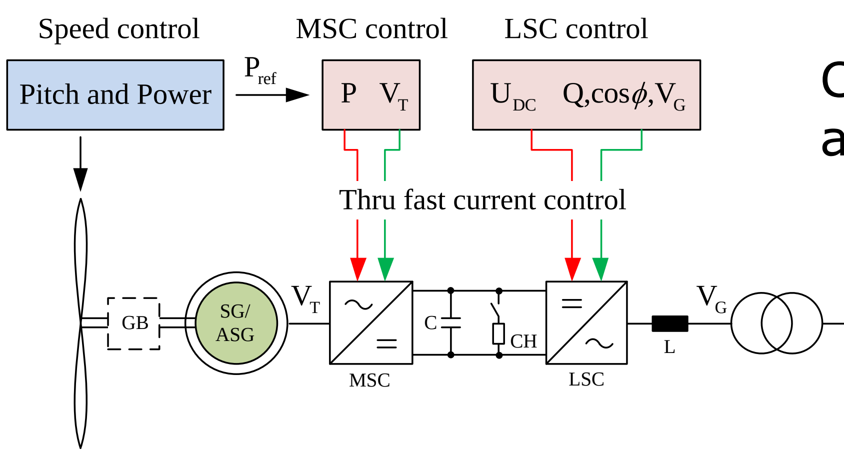
Wind Turbines

DFIG Type 3



Change to 16⅔ Hz is difficult, 16⅔ Hz DFIG is too heavy

Full rated WT Type 4



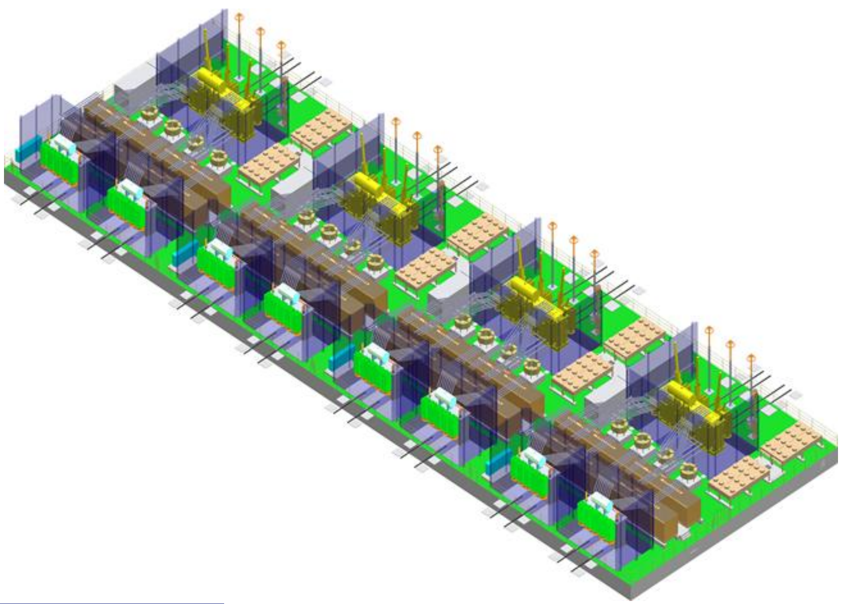
Change to 16⅔ Hz is easily accomplished

16⅔ - 50 Hz Converter

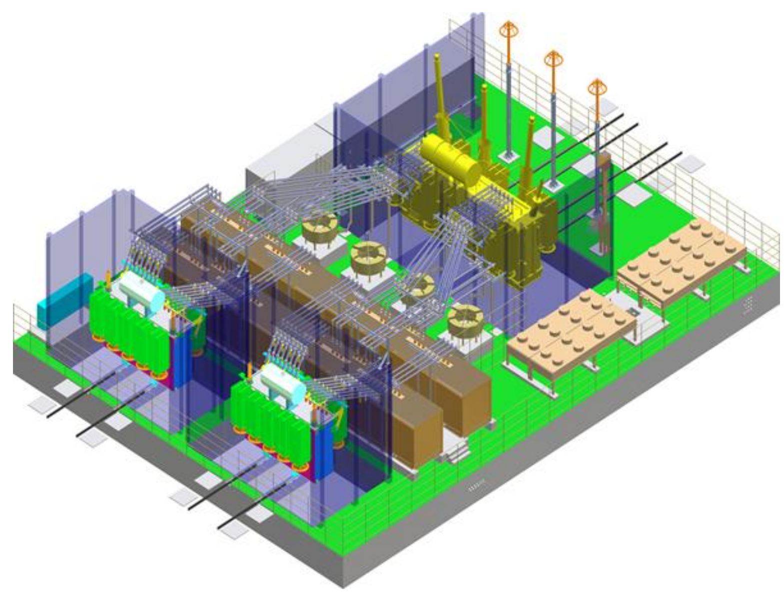
Already developed for single phase

Example Datteln

50 Hz side: 4x103 MW
With overload: 138 MW
Nominal: 413 MW

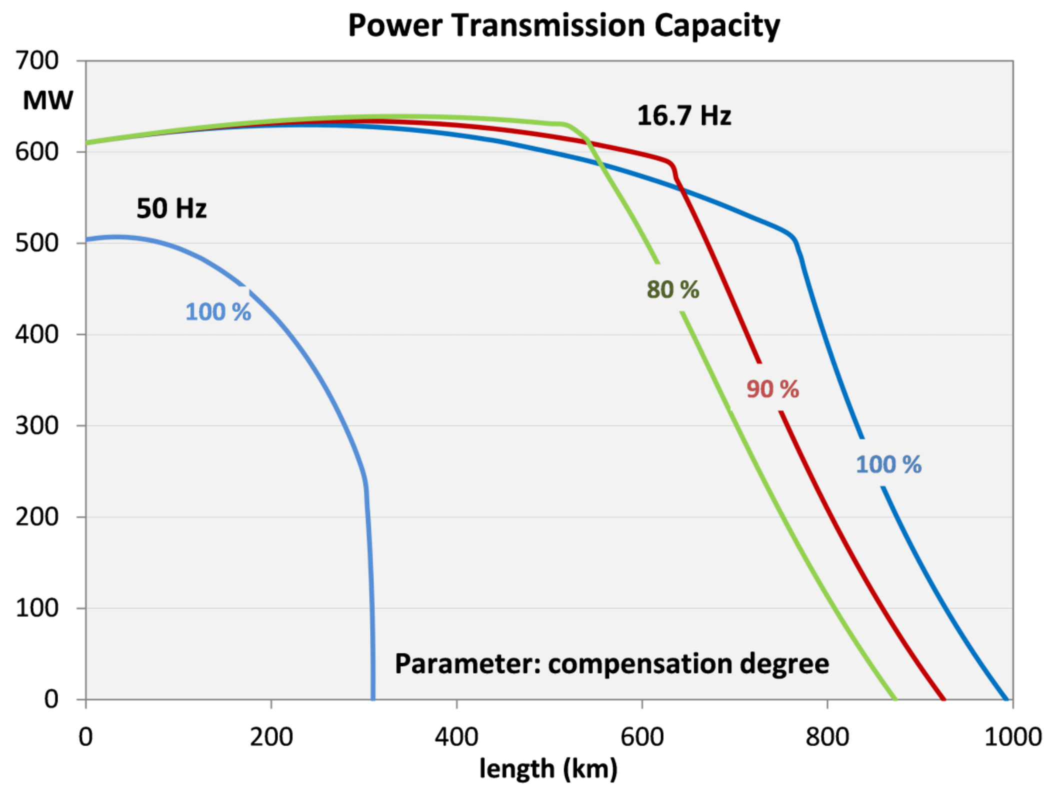


103 (138) MW unit



245 kV Cable

245 kV Submarine Cable 1200 mm² Cu/RM



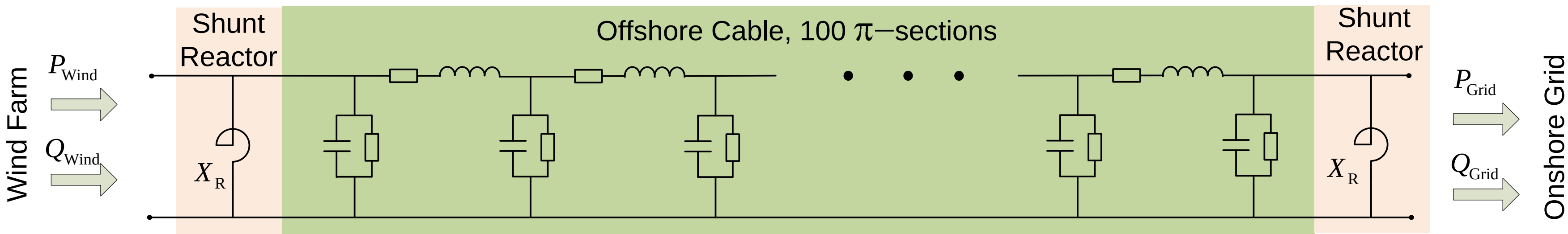
245 kV three phase XLPE submarine cable up to 2000 mm² Al and 1600 mm² Cu are available or can be built

245 kV Cable

245 kV Submarine Cables

	2000 mm² Al/RE		1200 mm2 Cu/RM	
Parameter	50 Hz	16⅔ Hz	50 Hz	16⅔ Hz
I_{max}/ kA	1.3	1.6 (1.5)	1.3	1.6 (1.5
S_n/MVA	498	623.8	504.1	610
R´/mΩ/km	38	22.2	31.9	20.4
L´/mH/km	0.34	0.34	0.37	0.37
X´/mΩ/km	107	37	117	39
C´/nF/km	227	227	191	191
G´/nS/km	71	22	60	20

Calculation of Transmission Capacity

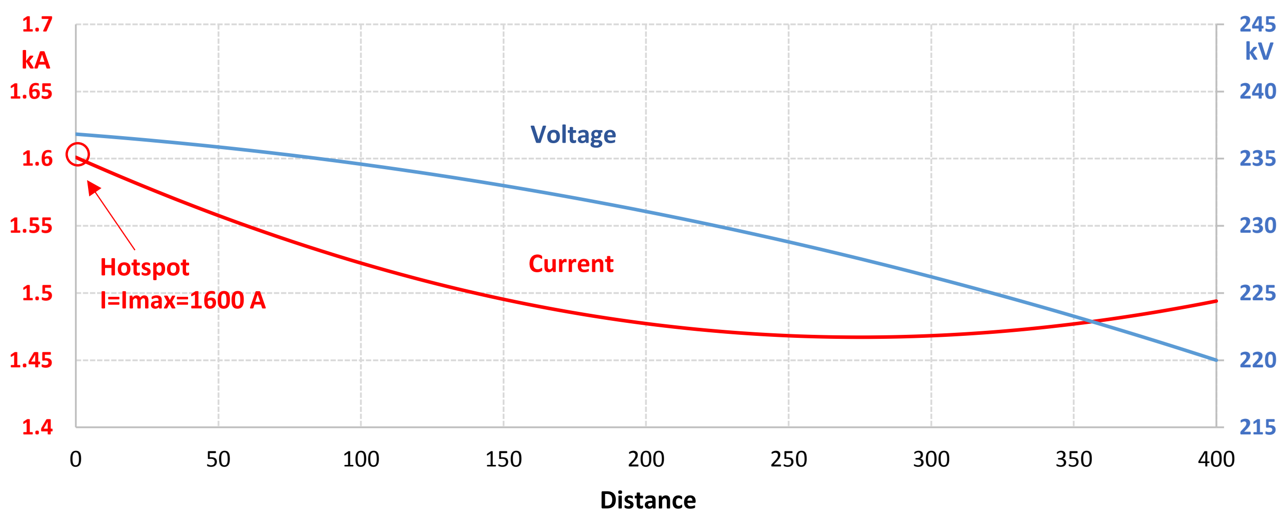


Shunt reactors are calculated for full compensation of the cable under no load conditions $X_R = 2 \cdot \frac{1}{2\pi f \cdot C'_{cable} \cdot l}$

Example: 1200 mm² Cu/RM Cable, 400 km distance

$P_{Wind} = 617\ \mathrm{MW}$

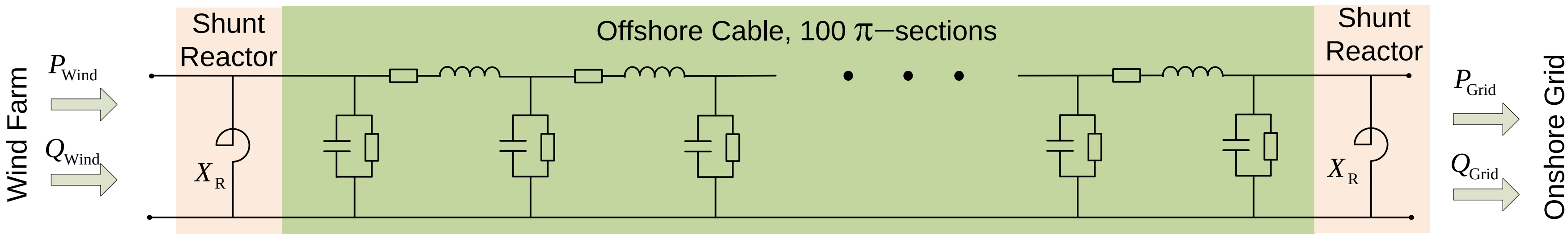
$Q_{Wind} = 0\ \mathrm{Mvar}$



$P_{Grid} = 561\ \mathrm{MW}$

$Q_{Grid} = -94\ \mathrm{Mvar}$

Calculation of Transmission Capacity

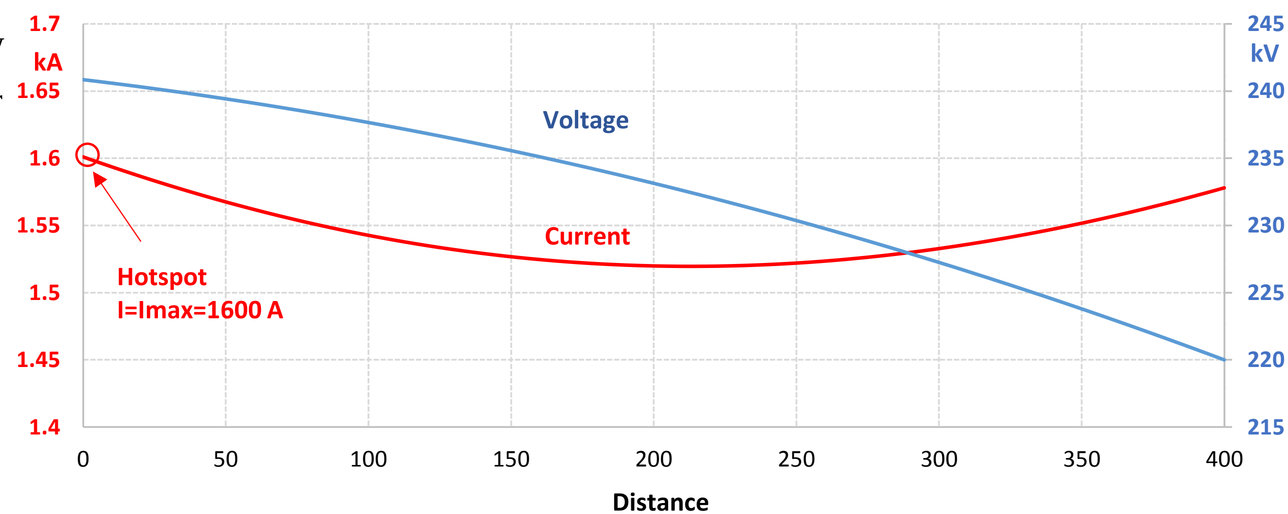


Shunt reactors are calculated for full compensation of the cable under no load conditions $X_{\text{R}} = 2 \cdot \dfrac{1}{2\pi f \cdot C'_{\text{cable}} \cdot l}$

Example: 1200 mm² Cu/RM Cable, 400 km distance

$P_{\text{Wind}} = 643\ \text{MW}$

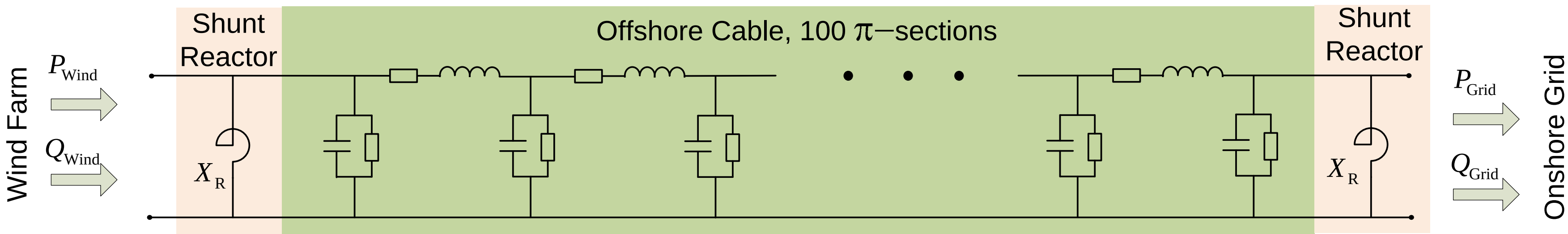
$Q_{\text{Wind}} = 53\ \text{Mvar}$



$P_{\text{Grid}} = 584\ \text{MW}$

$Q_{\text{Grid}} = -53\ \text{Mvar}$

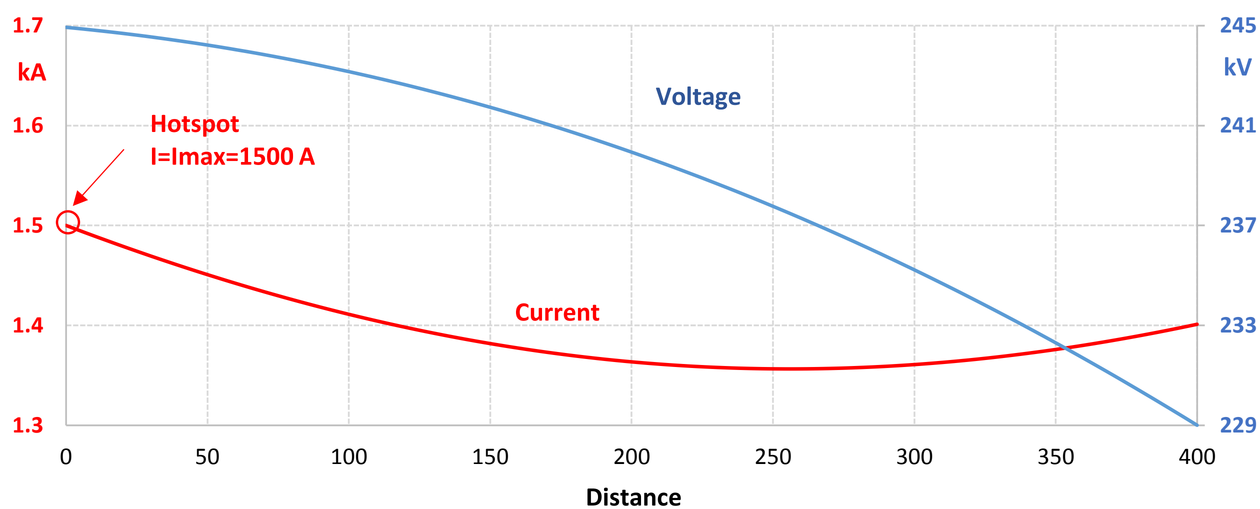
Calculation of Transmission Capacity



1200 mm² Cu/RM Cable, Imax=1500 A, 400 km distance
Var demand supplied solely from the grid side

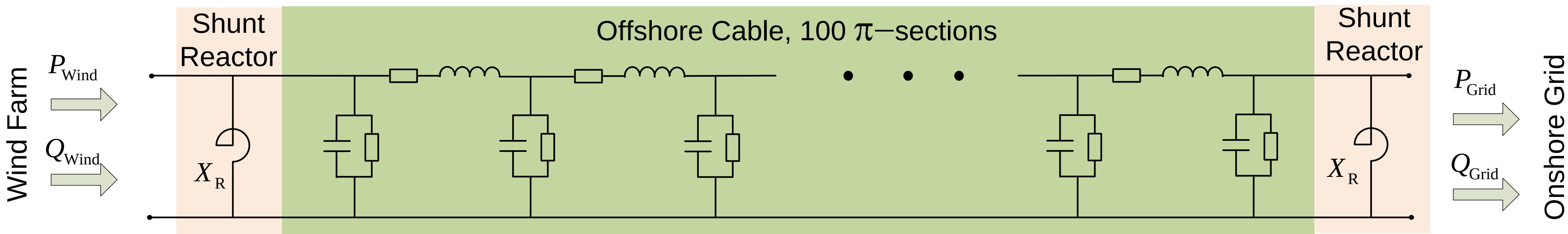
Transmission Capacity: $P_{Wind} = 589\ \mathrm{MW}$ $P_{Loss} = 8.1\%$

$P_{Wind} = 589\ \mathrm{MW}$
$Q_{Wind} = 0\ \mathrm{Mvar}$



$P_{Grid} = 541\ \mathrm{MW}$
$Q_{Grid} = \text{-}84\ \mathrm{Mvar}$

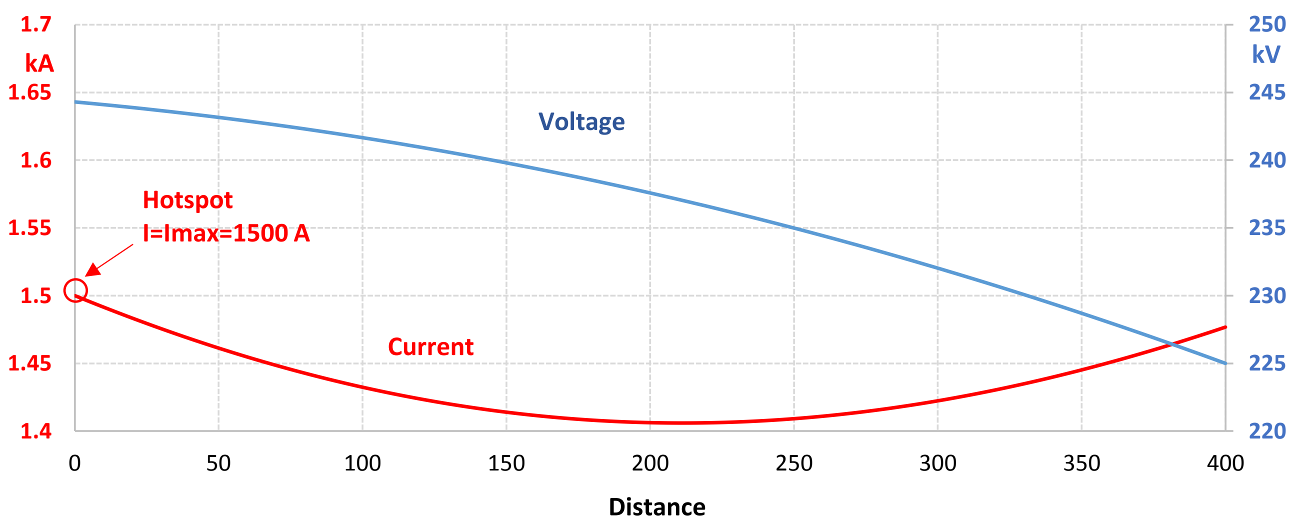
Calculation of Transmission Capacity



1200 mm² Cu/RM Cable, Imax=1500 A, 400 km distance
Var demand distributed equally to both ends

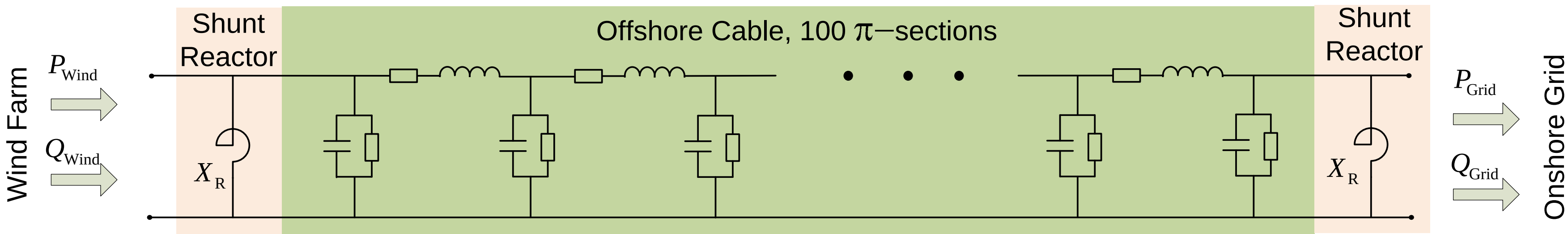
Transmission Capacity: $P_{Wind} = 604\ \text{MW}$ $P_{Loss} = 8.4\%$

$P_{Wind} = 604\ \text{MW}$
$Q_{Wind} = \text{-}45\ \text{Mvar}$



$P_{Grid} = 553\ \text{MW}$
$Q_{Grid} = \text{-}45\ \text{Mvar}$

Calculation of Transmission Capacity

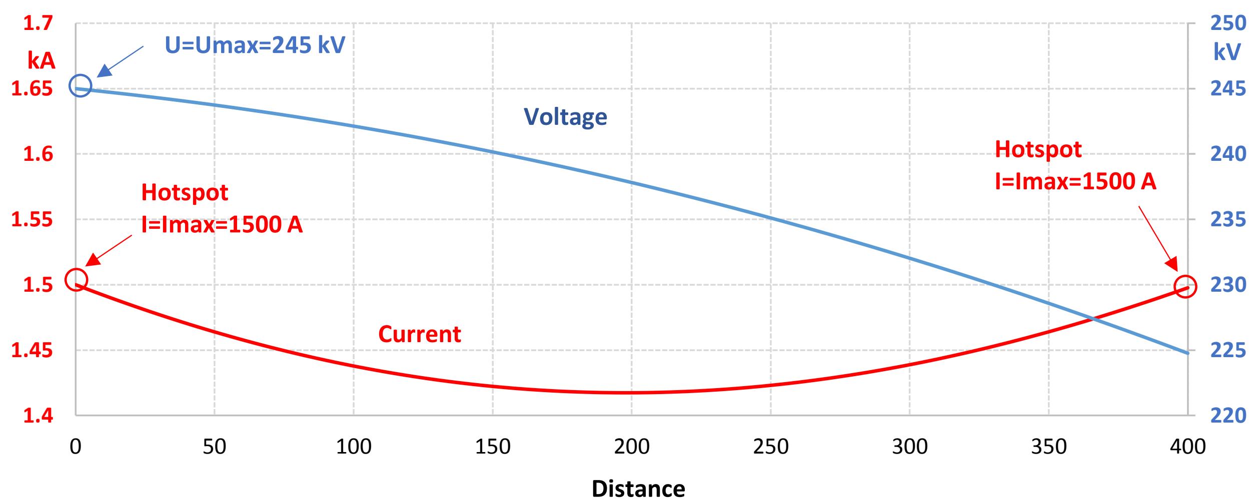


1200 mm² Cu/RM Cable, Imax=1500 A, 400 km distance optimized operation for max. active power transmission

Transmission Capacity: $P_{\text{Wind}} = 610\ \text{MW}$ $\quad P_{\text{Loss}} = 8.5\%$

$P_{\text{Wind}} = 610\ \text{MW}$

$Q_{\text{Wind}} = \text{-58 Mvar}$



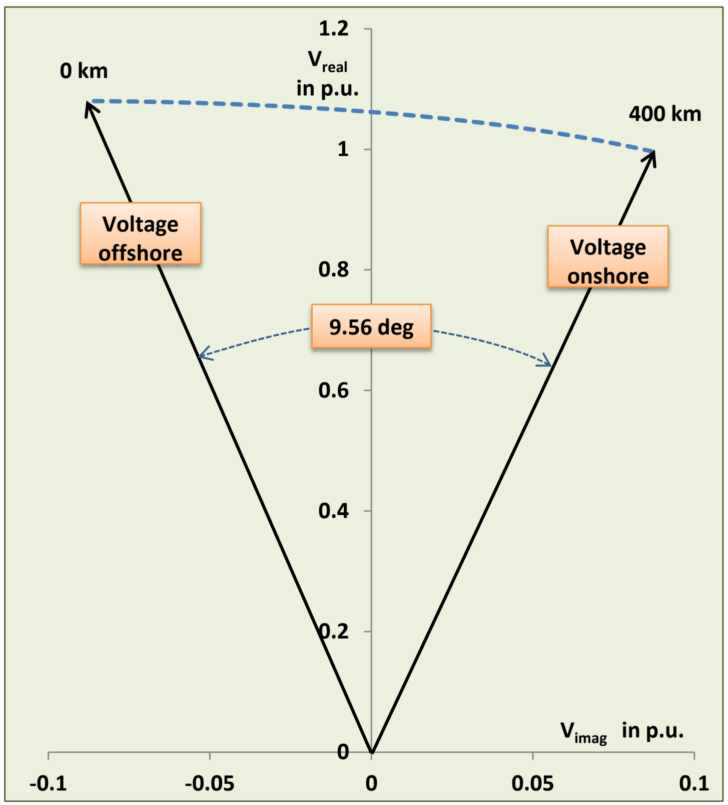
$P_{\text{Grid}} = 558\ \text{MW}$

$Q_{\text{Grid}} = \text{-34 Mvar}$

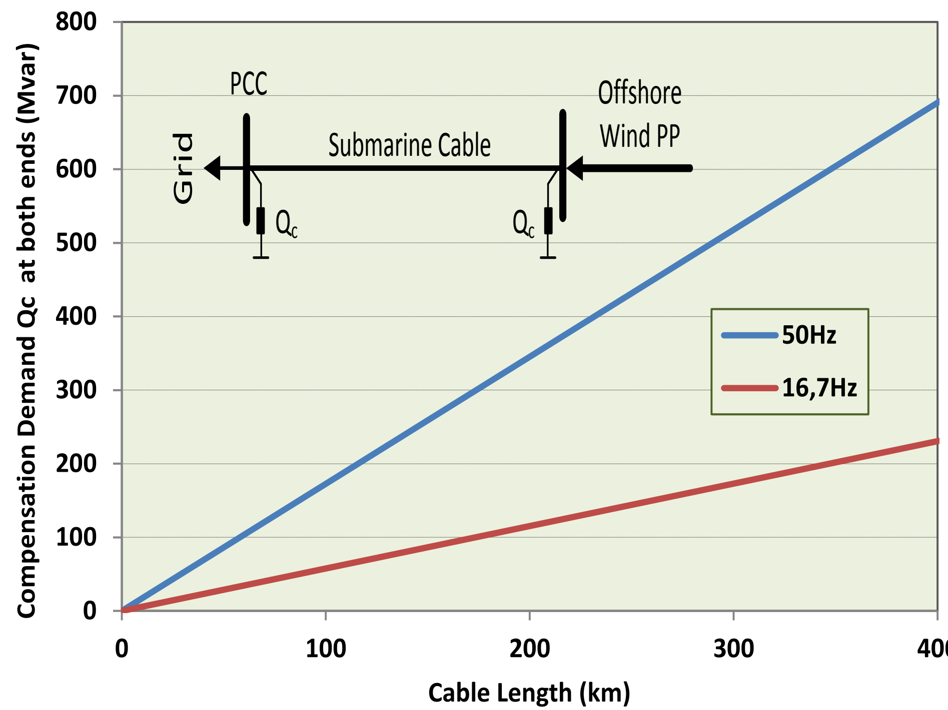
Transmission Characteristic

245 kV Submarine Cable 2000 mm² Al/RE

Voltage and voltage angle transmission of 600 MW over 400 km



Compensation demand



Hypothetic Nord Sea Grid

Meshed North Sea Grid with 16⅔ Hz at 220 kV level would be possible!

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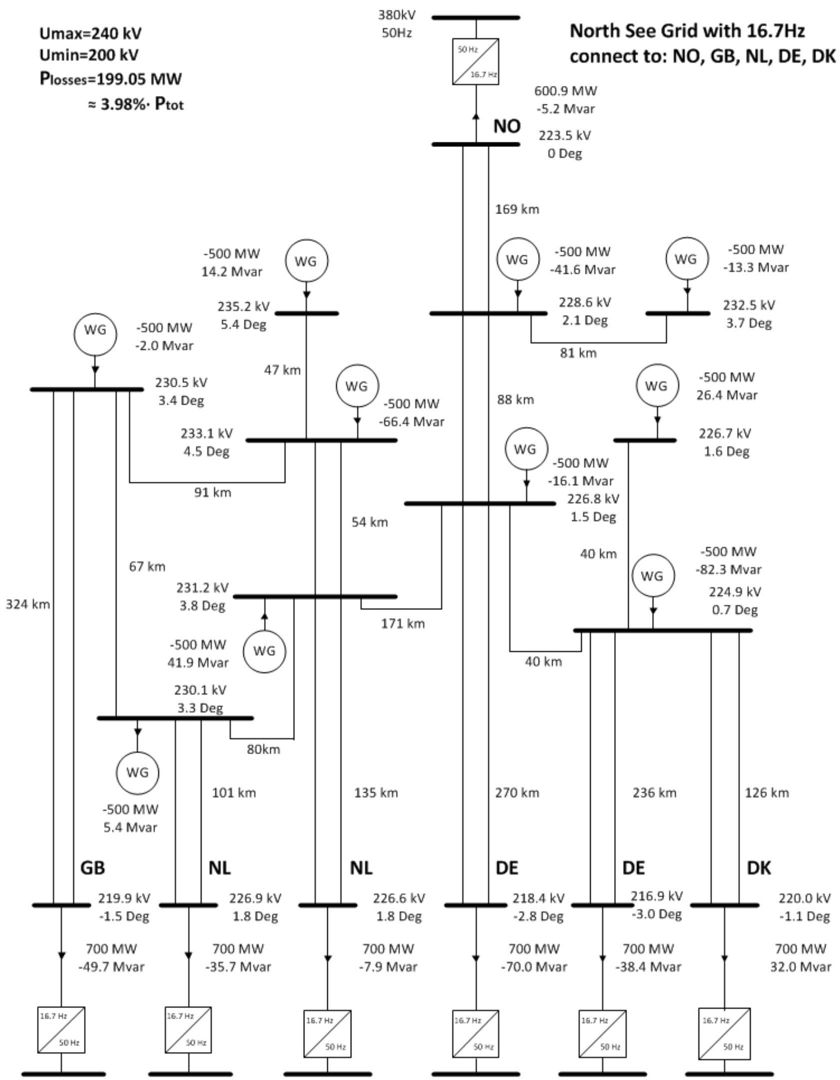
Power Flow in the North Sea Grid



Assumed total generation power: 5000 MW

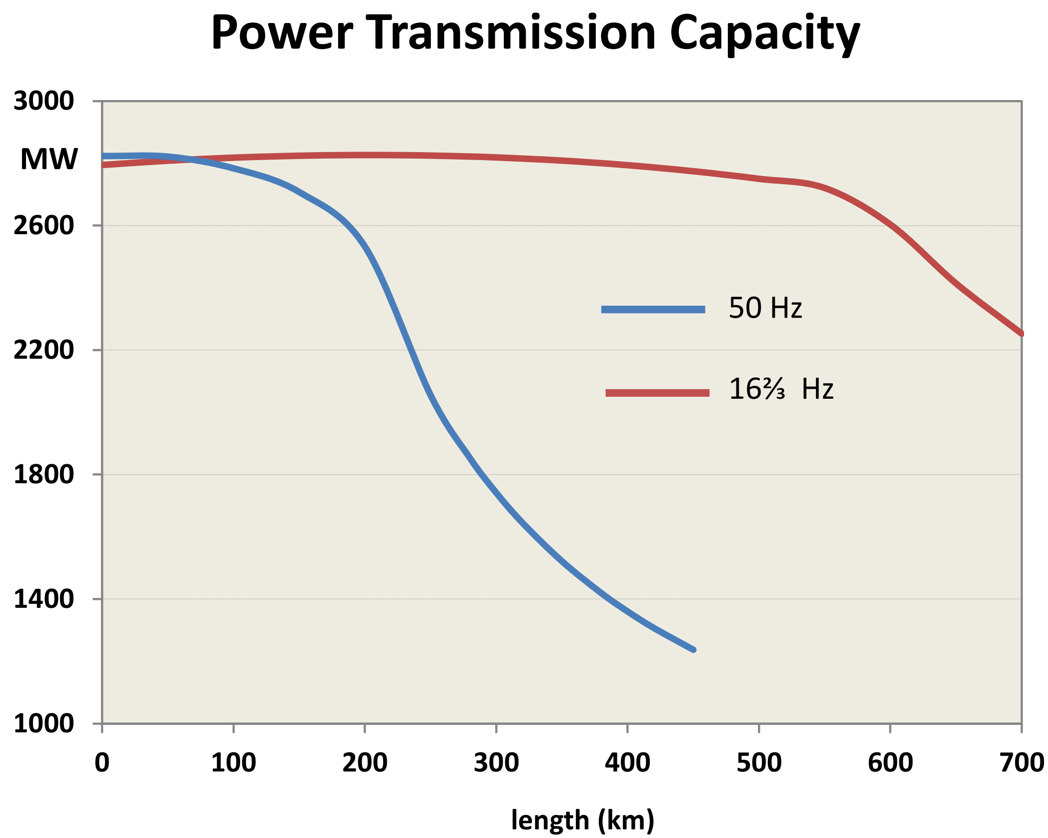
- Acceptable voltage drops
- Voltage angle differences are small
- Losses are acceptable

16⅔ Hz Transformer

16⅔ Hz Transformer, 15 MVA;
120/17,25 kV, ONAN-Hermetik; Ii0
(Quelle: Alstrom)

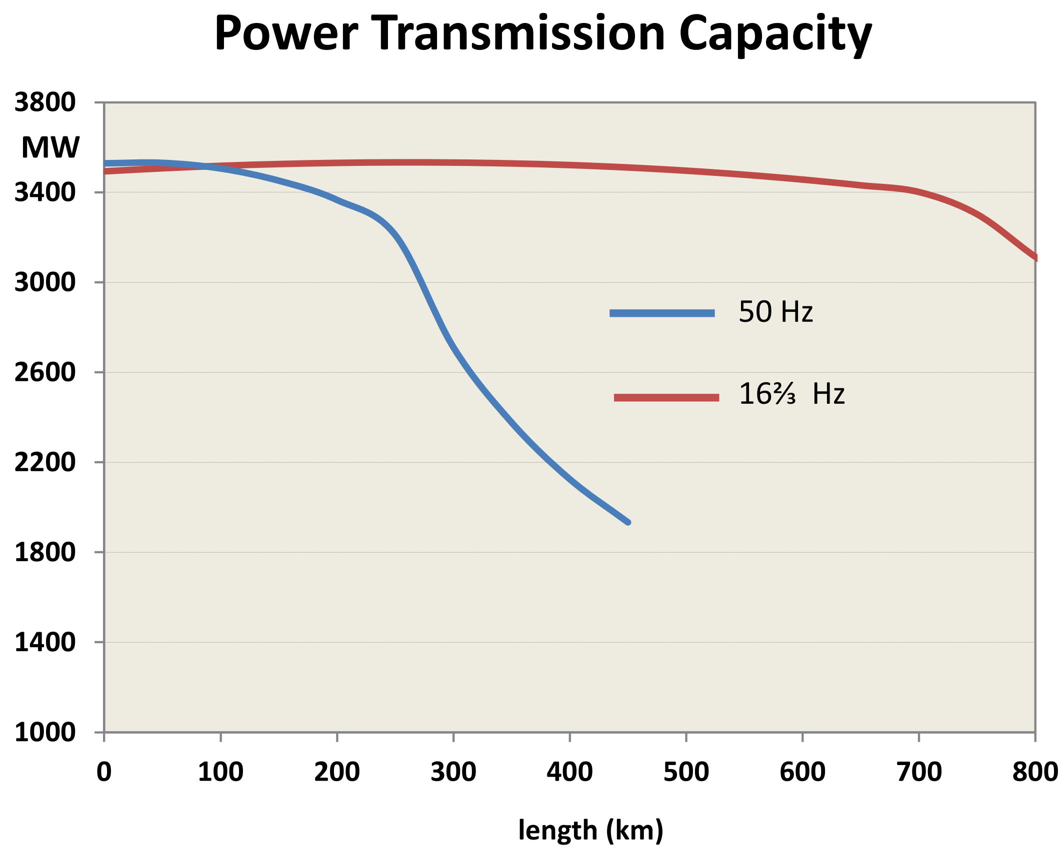
- Experience in building 16⅔ transformers are available
- Weight is about 2x more than that of 50 Hz transformers

Transmission Capacity of 400 kV Overhead Lines



Conductor: 4xAl/St 550/70
R´ = 0,01315 Ohm/km ; X´ = 0,26 Ohm/km ; C´ = 0,014 µF/km
I_{max}=4080 A

Transmission Capacity of 500 kV Overhead Lines

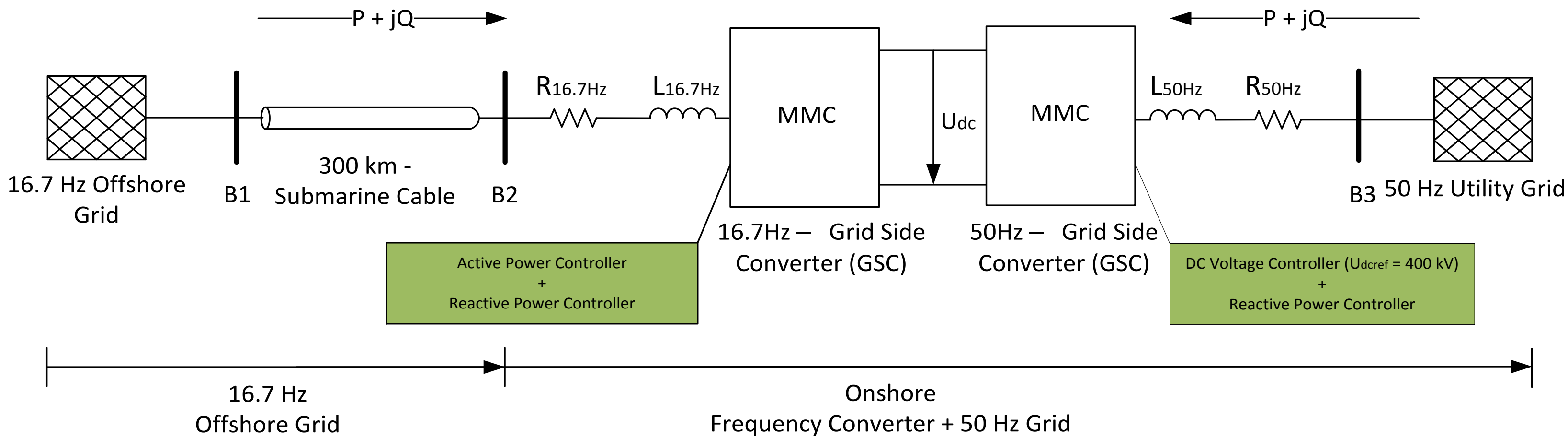


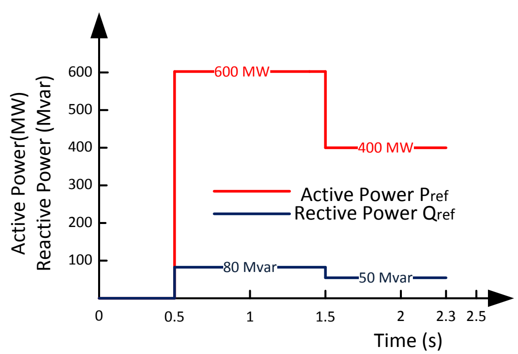
Conductor: 4xAl/St 550/70

R´ = 0,01315 Ohm/km ; X´ = 0,26 Ohm/km ; C´ = 0,014 µF/km

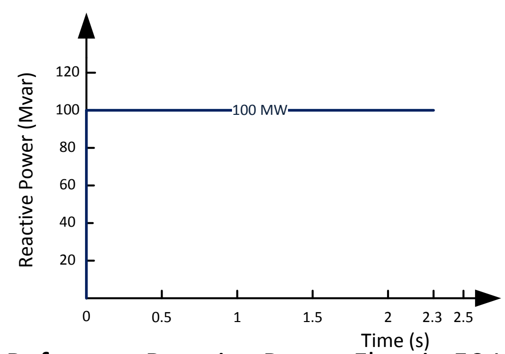
I_{max}=4080 A

Dynamic Simulation





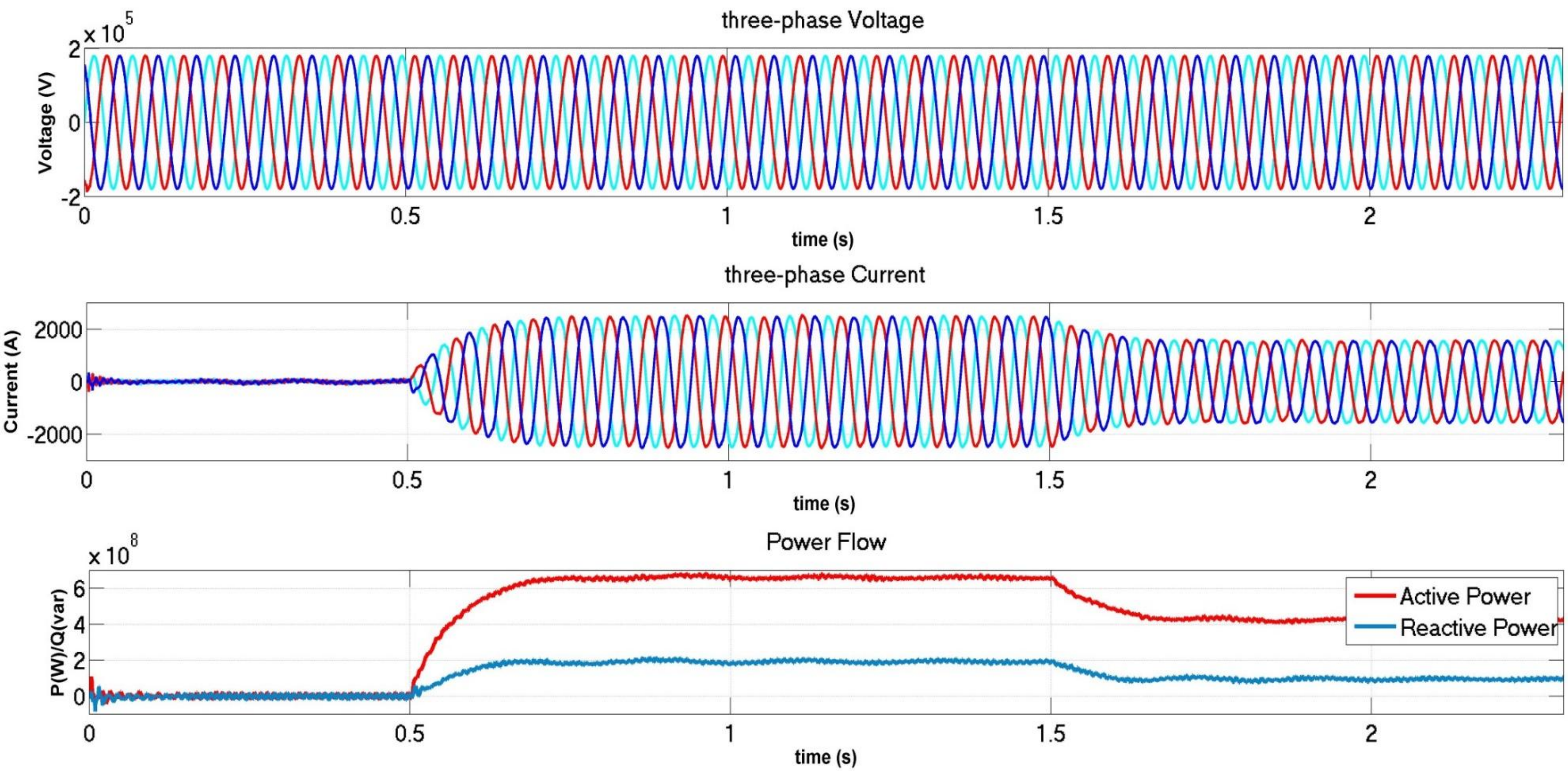
(a) Reference Power Flow in 16.7 Hz Grid



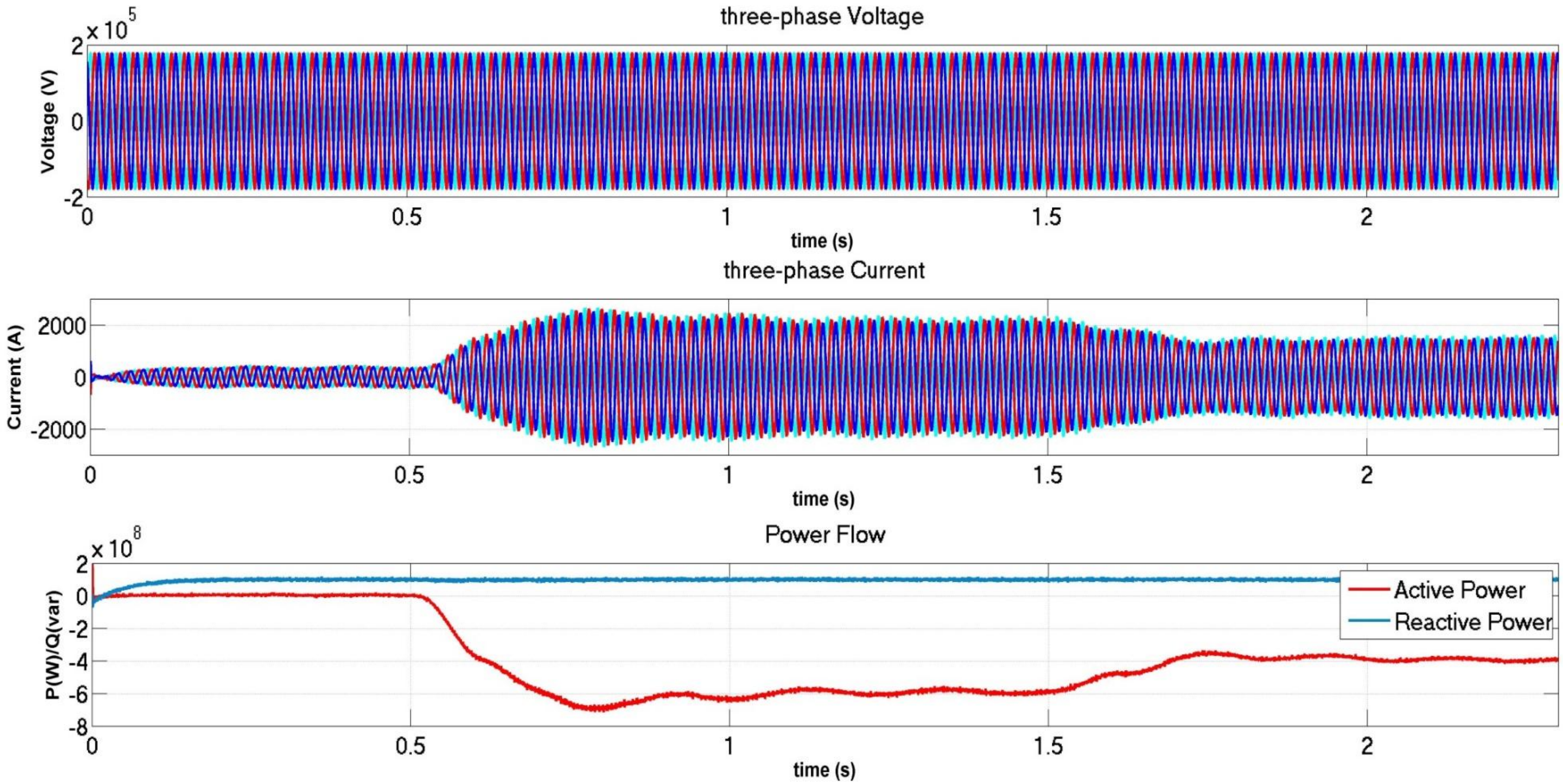
(b) Reference Reactive Power Flow in 50 Hz Grid

Simulation Results – 16.7 Hz side

Sending End



Simulation Results – 50 Hz side



Conclusions

The integration of offshore wind farms by three phase 16⅔ Hz technology and setting up a 16⅔ Hz offshore grid is a favorable alternative to DC links

- Converter are only onshore, easy to acces and not affected by serious weather conditions
- No need for HVDC platform offshore
- Offshore are only approved technologies like transformer and switch gears
- Due to meshed 220 kV grid (n-1) security is possible
- Extention to 400 kV (500 kV) onshore overlay grid is possible by 16⅔-Hz technology


Thank you for your attention!