ENERGY

Power Frequency Optimisation

For Offshore Wind Farms

EERA DeepWind Conference, Trondheim, 2015

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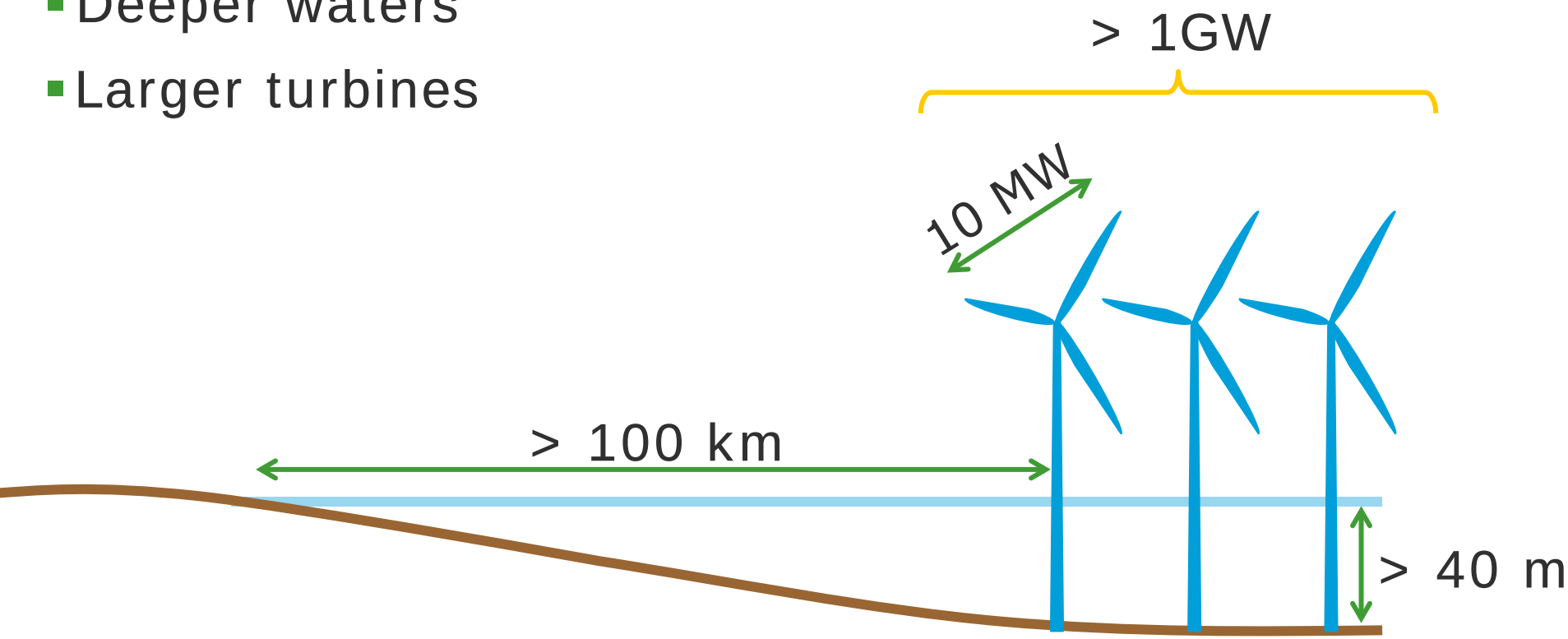
Introduction

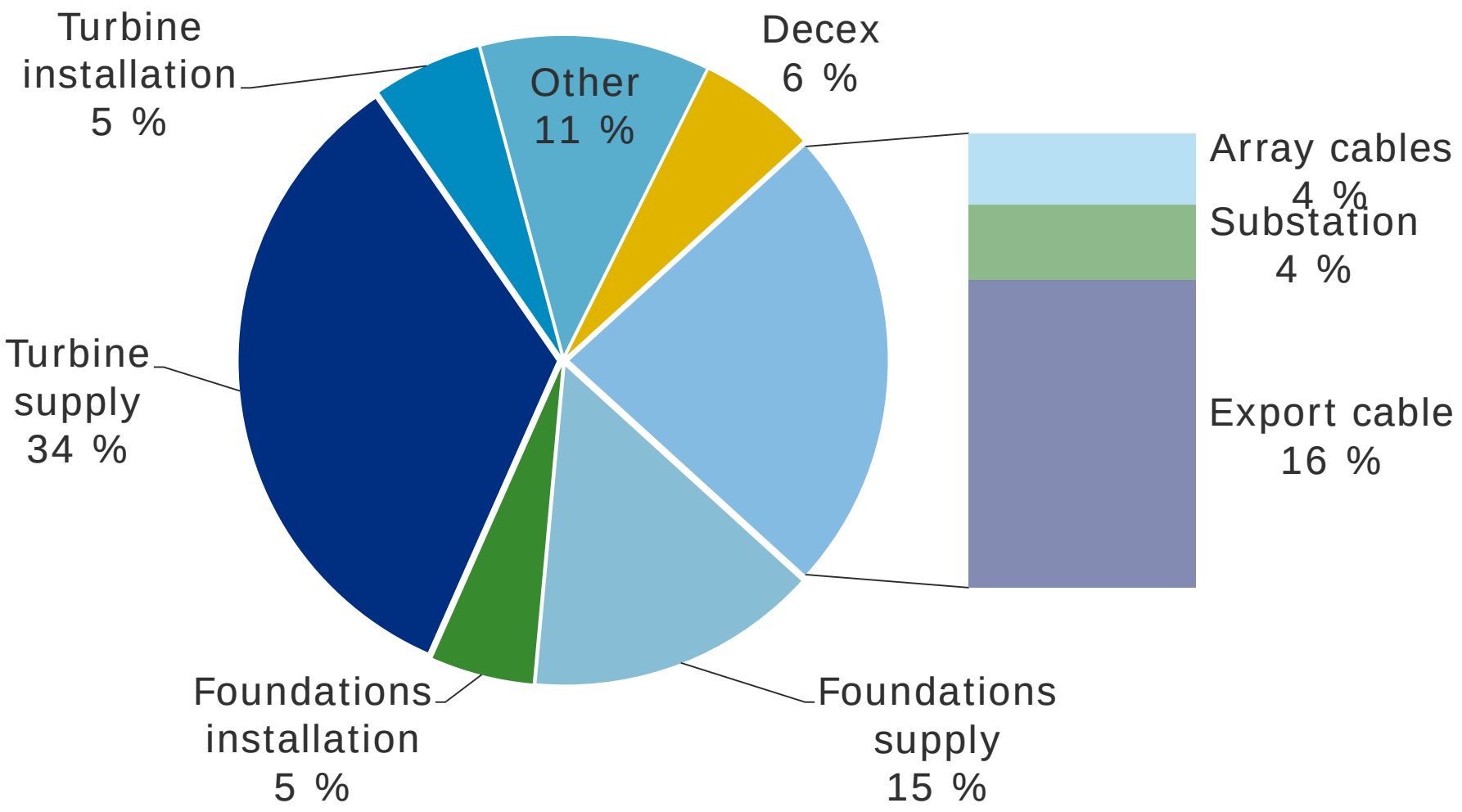
- Introduction
- Wind energy export technologies
- Frequency sensitivity study
- Levelised Cost of Energy comparison
- Conclusion

Trends in offshore wind energy

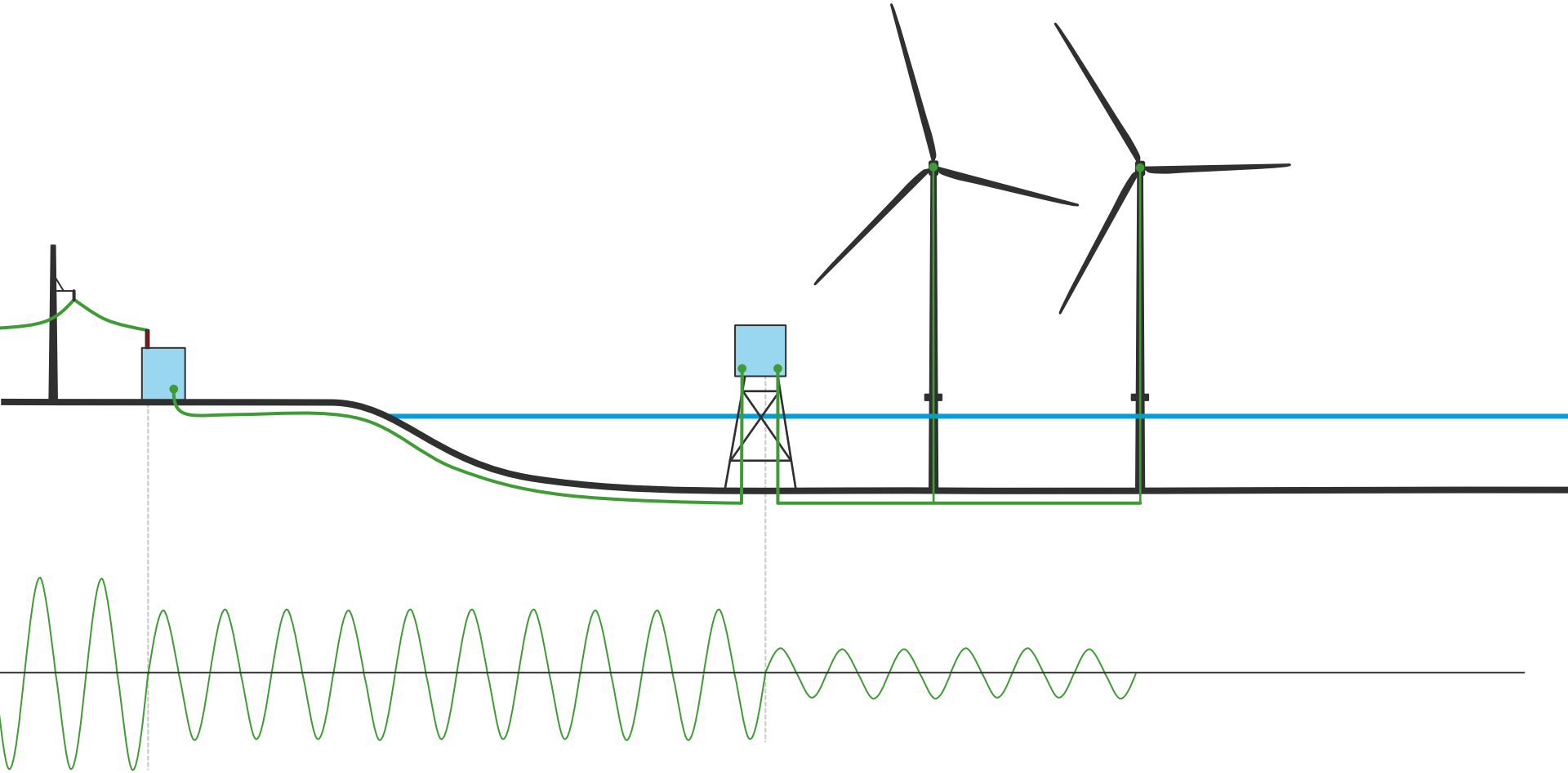
- Larger wind farms
- Further distance-to-shore
- Deeper waters
- Larger turbines



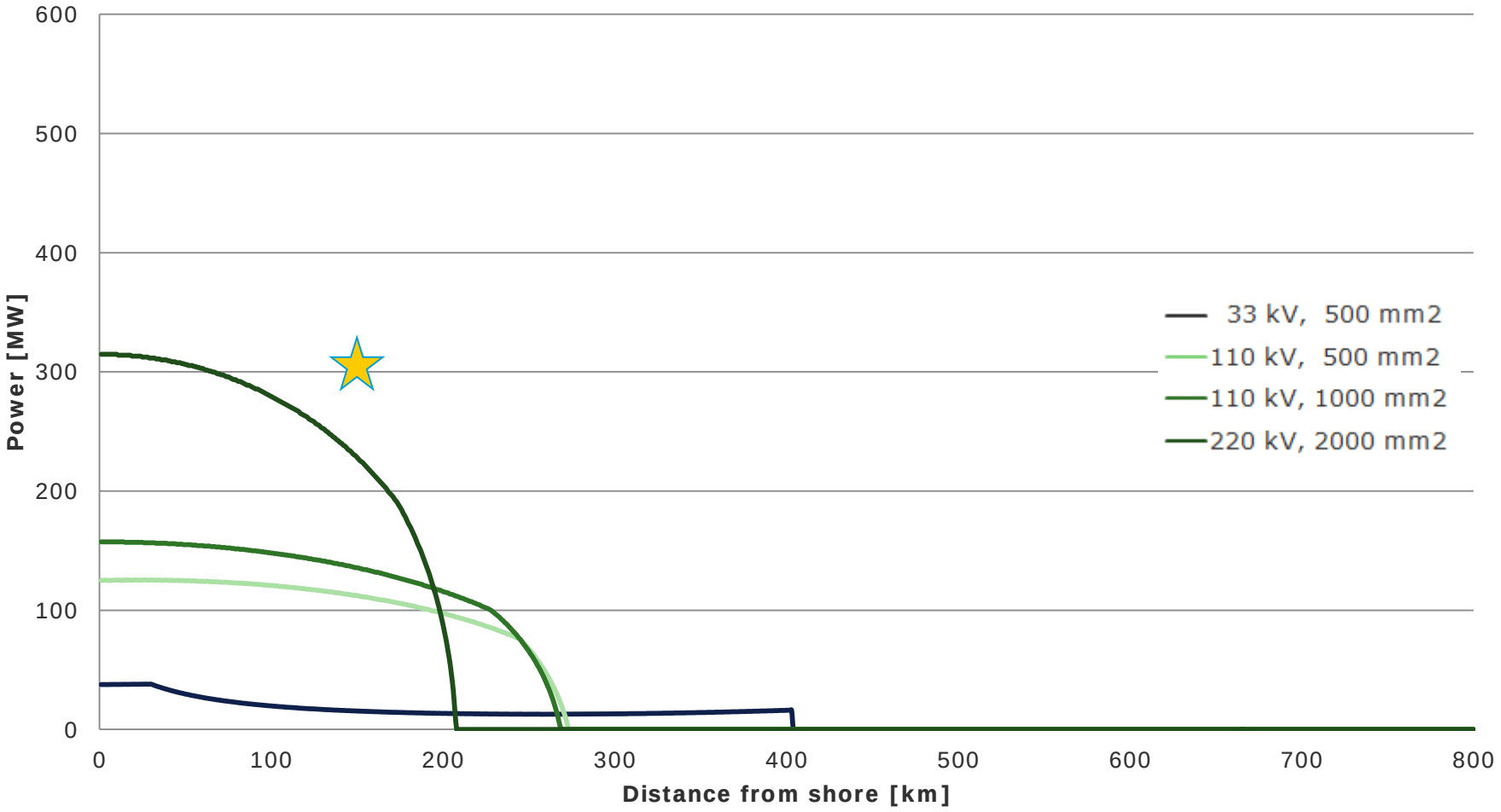
CAPEX build-up



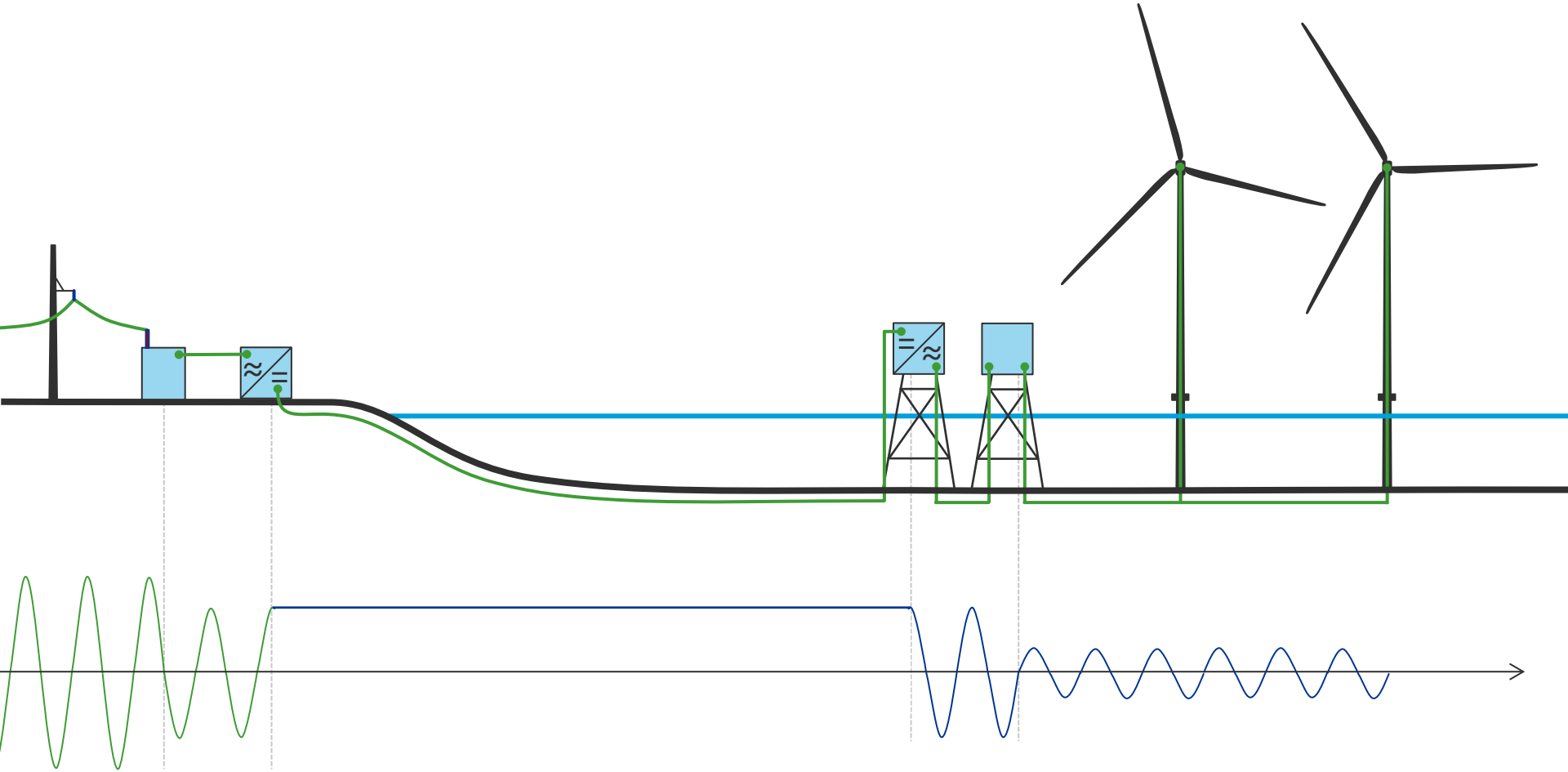
Offshore wind technology – 50 Hz Alternating Current - HV



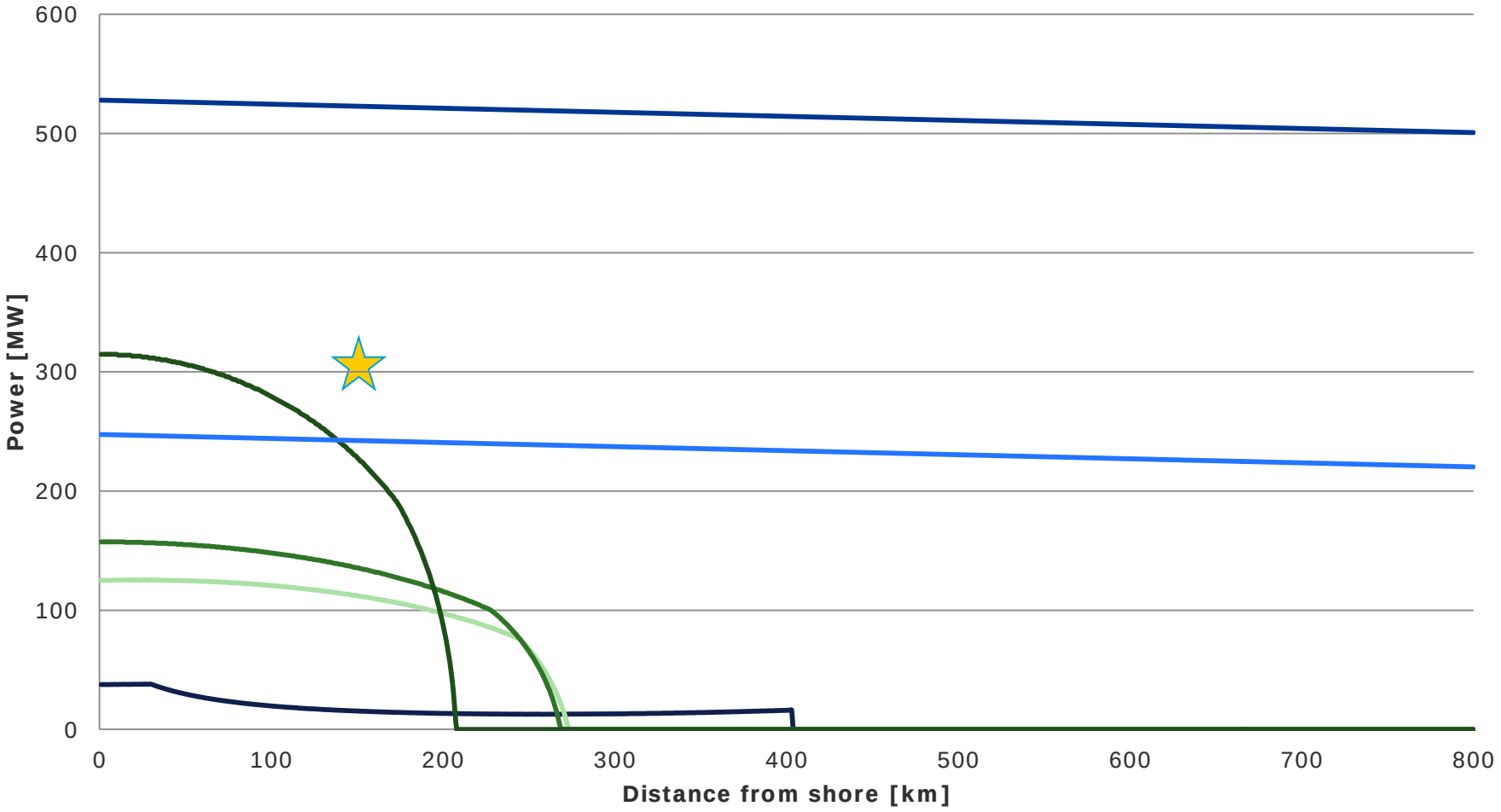
Power vs Distance



Offshore wind technology – High Voltage Direct Current



Power vs Distance

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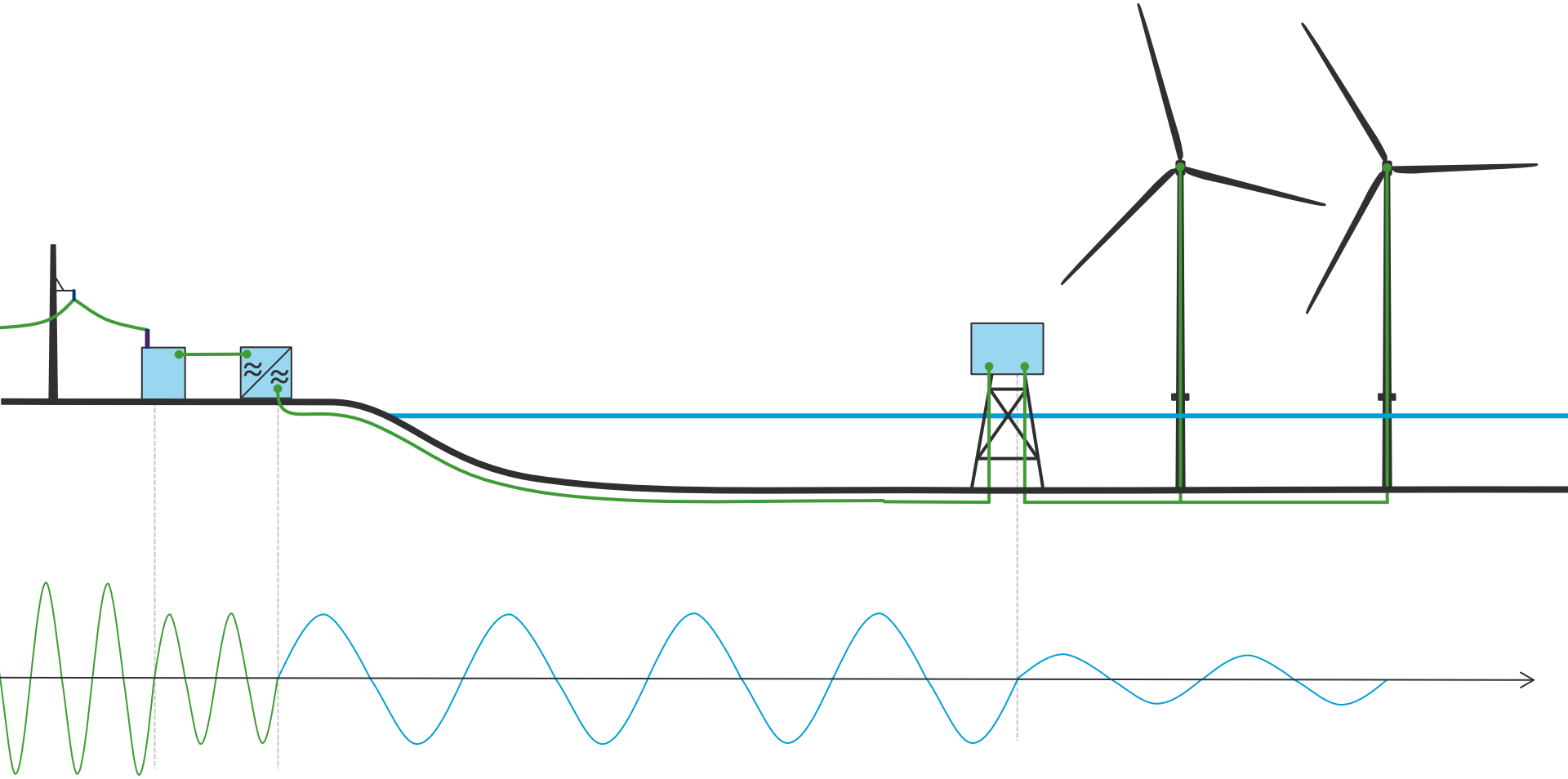
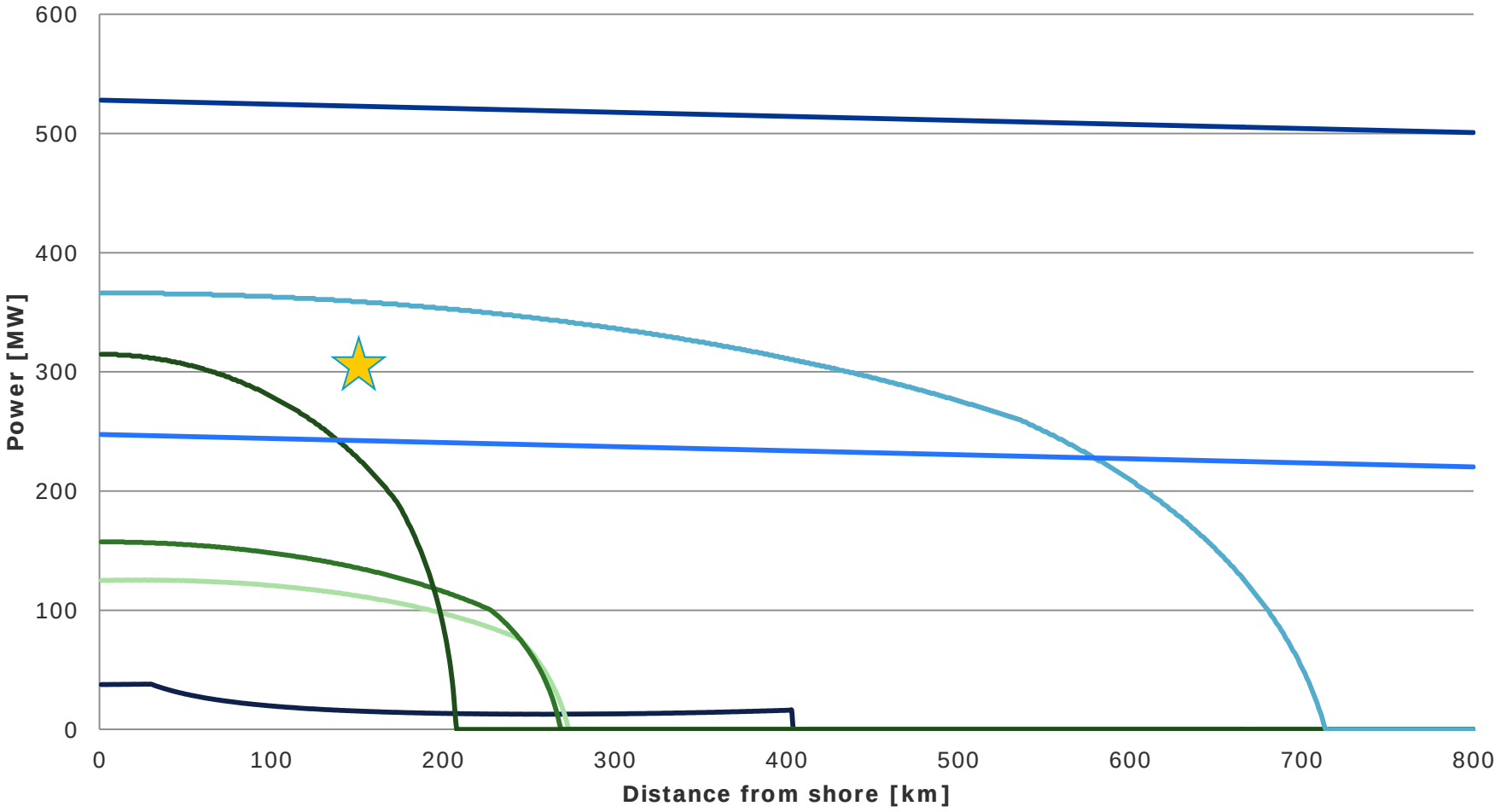
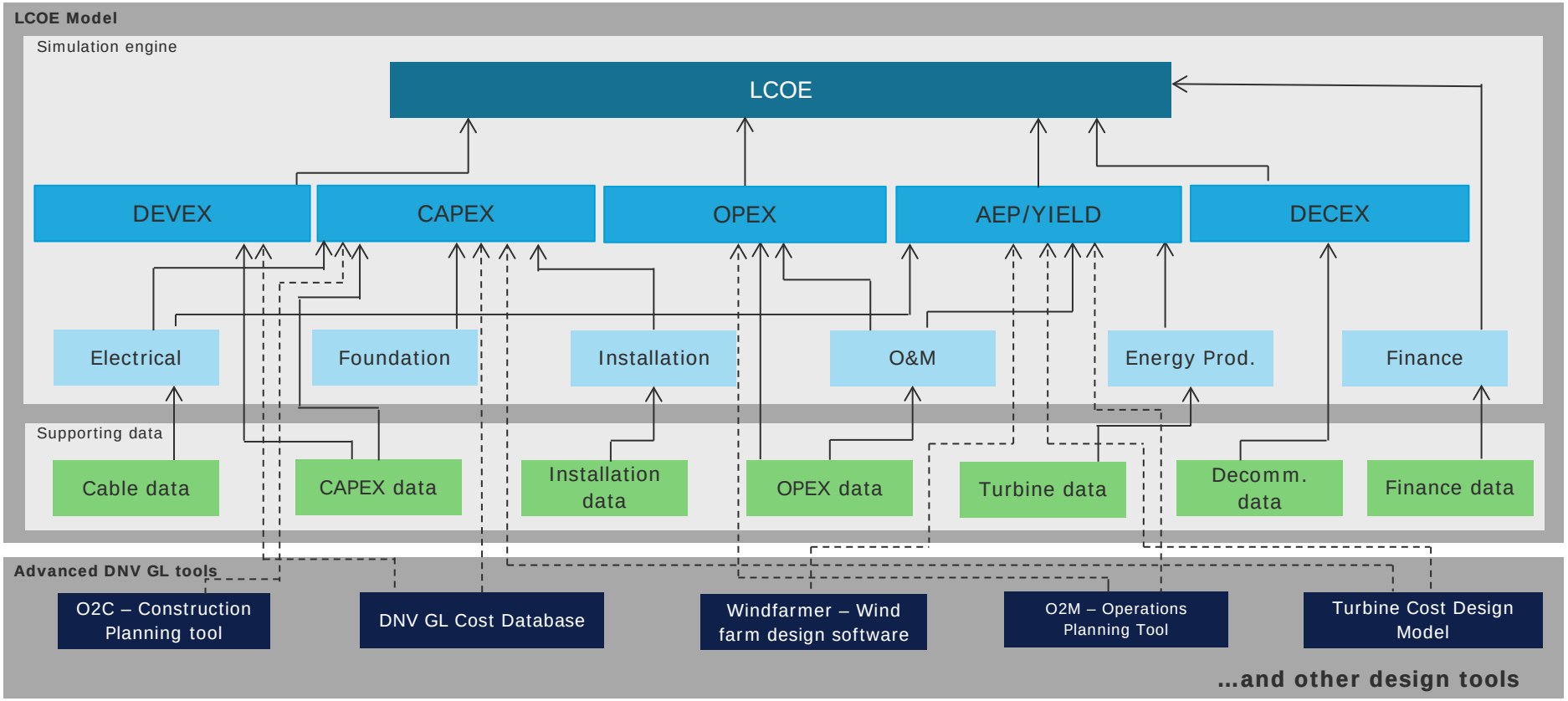
Offshore wind technology – Low Frequency AC



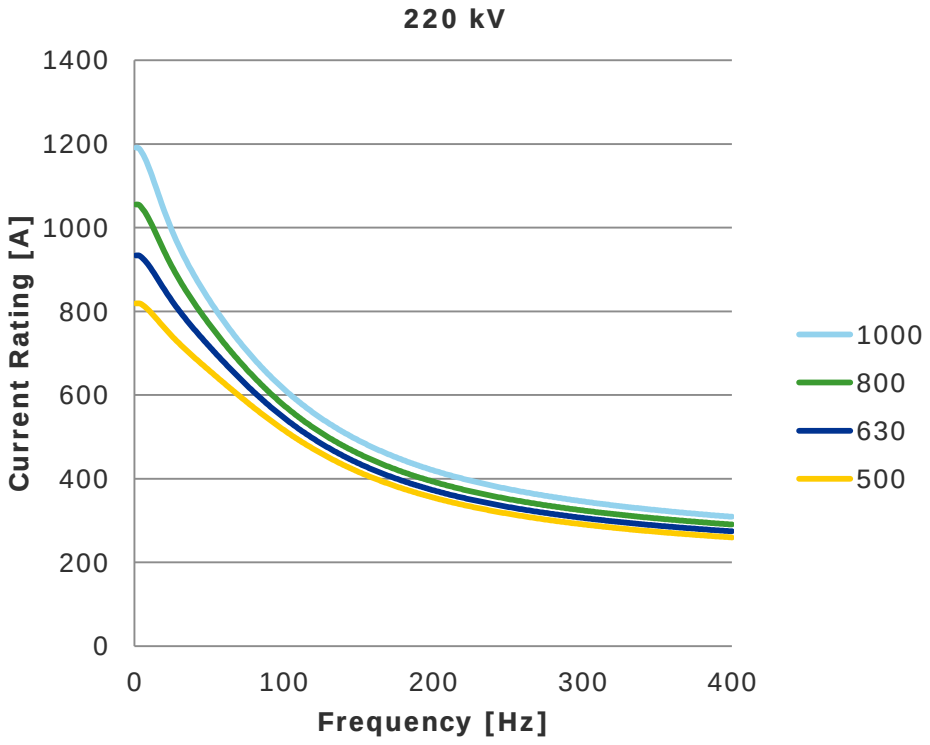
Power vs Distance

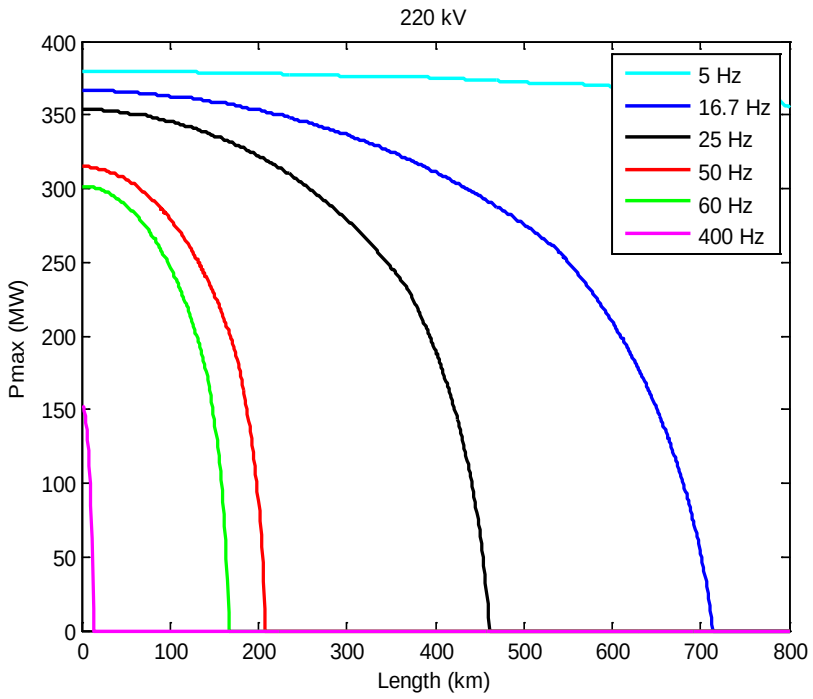


Levelised Cost of Energy – Offshore wind farms

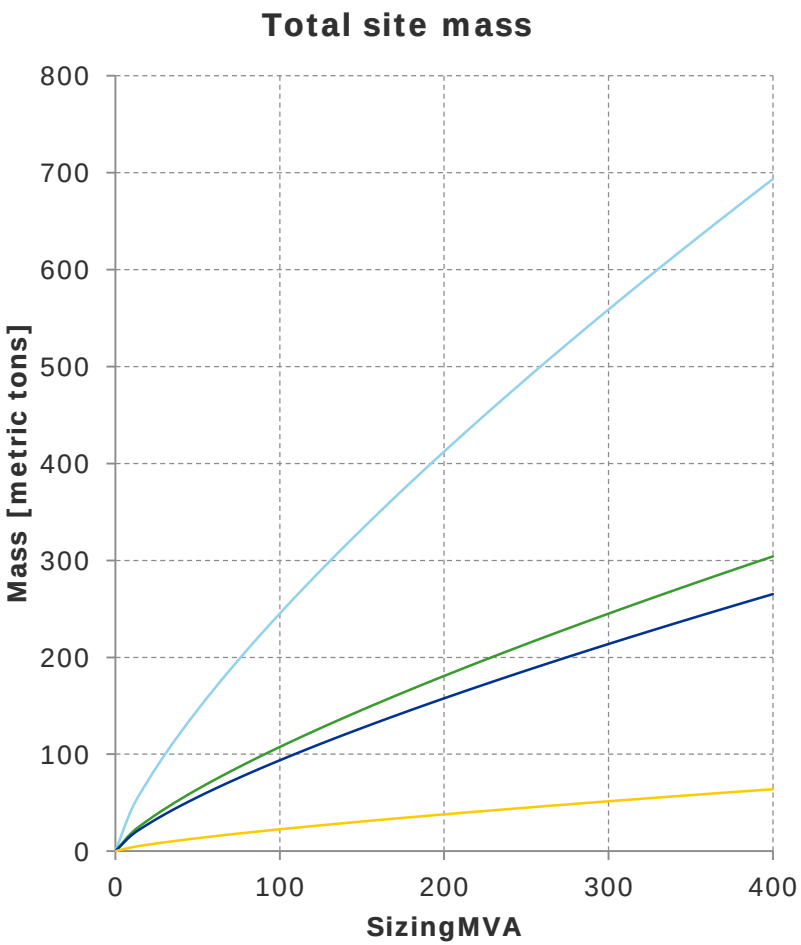


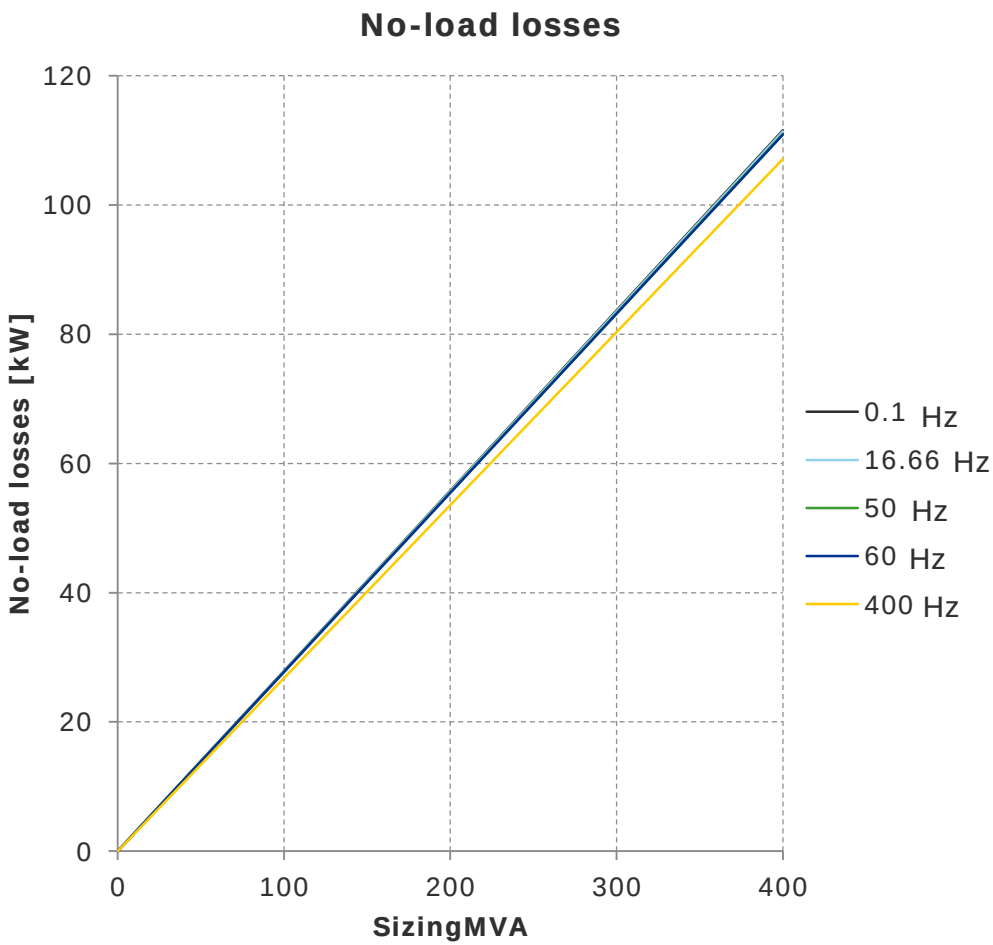
Modelling – Export cables





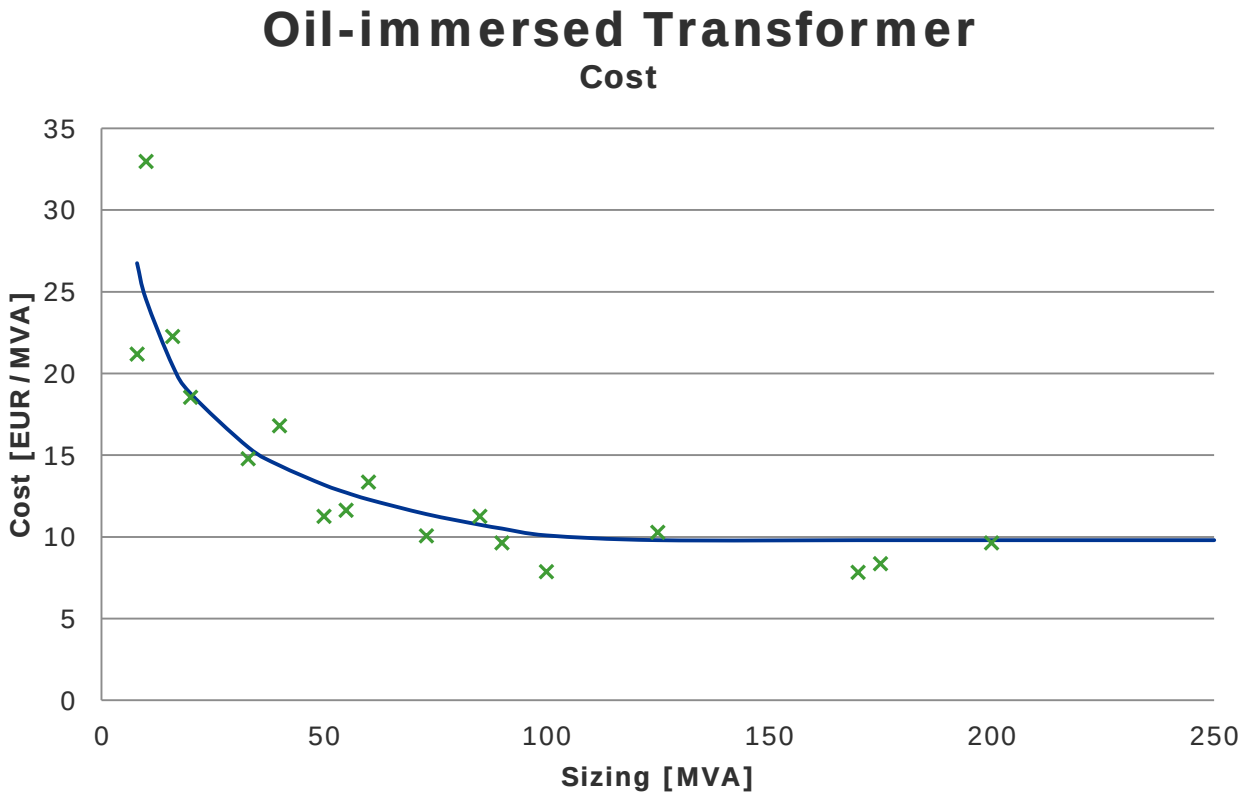
Modelling - Transformers





Modelling - Costs

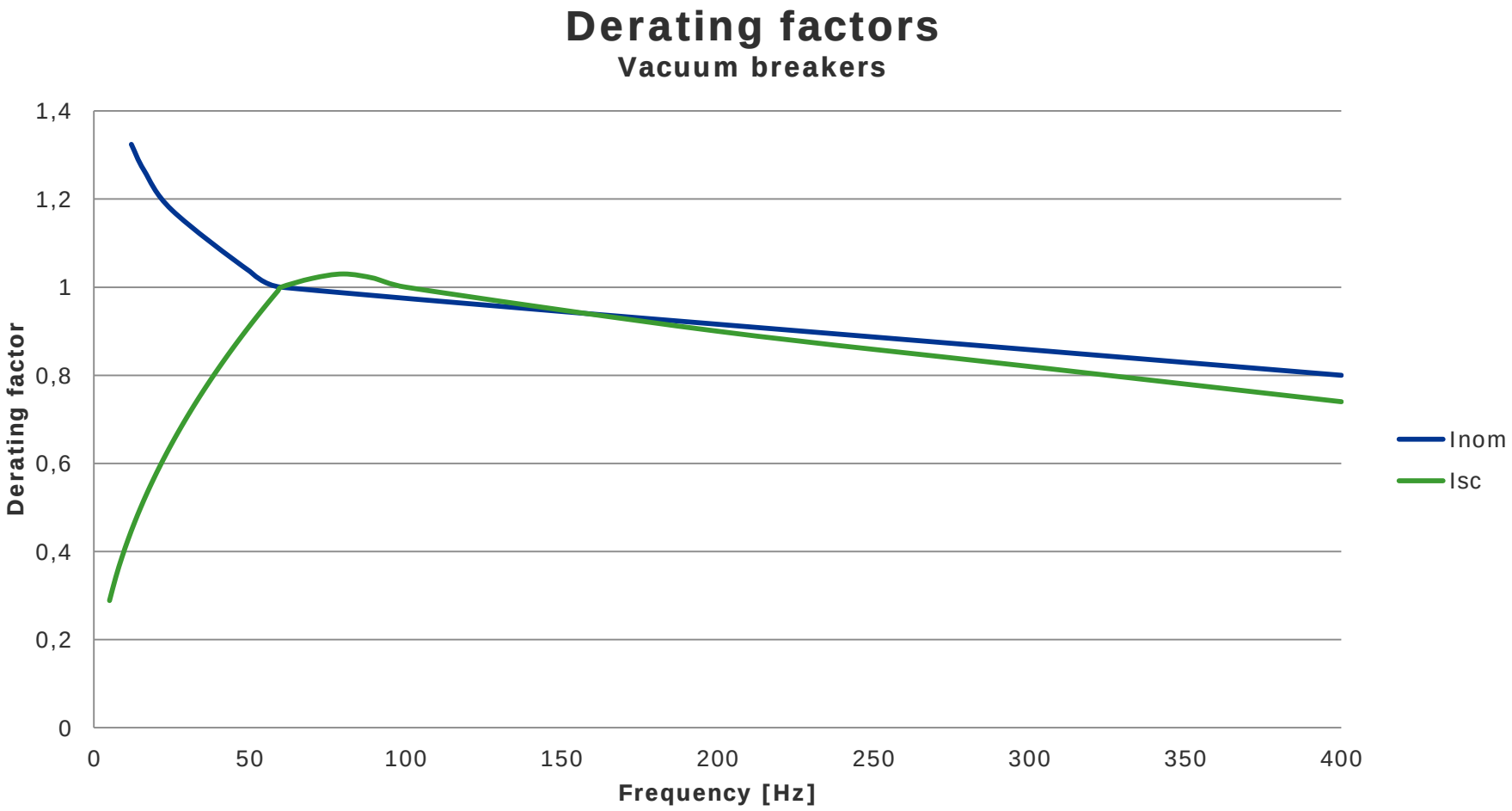
- Cost data base
- Scaling as function of frequency
  - Weight change
  - Derating factors



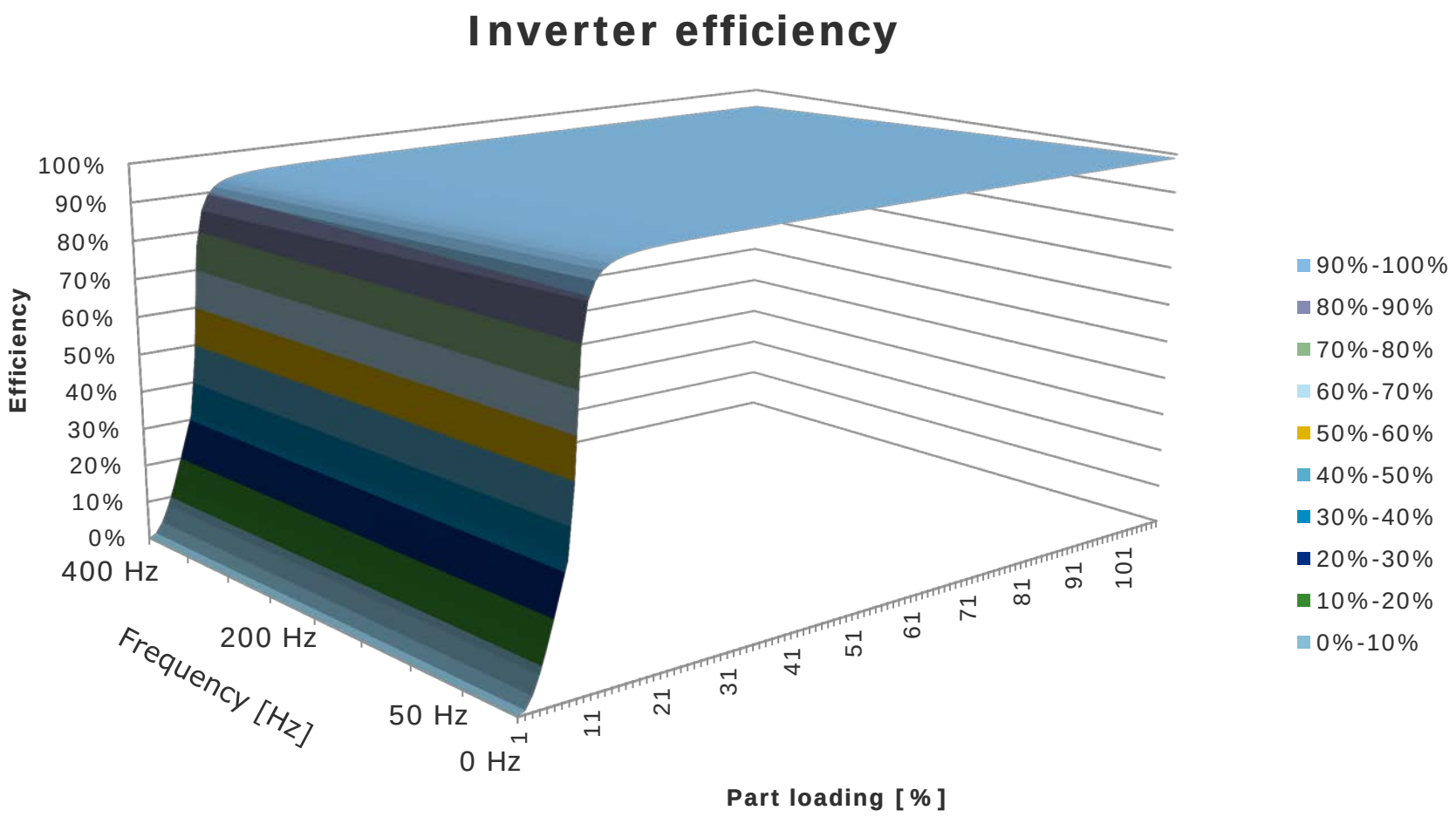
Modelling – Shunt reactors

- Same sizing function as transformer but…
  - Size independent from frequency
  - Size determined by cable capacitance
- Losses same as no-load losses of transformer of same size
- Weight is ½ of transformer of same size
- Costs are 2/3 of transformer of same size

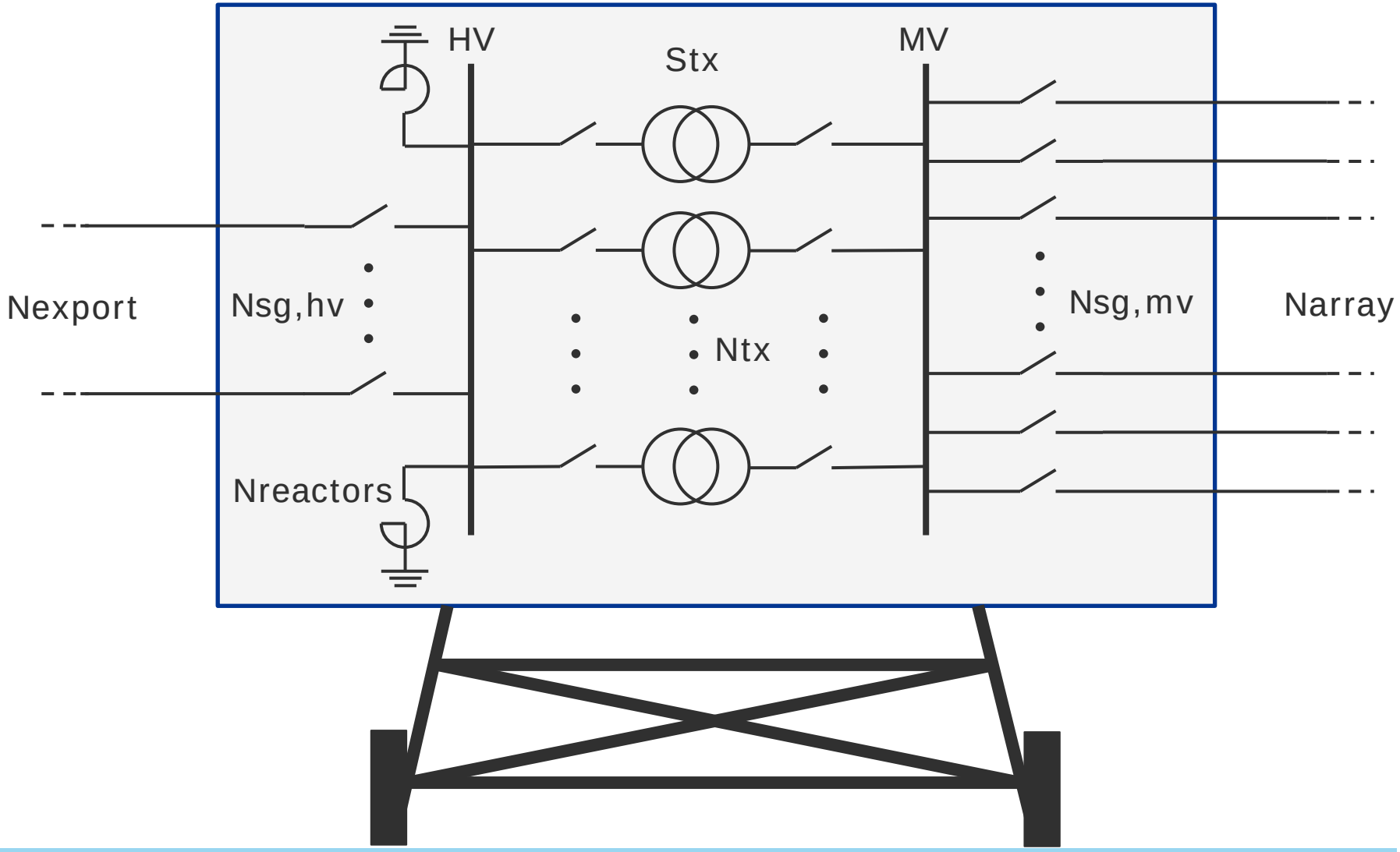
Modelling - Switchgear



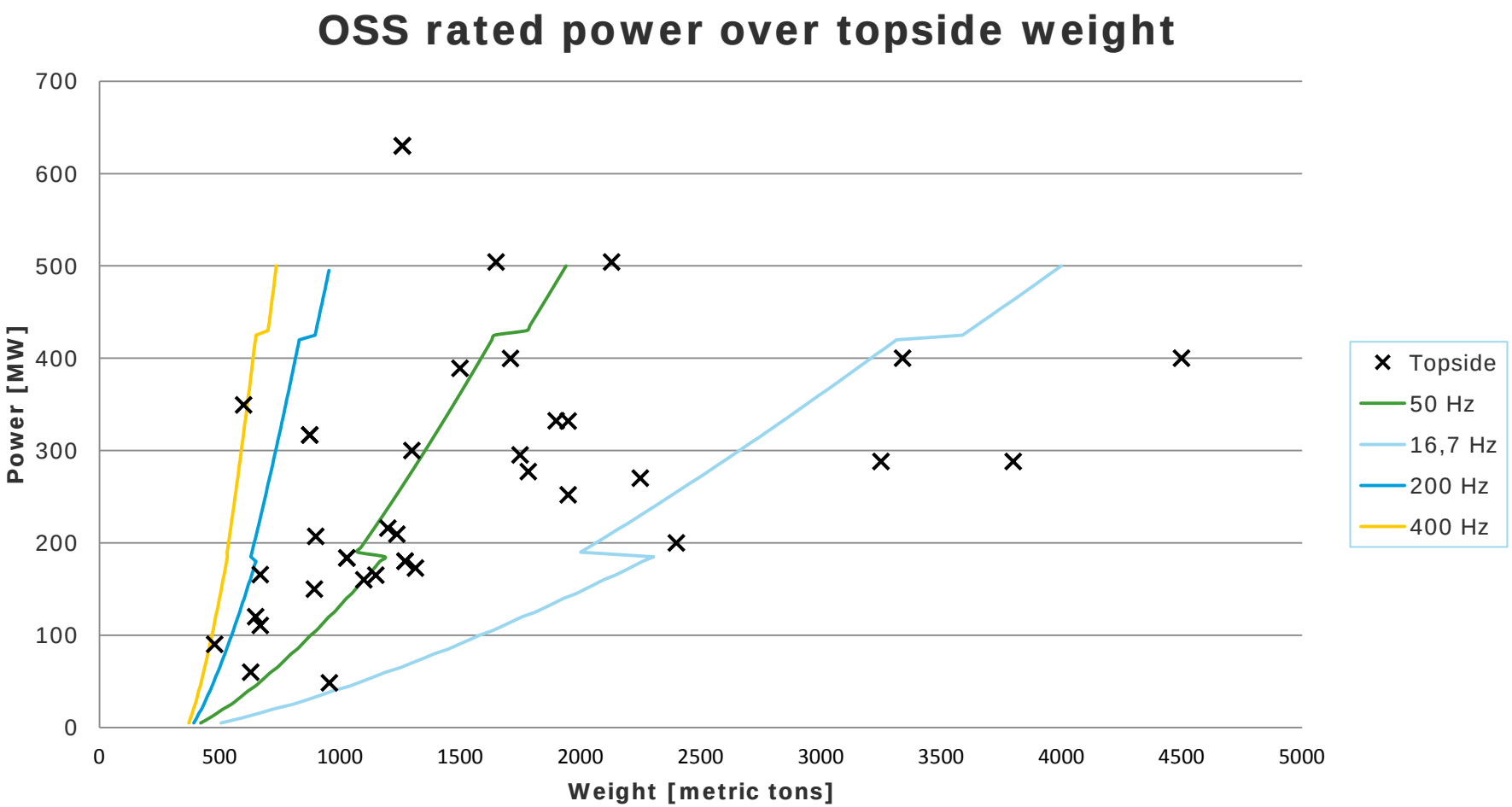
Modelling - Converters



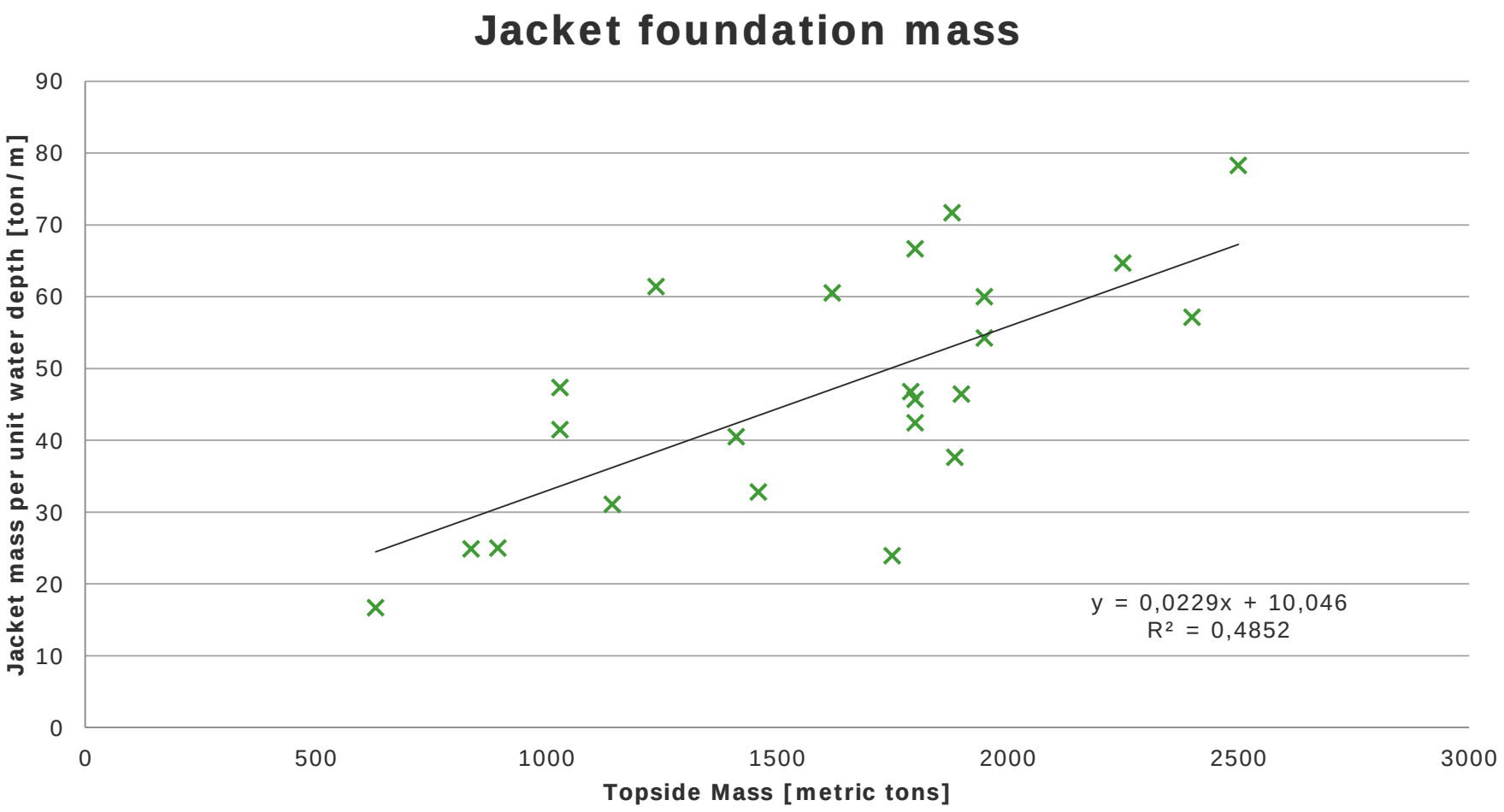
Modelling - Substation



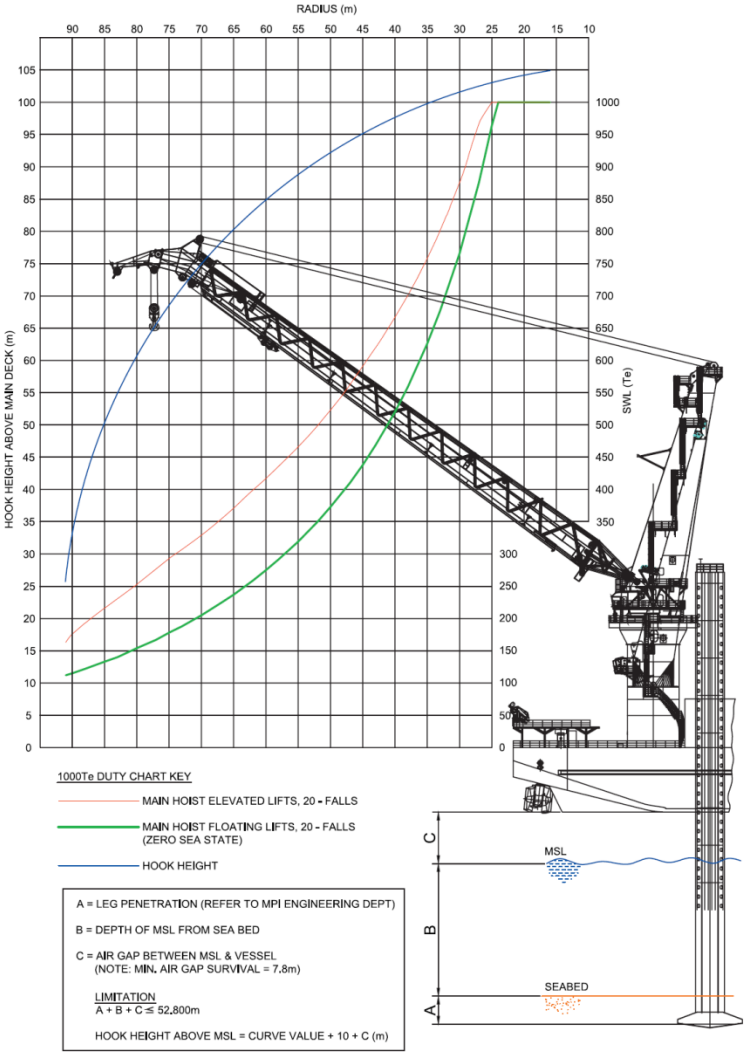
Modelling - Substation



Modelling - Structural



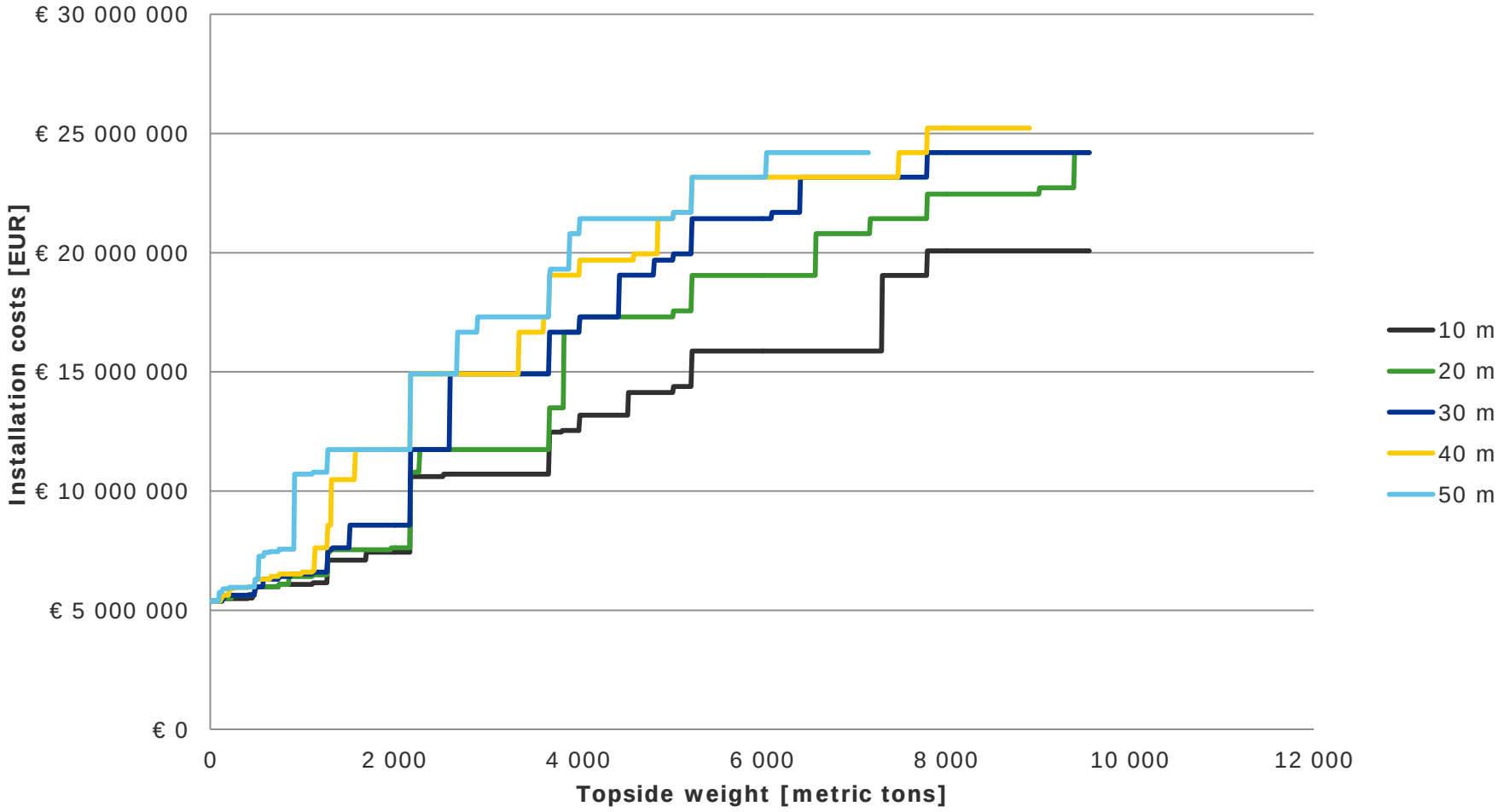
Modelling – Installation Vessels



- Midterm Day Rate: 105 k€

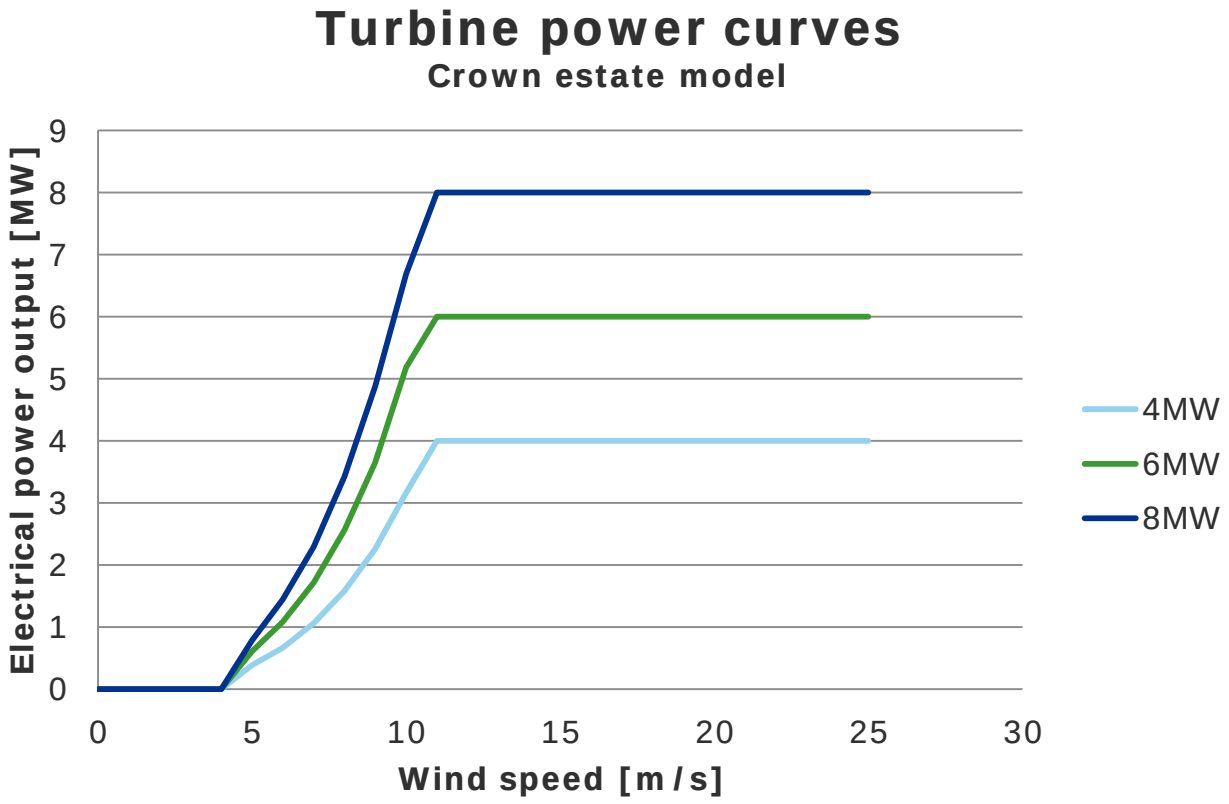
Lifting	max	30 m
capacity	1000 t	525 t
height above deck	105 m	92.5 m

Modelling – Installation costs

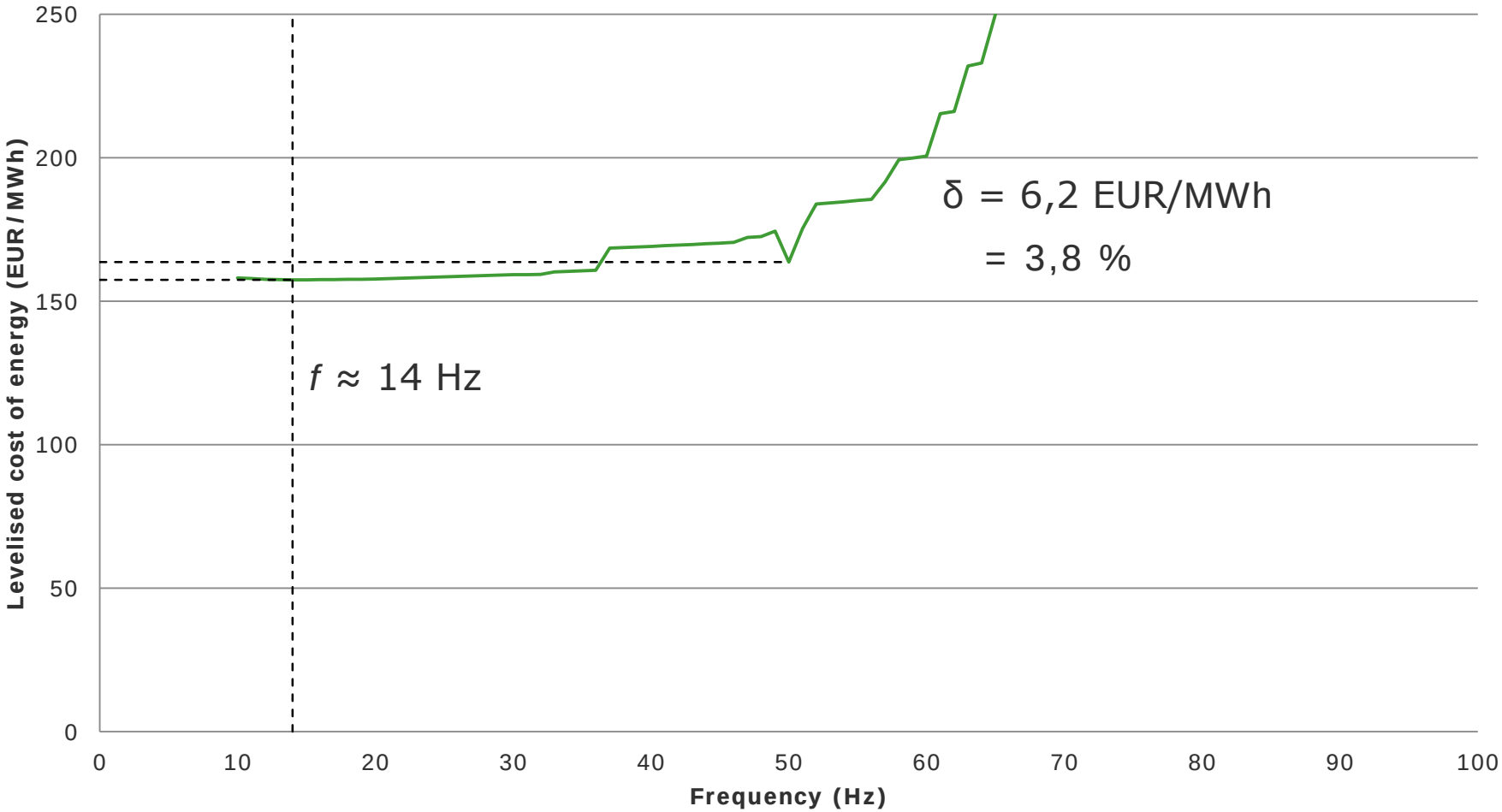


Modelling - Turbines

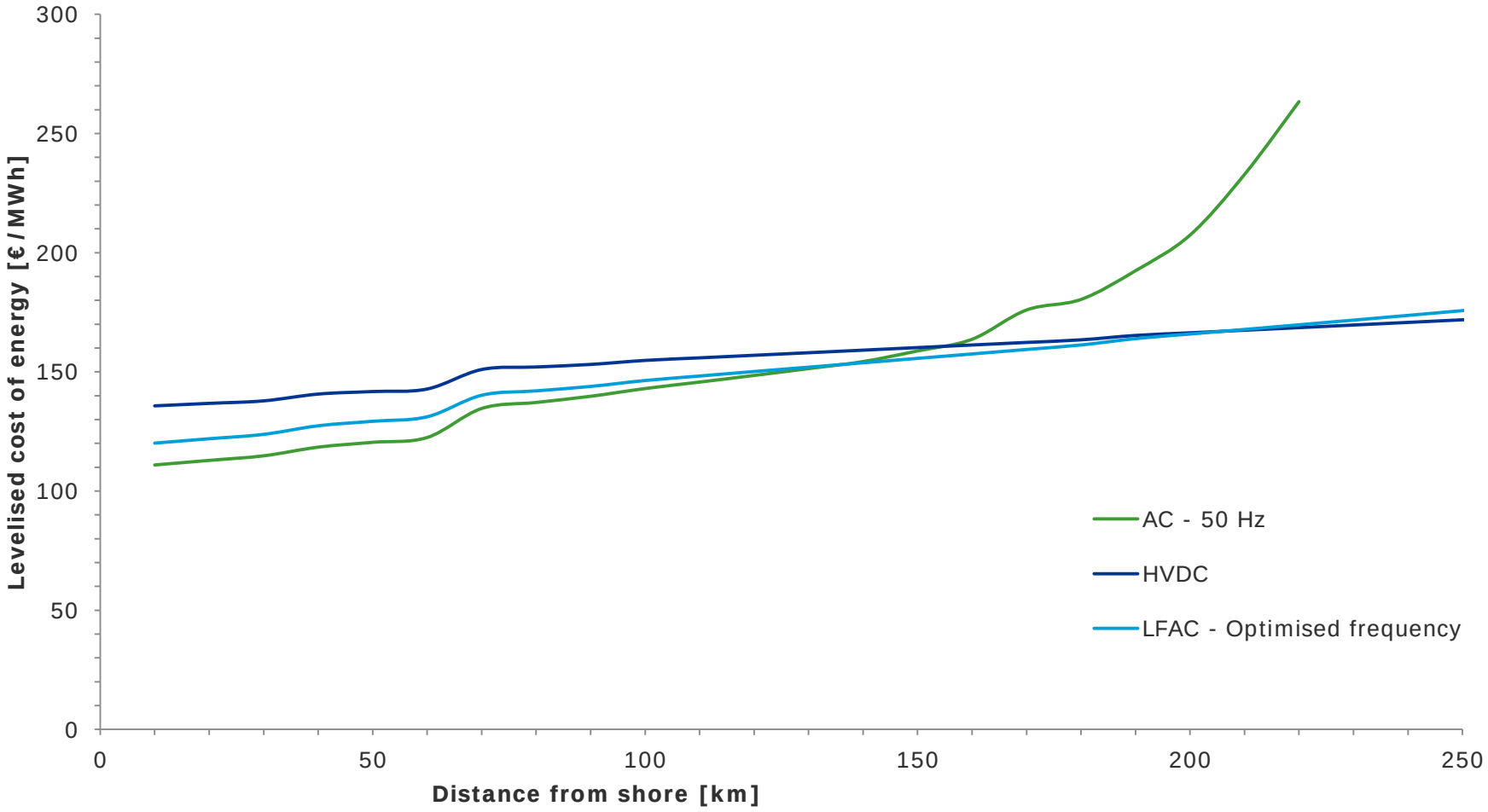
- Direct-drive
- Power curve
- Frequency dependency
  - Transformer cost
  - Switchgear cost
  - Converter efficiency



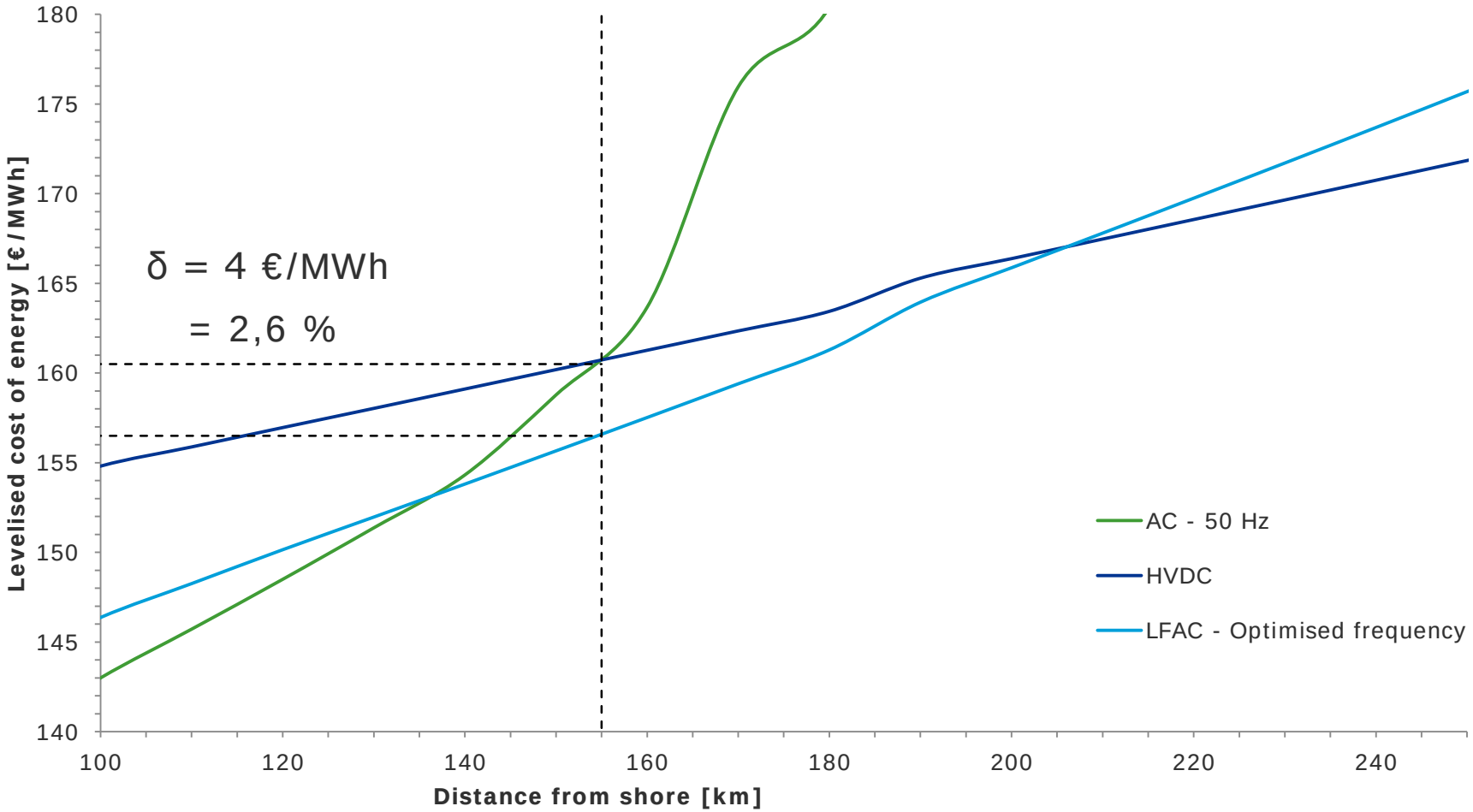
Results – LFAC connected 600 MW wind farm - 160 km



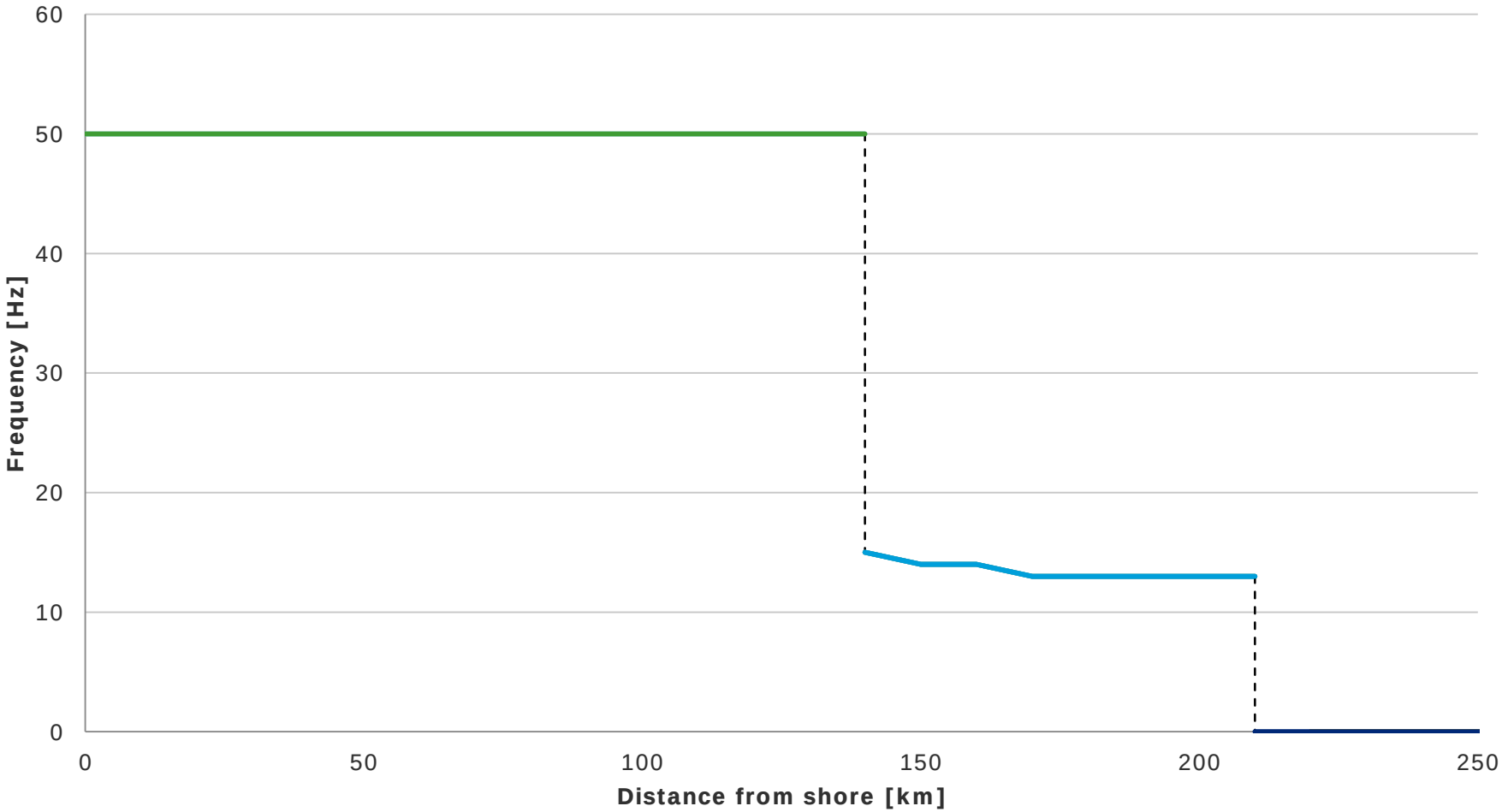
Offshore wind technology – 50 Hz AC vs HVDC vs LFAC



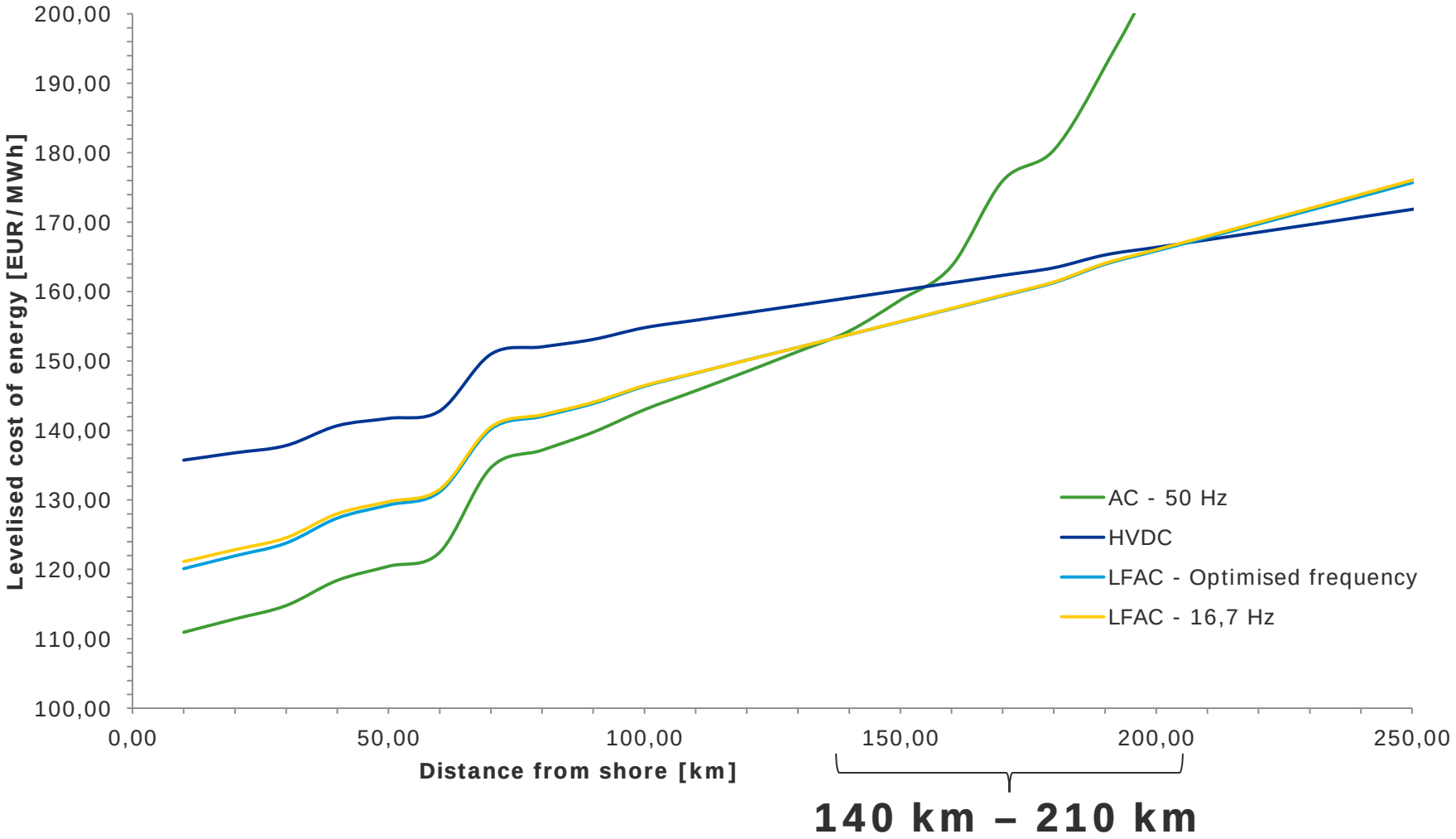
Offshore wind technology – 50 Hz AC vs HVDC vs LFAC



Optimal frequency for 600 MW offshore wind farm



Results - Export technologies for 600 MW wind farm



Possible market share: 140 < km < 210

Wind farm	Max Installed power [MW]	Distance from shore [km]
Concordia I	500	156
Concordia II	500	156
Dogger Bank Teesside A (Tranche B)	1200	196
Dogger Bank Teesside B (Tranche B)	1200	165
Dogger Bank Teesside C (Tranche C)	1200	157
Dogger Bank Teesside D (Tranche C)	1200	192
Dogger Bank Tranche D	2400	197.17
Euklas	1040	143
GAIA I	434	151
GAIA II	280	135
GAIA V	504	155
HTOD 1	486	205
HTOD 2	510	158
HTOD 3	504	190
HTOD 4	570	190
HTOD 5	476	170
HTOD 6	384	188
Jules Verne	480	174
Nemo	480	183
Sørlige Nordsjø I (Category A area)	1500	149
Sørlige Nordsjø II (Category A area)	1500	149
Sørlige Nordsjøen	1000	150.04
Ventotec Nord 1	150	137
Ægir Havvindpark	1000	171.23

19,5 GW

Summary

- Offshore wind energy trends
- Export link technologies
- Frequency sensitivity analysis
  - Cables
  - Substation
  - Turbines
  - Installation
- Levelised cost of energy
- Cost comparison
  - 50 Hz for close to shore
  - LFAC competitive in mid range distance
  - HVDC for far from shore

"If you want to find the secrets of the universe, think in terms of energy, frequency and vibration."

Nikola Tesla

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