Control of HVDC systems based on diode rectifier for offshore wind farm applications

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Introduction

The integration of offshore wind energy into the power system, has led to progressive research in HVDC-converters where a possible solution is diode rectifier. The potential advantages with diode rectifier compared to conventional converters as Line Commutated Converter (LCC) and Voltage Source Converter (VSC) are:

- lower conduction losses
- reduced installation costs
- reduced converter size
- higher reliability

System model

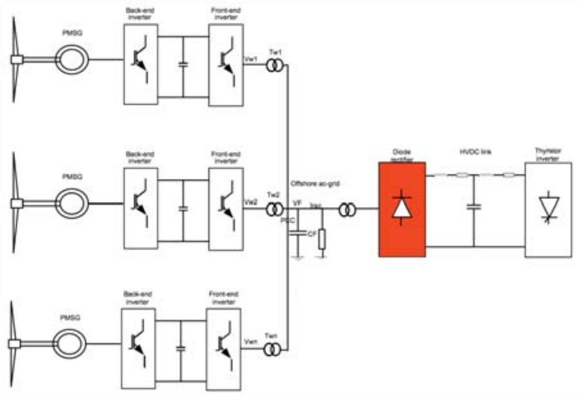

Figure 1: The system model studied

Objectives

- Examine the main adaptations of the control system with the system topology with diode rectifier
- Since the diode rectifier is uncontrolled, another part of the system will have to overtake the control of the ac-grid voltage and frequency, conventionally conducted by the HVDC converter
- The main field of reseach is the front end converters of the wind turbines, which can overtake the control of the ac-grid

Control system

Figure 1 can be described by equation 1-4 in a synchronous reference frame with $V_{Fq} = 0$, and makes the base for the control system. An extensive deduction of the control system based on these equations can be found in [1].

$$\frac{dI_{Fdi}}{dt} = -\frac{R_{Twi}}{L_{Twi}} I_{Fdi} + \omega_F I_{Fqi} + \frac{V_{Wdi}}{L_{Twi}} - \frac{V_{Fd}}{L_{Twi}} \quad (1)$$

$$\frac{dI_{Fqi}}{dt} = -\frac{R_{Twi}}{L_{Twi}} I_{Fqi} - \omega_F I_{Fdi} + \frac{V_{Wqi}}{L_{Twi}} \quad (2)$$

$$\frac{dV_{Fd}}{dt} = \frac{1}{C_F} \sum_{i=1}^{n} I_{Fdi} - \frac{1}{C_F} I_{Racd} \quad (3)$$

$$\omega_F V_{Fd} = \frac{1}{C_F} \sum_{i=1}^{n} I_{Fqi} - \frac{1}{C_F} I_{Racq} \quad (4)$$

Phase Locked Loop

- The Phase Locked Loop (PLL) extracts the voltage signal at the point of common coupling (PCC) to determine the phase angle and frequency of the ac-grid
- The system model has unidirectional power flow, and the traditional PLL can not achieve its function
- A fixed reference signal of the phase angle and frequency was proposed in [2]
- Another solution is to modify the traditional PLL with an integrated phase angle reference [3]. This PLL is shown in equation 5.

$$\frac{d\theta}{dt} = \omega^* + \Delta\omega = \omega^* + K_P(V_{Fq} - V_{Fq}^*) + K_I \int (V_{Fq} - V_{Fq}^*) dt \quad (5)$$

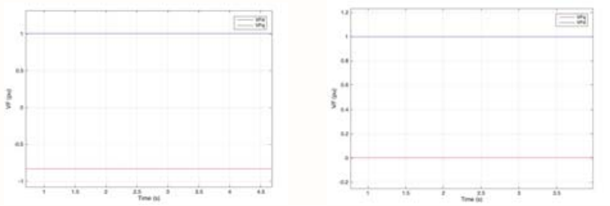

Figure 2: The voltage V_F, at PCC, using fixed reference signal and modified PLL respectively

Droop control

The droop control can be constructed from P/V and Q/f relations as seen from the system equations with output/input terminology. The latter can also be shifted to a f/Q droop where the output of this droop control then can be used as the input to the modified PLL.

Figure 3: Conventional solution: P/V and Q/f droop | Our solution: P/V and f/Q droop

With P/V and Q/f droop method the frequency, voltage and current control loop is following its reference, but with a large steady state error. In addition V_{Fq} is no longer zero.

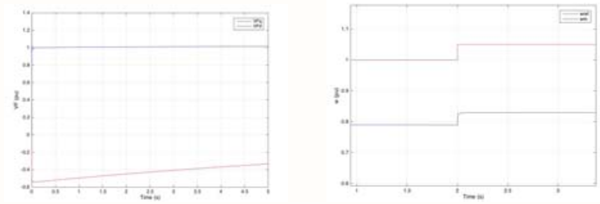

Figure 4: (a) V_F at PCC (b) frequency control, both with P/V and Q/f droop control

The P/V droop is maintained while the Q/f curve is shifted and the frequency is used as the integrated phase angle in the PLL. With this method $V_{Fq} = 0$

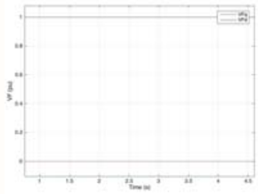

Figure 5: The voltage, V_F, at PCC in the distributed model with P/V and f/Q droop control

Summary and conclusions

- The PLL was found as a crucial part of the control strategy since the control method was based upon the assumption that $V_{Fq} = 0$
- The conventional PLL could not serve its function together with diode rectifier as HVDC converter
- Fixed reference signal of frequency was attempted applied, but V_{Fq} was not zero
- PLL with integrated phase angle reference was chosen for further simulations
- Droop control relating ω^* to the modified PLL was successfully implemented
- Reactive power sharing among the turbines was achieved
- Active power control was implemented in a master-slave technique
- Further work will include improving the active power control to also obtain active power sharing among the turbines

References

[1] R. Blasco-Gimenez et al., "Distributed voltage and frequency control of offshore wind farms connected with a diode based HVDC link", Nov. 2010

[2] H.Eckel et al., "FixRef: A control strategy for offshore wind farms with different wind turbine types and diode rectifier HVDC transmission", June 2016

[3] S. Sanchez "Stability Investigation of Power Electronic Systems", March 2015