Scaled Hardware Implementation of a Full Conversion Wind Turbine for Low Frequency AC Transmission

Dr. Ronan Meere
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Ismail Ibrahim, Jonathan Ruddy, Cathal O’Loughlin and Terence O’Donnell

Ronan Meere (Senior Researcher Power Systems)
Electrical Engineering Department (Electricity Research Centre) (Energy Institute)
University College Dublin
Ireland
ronan.meere@ucd.ie
Presentation Overview

• Background to LFAC transmission for offshore wind
• Design of an LFAC grid compatible wind turbine
• Onshore VSC design
Why Low Frequency AC?

Transmission capability stability limit:

\[ P_{\text{max}} = \frac{V^2}{X}; \quad X = 2\pi f L; \]

\[ f, X, P_{\text{max}} \]
Onshore Frequency Changer

Back to Back VSC onshore

Offshore Platform

Windfarm Collection Network

16.7 Hz AC

Ruddy et al. 2016  “Low Frequency AC transmission for offshore wind power: A review”
Fischer et al. 2012 "Low frequency high voltage offshore grid for transmission of renewable power"
Jafar et al. 2014 "Low Frequency AC Transmission for Grid Integration of Offshore Wind Power"
Olsen et al. 2014 "Low Frequency AC Transmission on large scale Offshore Wind Power Plants, Achieving the best from two worlds?"
Wind Turbine Collection Network

- Real Time Simulation (RTS) UCD

**Step 1**: Can you design a full conversion WT at 16.7 Hz?
WT Connecting to an LFAC Grid

• Fixed speed and DFIG wind turbine configurations – larger generators to overcome start-up transients

• Full conversion WT – ability to reconfigure the converter to synchronise to the 16.7 Hz grid

• Design of the WT Trafo needs to be relocated on the platform or tower
Overall LFAC Transmission System

Full Conversion Wind Turbine Connected to 16.7 Hz Grid

LFAC Collection Network
Offshore Transformer Platform
16.7 Grid - LFAC sub sea cable
Offshore Frequency control
AC Voltage control
DC Voltage Control
BtB Converter onshore
Lab Setup

Real Time Simulation (Opal-RT) Software

DC Bus Voltage / Reactive Power Controller

Flux/ Torque Controller

Qsref Vdcref Pext

Teref imref

Grid 16.7 Hz

Controlled DC Voltage Power Port

Variable Frequency VSC Converter

Generator SCIG

Wind Turbine Simulator

Pgrid Pext Pgen
Generator Side VSC Control

- VSC control maintains a \((T_e \propto \omega_r^2)\) relationship for the generator so that MPPT (Maximum Power Point Tracking) is guaranteed.
- The VSC can set both stator frequency of the generator to control speed and also stator current \(i_s\) to control the electrical torque \(T_e\)

\[
T_e = \frac{3}{2} \frac{L_m}{1+\sigma} \hat{i}_{mr} i_{sq}
\]
• Torque control maintains $i_{mr}$ (magnetising current) **constant** to a fixed value while using $i_{sq}$ to set $T_e$

• A **flux observer** is used to estimate the magnetising current $i_{mr}$
The flux/torque compensator block receives a reference value for the magnetizing current reference $i_{mr\text{ref}}$ and an electrical torque reference $T_{eref}$ as inputs and then outputs reference values for the stator d and q currents, $i_{sd\text{ref}}$ and $i_{sq\text{ref}}$ which in turn serve as inputs to the inner $dq$ current controller.

The flux/torque compensator block can be represented by the following equations:

\[
\hat{i}_{mr\text{ref}} = \sqrt{\frac{2}{3}} \frac{V_{sn}}{(1 + \sigma_s)L_m \omega_0}
\]
• PLL is utilized to synchronize the converter with the offshore 16.7 Hz grid

• The DC bus voltage controller maintains a constant DC-link voltage
Pictures of the Actual Setup

MG SET 16.7 Hz Grid

Back To Back VSC Converter

SCIG-Dynamometer Set

Opal-RT Real Time Simulator Control (Software)
Test Procedure

Generator Side

Applied Torque Measured

Rotor Speed Measured

Grid Side

DC voltage Grid Side Converter Measured
Measured Power Export Test

- Grid Current (A)
- Grid Voltage (V)
- Power (W)
- Torque Applied (Nm)
- Mechanical Power Applied (W)
- Active Power Exported (W)
- Electrical Torque, $T_e$ (Nm)
- Rotor Speed (RPM)

Equation: $T_e \propto \omega^2_r$
Grid-Side Phase Lock Loop at 16.7 Hz

abc-dq Transformation

Vsd
vsc
vsb
vsa
Vsq
H(s)
Saturation
VCO
ω
ρPLL

104.88 rads/s
100 V
0 V
Next Steps

• **Step 2**: Onshore VSC Back/Back step 16.7 Hz to 50 Hz

Step 2 Onshore VSC

- Poster covers this in detail:

Design and Modelling of a LFAC transmission system for offshore wind

Jonathan Ruddy (jonathan.ruddy@ucdconnect.ie), Dr. Ronan Meere (ronan.meere@ucd.ie),
Dr. Terence O’Donnell (terence.odonnell@ucd.ie)
Other Work in Progress for LFAC

- Transformer Optimisation
  16.7 Hz
  2 – 2.5 times the gross weight of a 50 Hz transformer for the same power

- Hypothetic Nord Sea Grid – Istvan Erlich “16.7 Hz – The Missing Link” Meshed
  North Sea Grid
Review

- LFAC is a real alternative to VSC-HVDC
- Demonstrated an operational LFAC connected WT
- Build the onshore BtB converter in hardware
- Evaluate the system under grid connection conditions
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Thank You

Questions?