Design and Modelling of a LFAC Transmission System for Offshore Wind

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Introduction

Low Frequency AC (LFAC) transmission has recently been suggested by industry and academia as a competitor to HVDC transmission for the interconnection of offshore wind [1]. Offshore cables operated at low frequencies, (16.7 Hz), extend the maximum power transmission distance of the cable from 60-80 km for 50 Hz to 180-200 km for 16.7 Hz [2].

Advantages of LFAC

- No offshore converter station reduces complexity offshore
- Uses AC technology (lots of experience onshore)
- No DC breakers required – 16.7 Hz AC breakers available
- Economic analysis - LFAC viable competitor to HVDC [3]
- Low frequency experience in railway

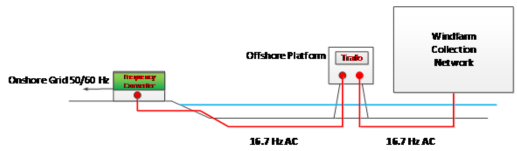

Fig 1: Overview of LFAC transmission system for offshore wind

Objective

This work aims to develop the design and modelling of the Low Frequency AC offshore transmission system in particular the 16.7 Hz offshore grid frequency and voltage controlled by the Voltage Sourced Converter.

Techno Economic Analysis [4]

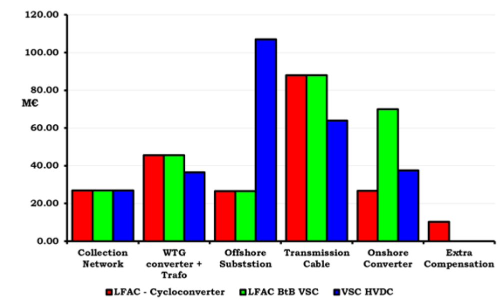

Fig 2: Cost Comparison between LFAC and HVDC

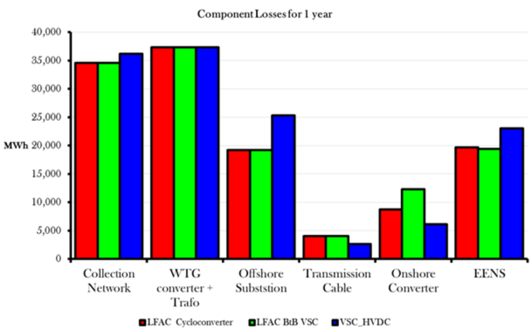

Fig 2: Loss Comparison between LFAC and HVDC

Summary	Capital Cost (M€)	Losses (MWh)
LFAC Cycloconverter	224.27	123,455
LFAC Btb	**257.17**	**126,785**
VSC – HVDC	272.03	130,639

Acknowledgement

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Onshore converter Comparison [5]

Cycloconverter

- Thyristor based
- High Harmonic content
- Pf (~ 0.78 lagging)
- Less expensive than BtB
- Frequency step up issues
  Inter-harmonics and sub-harmonics
- Compact converter station

Back to Back VSC converter

- Small Harmonic content
- IGBT power switches
- Independent control over P&Q
- Large converter stations
- Any output frequency possible

Techno Economic Conclusion–
LFAC comparable to HVDC & Use Back to Back VSC converter onshore instead of Cycloconverter [4]

LFAC System Modelling

Parameters

DC link Voltage	400 kV
Nominal Power	200 MVA
Dc Link Capacitance	100 µF
LFAC voltage	150 kV
Offshore Frequency	16.7 Hz
C_{f_LF}	40 µF

Phase Reactor Design at LFAC

$$L = \frac{0.15*Zbase}{100\pi} \text{ @ 50 Hz} = 0.0537\ H$$

$$L_{LF} = \frac{0.15*Zbase}{33.4\pi} \text{ @ 16.7 Hz} = 0.1608\ H$$

Keeping X/R ratio constant: $R = R_{LF} = 0.3375\ \Omega$

Grid forming VSC control
The grid forming control is developed using a controlled frequency VSC. The control is adapted from Chapter 9 of Yazdani [6]. The objective is to regulate the amplitude and frequency of the offshore voltage (V_{abc}) in response to changes in the offshore current (I_{oabc}). The capacitance C_f is required as part of the RLC filter to ensure voltage support and to filter switching current harmonics. The controlled frequency is controlled in dq mode similar to the grid imposed frequency converter (VSC 2).

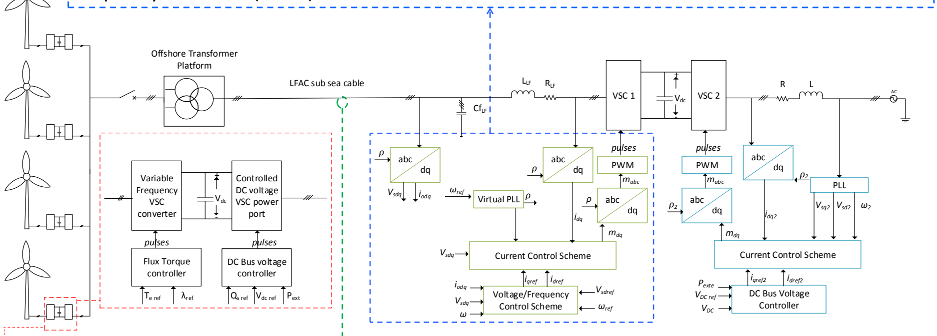

Fig 4: Control scheme for Offshore wind turbine and onshore Back to Back converter for LFAC

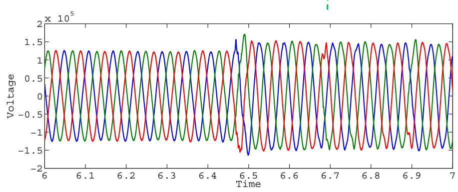

Fig 5: LFAC offshore voltage at 16.7 Hz responding to increase in reference voltage from 120 kV to 150 kV

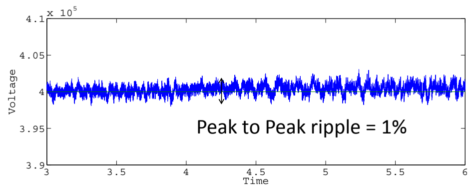

Fig 6: DC link voltage between VSC 1 and VSC 1. DC voltage controller maintains voltage with less than 1% peak to peak ripple.

Full conversion wind turbine control at 16.7 Hz has been verified and demonstrated in paper by Dr. Ronan Meere, "*Scaled Hardware Implementation of a Full Conversion Wind Turbine for Low Frequency AC transmission*" presented at EERA DeepWind 2016

Future work:

- Synchronisation of offshore converters to power electronically formed LFAC grid
- Scaled Model + hardware verification of entire LFAC system incorporating work by Dr. Meere
- Development of control mechanisms for system services i.e. frequency support, voltage support
- Testing of grid code compliance i.e. faults offshore and onshore

References

[1] **W. Fischer**, R. Braun, and I. Erlich, "Low frequency high voltage offshore grid for transmission of renewable power," in *3rd IEEE PES Innovative Smart Grid Technologies Europe*, 2012.
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[3] **J. Ruddy**, R. Meere, and T. O'Donnell, "A Comparison of VSC-HVDC with Low Frequency AC for Offshore Wind Farm Design and Interconnection," in *EERA DeepWind'2015Deep Sea Offshore Wind R&D Conference, 04-06 Feburary*, 2015.
[4] **J. Ruddy**, R. Meere, and T. O'Donnell, "Low Frequency AC transmission as an alternative to VSC-HVDC for grid interconnection of offshore wind," in PowerTech, 2015 IEEE Eindhoven , vol., no., pp.1-6, June 29 2015-July 2 2015
[5] **J. Ruddy**, R. Meere, and T. O'Donnell, "Low Frequency AC transmission for offshore wind power: A review", Renewable and Sustainable Energy Reviews, Volume 56, April 2016, Pages 75-86, ISSN 1364-0321
[6] **A. Yazdani** and R. Iravani "Voltage-Sourced Converters in Power Systems, Modeling, Control and Applications"