A Comparison of VSC-HVDC with Low Frequency AC for Offshore Wind Farm Design and Interconnection

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Presentation Overview

- Motivation
- What is Low Frequency AC transmission?
- Research Question
- Results
  - Component Losses
  - Capital Costs
  - Reliability
- Conclusions

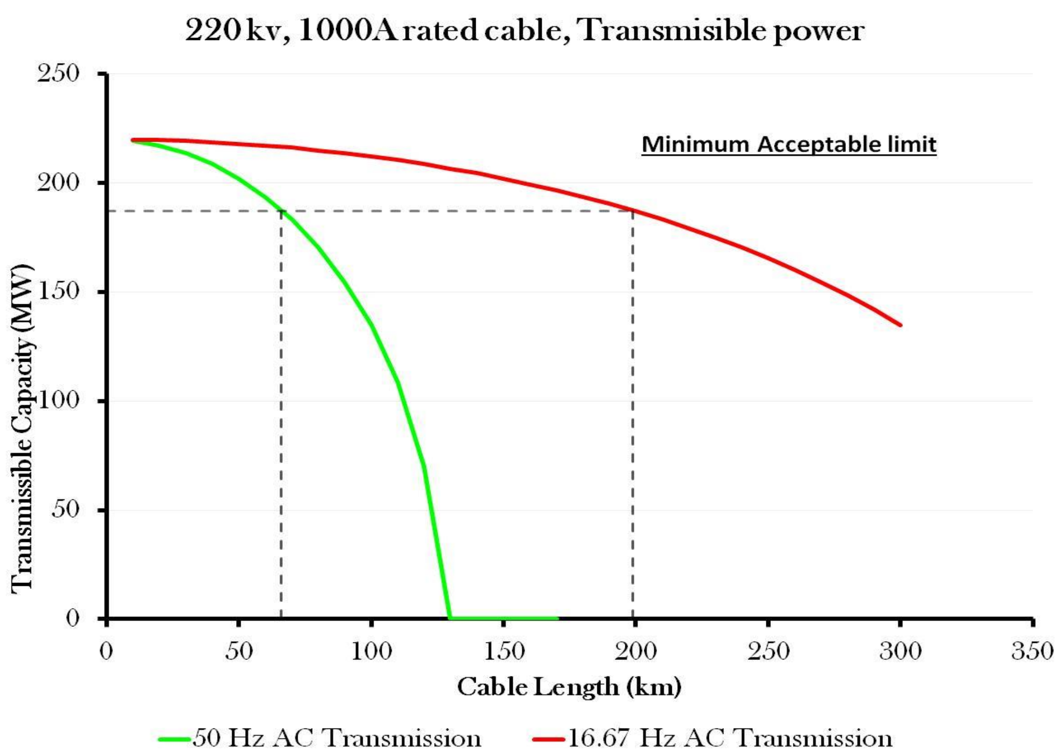
Motivation of Research

- Offshore wind becoming much more topical in recent years
- HVAC transmission favourable for near shore wind farms
- VSC – HVDC main option for far offshore wind farms
- Are there alternative options? – ***Low Frequency AC***

What is Low Frequency AC?

Transmission capability stability limit:

$P_{max} = \frac{V^2}{X}$; $X = 2\pi f L$; $\downarrow f, \downarrow X, \uparrow P_{max}$



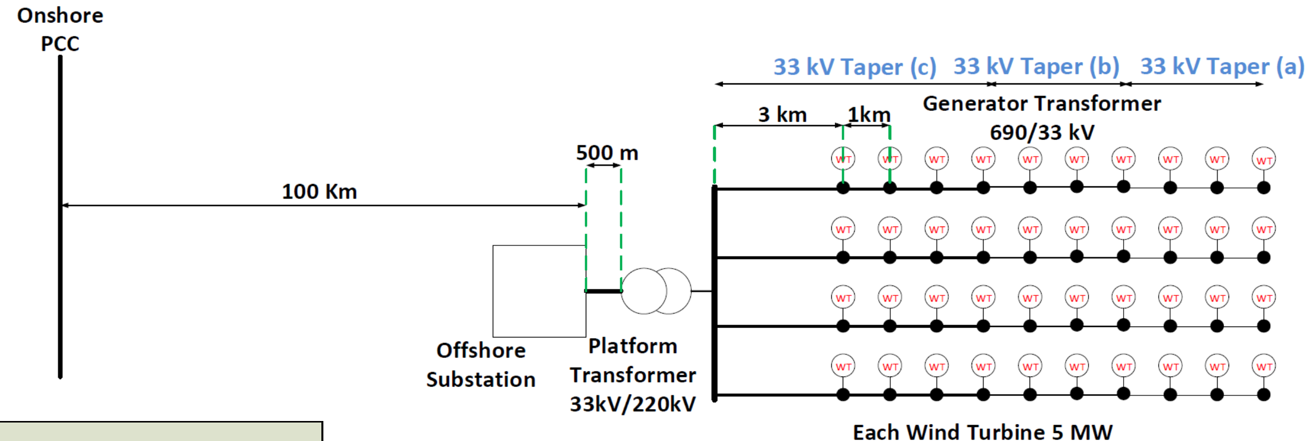
Why Low Frequency AC?

- Smaller capacitive charging currents = Increased transmission distance at lower frequency
- Removal of offshore converter = reduced size of offshore substation – implications for costs and losses
- Decreased losses?
- Increased reliability?
- AC system – AC breakers at 16.7 Hz possible

Research Question

Is Low Frequency AC transmission a viable competitor to VSC based HVDC for offshore wind?

Methodology



Site Selection: Irish Sea

Technical Comparison

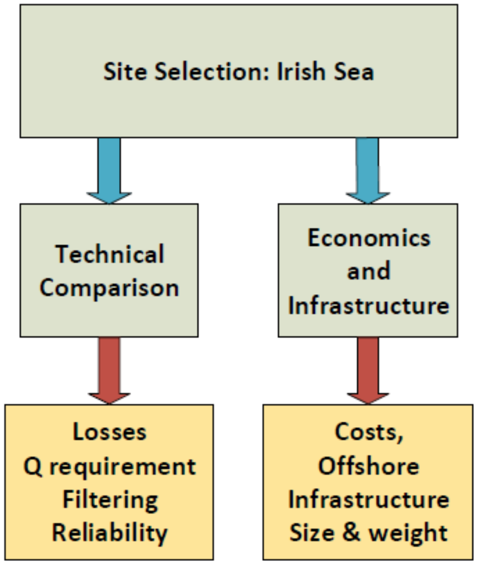
Economics and Infrastructure

Losses
Q requirement
Filtering
Reliability

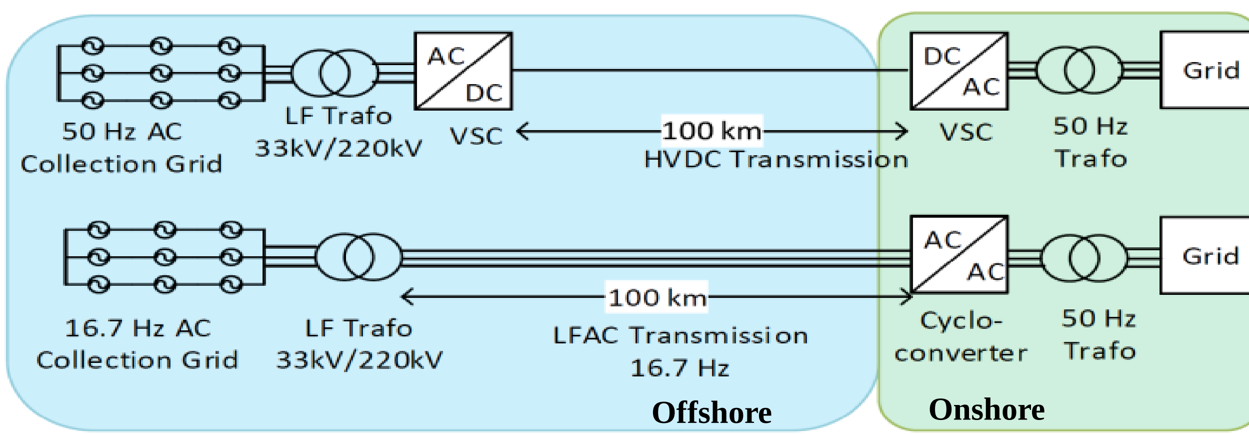
Costs,
Offshore Infrastructure
Size & weight

4 years wind data from site

Methodology for comparison



LFAC	VSC-HVDC
16.7 Hz Wind Turbine Transformers	50 Hz Wind Turbine Transformers
16.7 Hz Collection Network	50 Hz Collection Network
16.7 Hz Transformer	50 Hz Transformer
-	Offshore Converter (VSC)
16.7 Hz Transmission Cable	HVDC Transmission Cable
Onshore Cycloconverter	Onshore Converter (VSC)

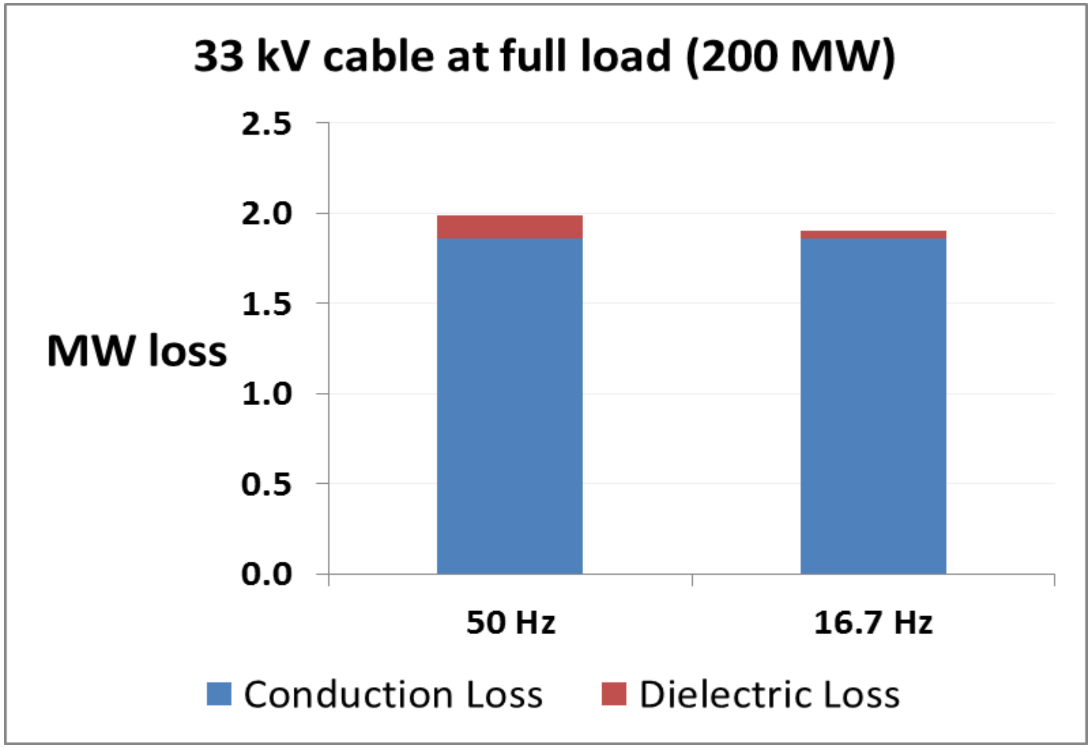


Cables : Frequency dependent losses

Charging current and Dielectric losses reduce with frequency

$$I_c = 2\pi fClV$$

$$W_d = 2\pi fCV^2 \tan\delta$$



Where W_d: Dielectric loss, *f*: frequency (Hz), *C*: capacitance (F), *V*: voltage (V), *tan δ*: insulation loss factor (0.0004 - XLPE)

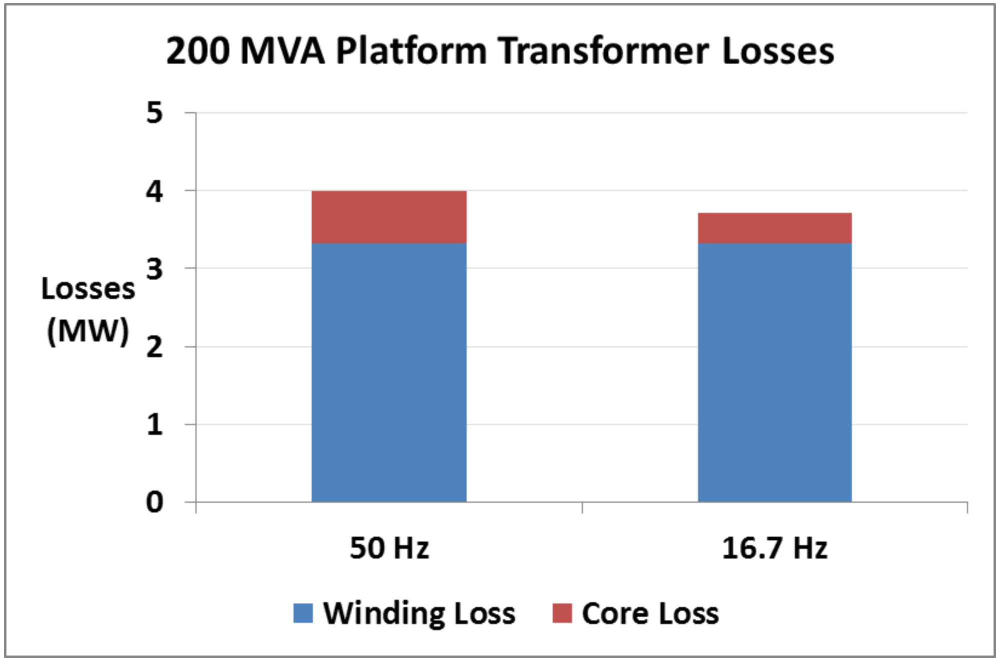
Transformer: Frequency dependent losses

Assuming A_w and winding loss constant:

$$P_{Core\_loss} = A_c A_w k f^{\alpha} B_{pk}^{\beta}$$

Where, $A_c \propto \frac{1}{f}$

$$P_{Core\_loss\_50Hz} : P_{Core\_loss\_16.7Hz} = 50^{\alpha} : 3\left(\frac{50}{3}\right)^{\alpha}$$



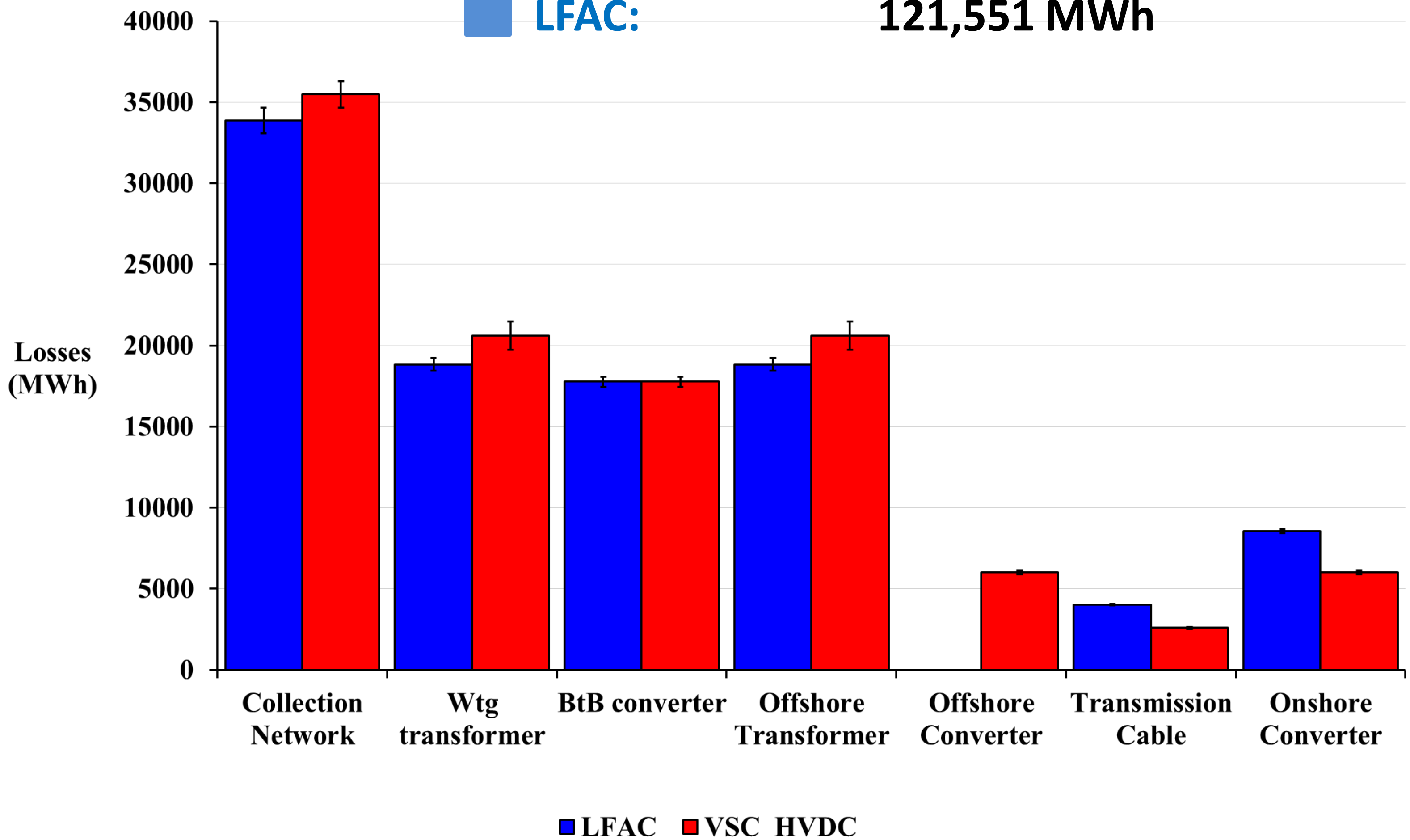
A_c: Area of core
A_w: Area of winding window
k: constant
f: frequency
B_{pk}: peak flux density
α and β:material constants.

α =1.5 for M130-27S electrical steel

Source: W. A. Pluta, “Core loss models in electrical steel sheets with different orientation,” Electr. Rev. ISSN 0033-2097, vol. 87, no. 9b, pp. 37–42, 2011.

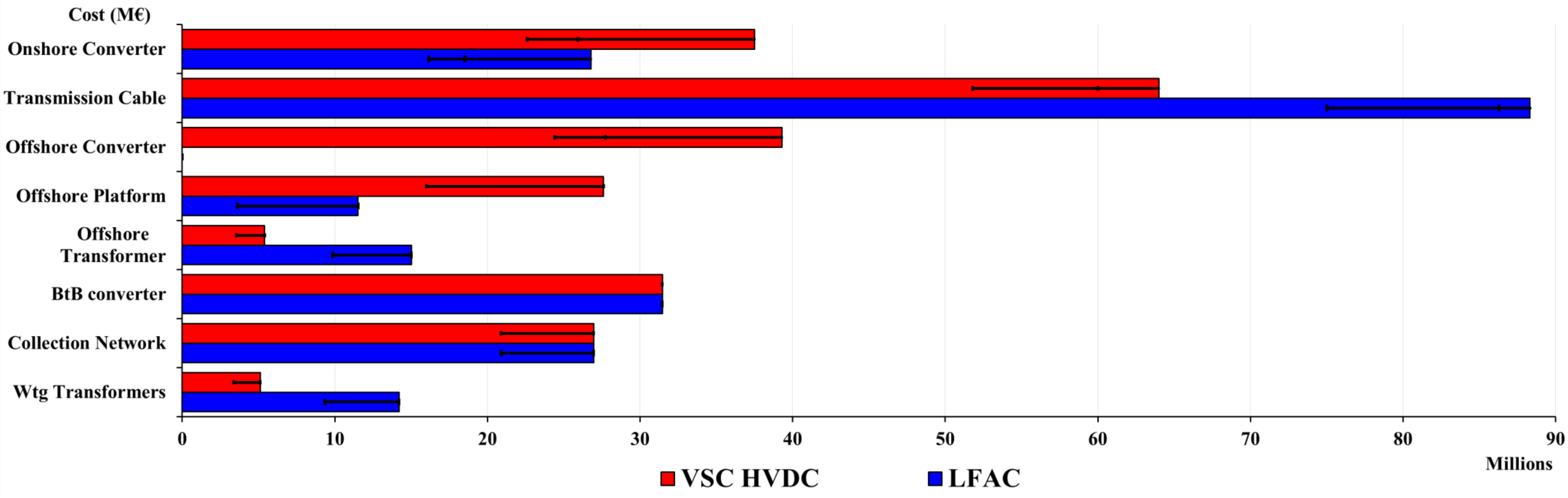
Energy Losses

VSC-HVDC: **132,383 MWh**
LFAC: **121,551 MWh**



Capital Investment Costs

LFAC = 214.2 M€ (-47.9 M€) **VSC-HVDC = 237.3 M€ (-62.3 M€)**



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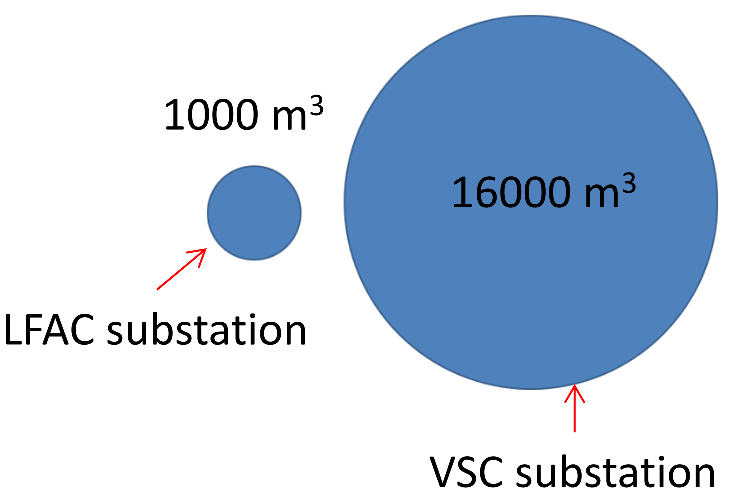
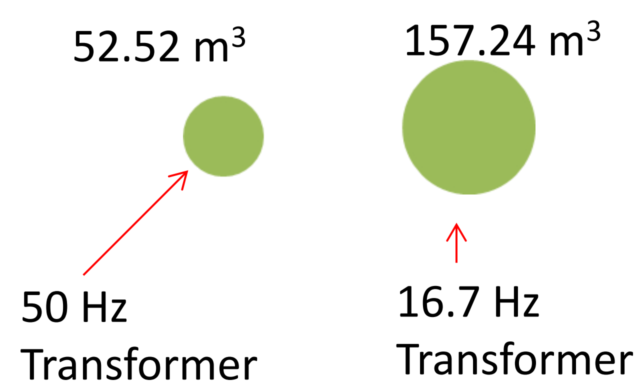
Component size

	VSC-HVDC		LFAC	
Component	Volume (m^3)	Weight (Tonnes)	Volume (m^3)	Weight (Tonnes)
LV/MV trafo	1.15	2.75	3.45	8.23
MV/HV Trafo	52.52	125	157.24	374.26
Offshore Substation	16000	N/A	1000	N/A





Reliability Analysis

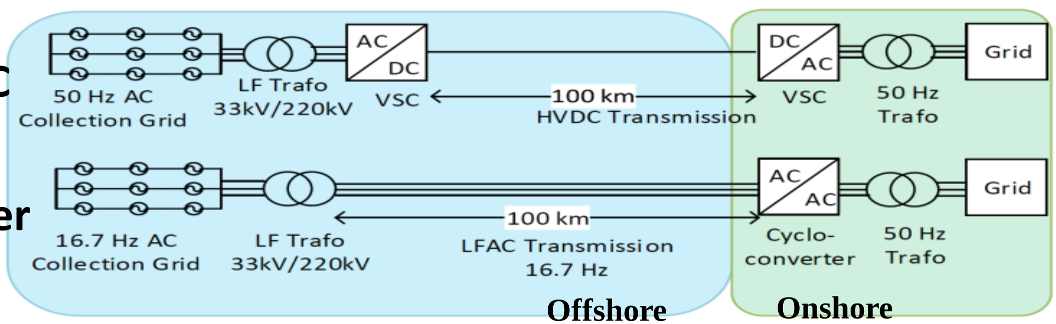
Calculated Unavailability from Mean Time to Repair and Failure rates data from literature

Component	λ (failures/yr.)	MTTR (hrs)
Collection network	0.008	2160
Circuit Breakers	0.032	720
Offshore Transformer	0.03	4320
Transmission Cable	0.08	720
VSC Onshore	0.05	720
VSC Offshore	0.05	50
Cycloconverter	0.101	50
Onshore Transformer	0.02	1440

	Annual Unavailability (hrs)	**Expected Energy Not Served (EENS)(MWh)**
LFAC_Cycloconverter	174.2	19,678
VSC_HVDC	207.9	23,319

VSC_HVDC

LFAC_Cycloconverter



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LFAC with a Cycloconverter

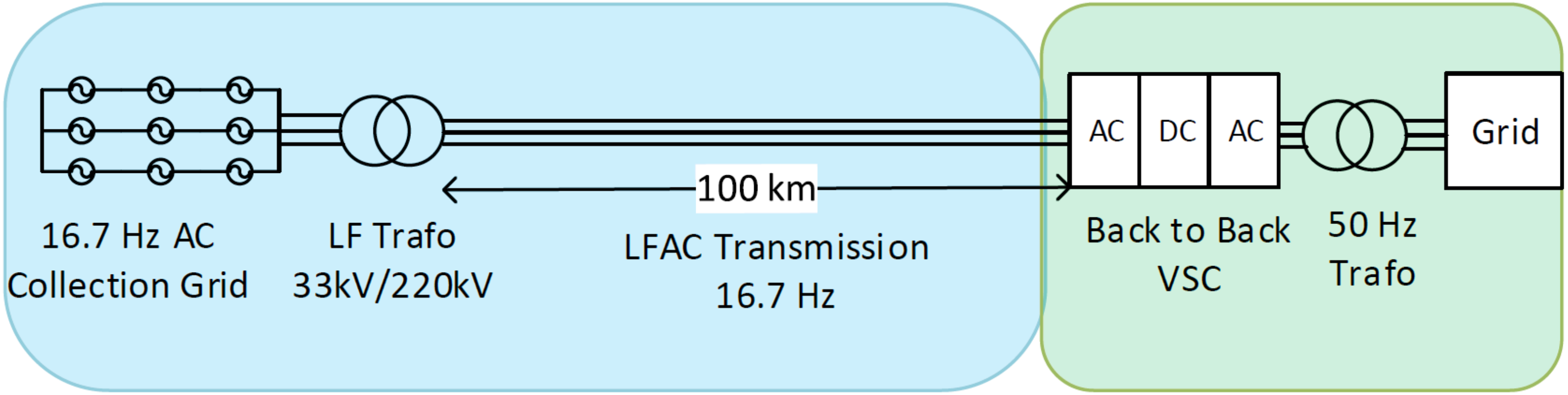
- LFAC has fewer losses
- LFAC with cycloconverter less expensive
- Reliability analysis indicated LFAC more reliable

BUT

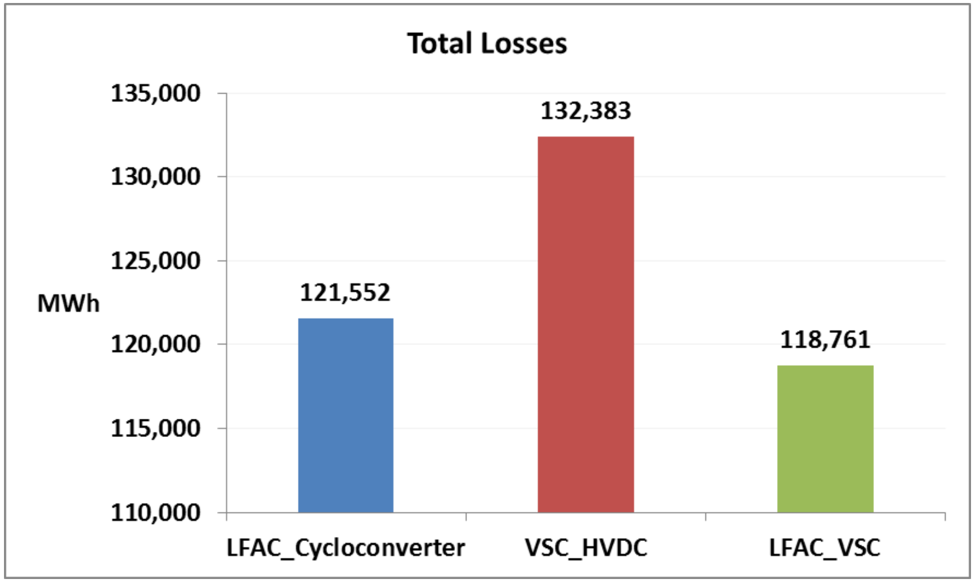
- Cycloconverter Caveats
  - Large filtering required
  - More difficult to achieve grid code compliance
  - Thyristors need strong AC network
  - Cycloconverter requires a large onshore site (land use)
- Impact of increasing Transformer size
  - May need to re-design nacelle to accommodate larger components

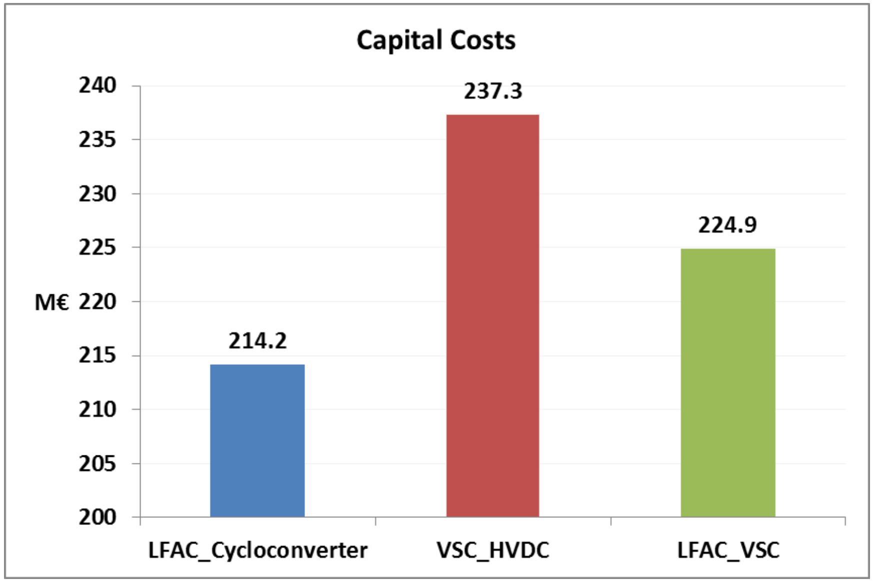
LFAC with a VSC

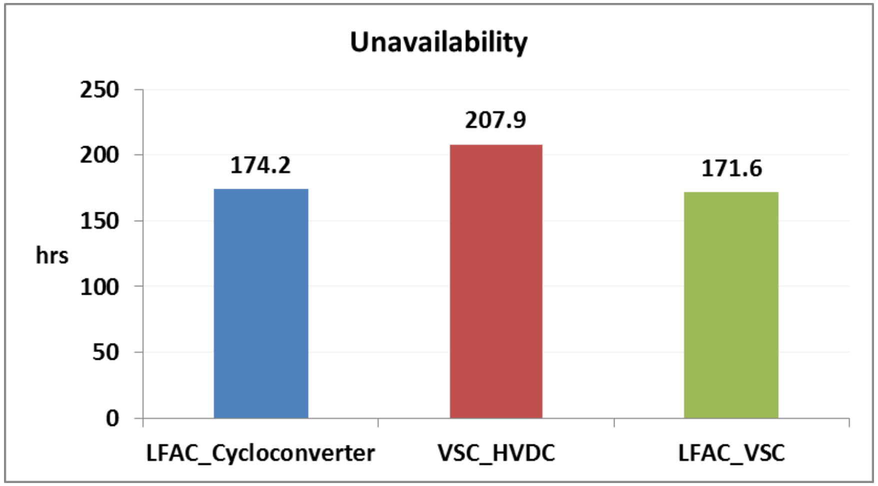
- Replace cycloconverter with a back to back VSC to convert from 16.7 Hz to grid frequency
- Still no offshore converter but VSC onshore

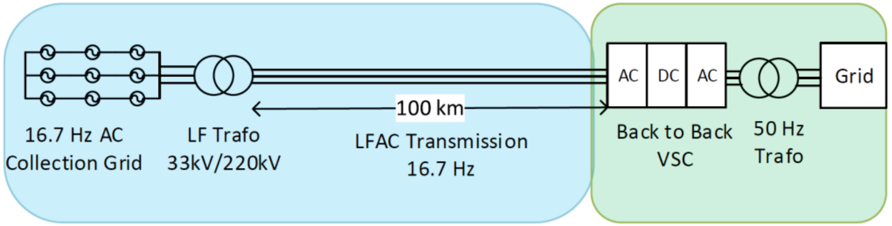


LFAC with a VSC









Key Conclusions

- LFAC with a cycloconverter viable competitor to HVDC but grid connection issues may prove difficult to overcome
- LFAC connected with a VSC combines the best of both options
- Removal of offshore converter drives reduction in losses, costs, and unavailability
  - However the magnitudes of these reductions may not be as large as first expected

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Thank you

- Questions?