From:	Dominika Phillips
To:	Hornsea Project Three; Kay Sully; KJ Johansson
Cc:	Andrew Guyton; Stuart Livesey
Subject:	Hornsea Project Three (UK) Ltd response to Deadline 3 (Part 7)
Date:	14 December 2018 21:03:00
Attachments:	image001.png D3_HOW03_Appendix 14_Markhams_Triangle.pdf D3_HOW03_Appendix 15_The Wash.pdf D3_HOW03_Appendix 16_NE_Ornithology Roadmap.pdf D3_HOW03_Appendix 17_Age class data.pdf D3_HOW03_Appendix 18_Kuhn et al._CIGRE_2016.pdf D3_HOW03_Appendix 19_Order Lim_amend.pdf

Dear Kay, K-J

Please find attached the seventh instalment of documents.

Best regards,

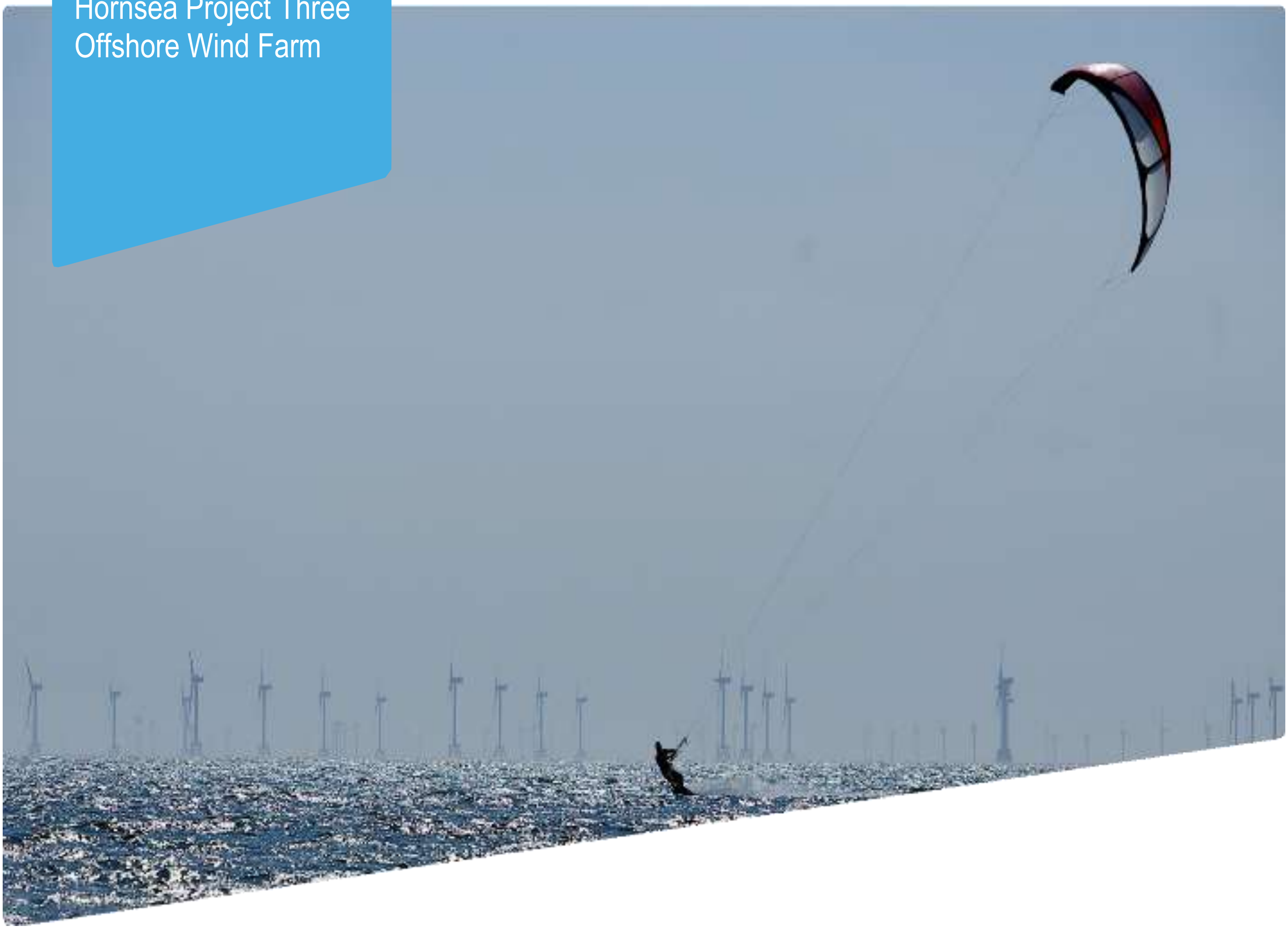
Dr Dominika Chalder PIEMA
Environment and Consent Manager

+44 (0) 7767 007 815

Environmental Management UK│ Wind Power
5 Howick Place │ London │ SW1P 1WG

Orsted

Hornsea Project Three
Offshore Wind Farm



Hornsea Project Three

Offshore Wind Farm

Appendix 18 to Deadline 3 Submission – Kuhn O., et al. - 2nd generation DC grid access for offshore wind farms: “HVDC in an AC fashion” (CIGRE 2016)

Date: 14th December 2018

Hornsea 3
Offshore Wind Farm

Ørsted

Document Control			
Document Properties			
Organisation	Ørsted Hornsea Project Three		
Author	Kuhn O., et al. 2016 - CIGRE		
Checked by	n/a		
Approved by	n/a		
Title	Appendix 18 to Deadline 3 Submission – Kuhn O., et al. - 2nd generation DC grid access for offshore wind farms: “HVDC in an AC fashion” (CIGRE 2016)		
PINS Document Number	n/a		
Version History			
Date	Version	Status	Description / Changes
14/12/2018	A	Final	Submitted at Deadline 3 (14/12/2018)

Ørsted

5 Howick Place,

London, SW1P 1WG

21, rue d'Artois, F-75008 PARIS
http : //www.cigre.org

B3-110

CIGRE 2016

2nd generation DC grid access for offshore wind farms: "HVDC in an AC fashion"

OLIVER KUHN, PETER MENKE, RAINER ZUROWSKI, TIMO CHRIST, SLAVOMIR SEMAN, GERALD GIERING, THOMAS HAMMER, DENIS IMAMOVIC
SIEMENS AG, GERMANY
JAN THISTED, PAUL BROGN, NIKOLAUS GOLDENBAUM
SIEMENS WINDPOWER A/S, DENMARK
oliver.kuhn@siemens.com

SUMMARY

The high potential of wind power far offshore calls for cost-effective solutions for grid connection. HVDC is the preferred technology for large scale offshore wind grid access. DC cables provide a very high power density and can easily cross long distances.
But current offshore DC technology suffers from large converter platforms due to air insulation, complex topology, high demands on the auxiliary systems, high maintenance efforts ultimately leading too high life cycle costs. Furthermore the planning, installation and operation of an HVDC offshore is an unknown territory outside Germany.
The new approach suggested uses

- Compact, robust, encapsulated power electronics which is installed and maintained like an AC power transformer.
- Encapsulated DC switchgear, which is installed and maintained like an AC GIS.

Result is an HVDC converter which – at first glance – looks like a gas insulated AC substation. The required platform size and weight is substantially reduced. The monolithic large converter platform is not needed anymore. The AC Offshore Substations are replaced by an AC/DC Offshore Substations, where the turbine strings can directly be connected to.
The total top side weight is reduced from approx. 26.000 tons to below 9.000 tons.
The operation costs are reduced as well since there is no complex control and no maintenance intensive auxiliary equipment like large air conditioning.
Finally the small platform size allows a fast erection in approx. 28 months till first power transmission. Aux power supply for the turbines can be commissioned even faster, if the cables are in place. Total project execution time is expected to be 48 months (12 months FEED-Phase plus 36 months erection)

KEYWORDS
HVDC, diode rectifier, offshore wind, grid access, GIS, platforms, DC switchgear, wind turbine,

Introduction

Summarizing their work on HVDC connected wind power plants CIGRE Study Committee WG B3.36 concludes: „similar and often redundant requirements are specified for both turbines and for HVDC hubs … (which) may … lead to oversizing equipment and implementation of redundant control systems“ [1].

Indeed today's DC connected offshore wind farms contain the most sophisticated power electronics the industry can deliver: full scale converters are meanwhile standard for offshore wind turbines and multi-level voltage sourced converters are the most powerful HVDC converters the manufactures can supply. All this comes at a price and increases complexity.

Therefore SC WG B3.36 suggests "Wind turbines may be requested to control the MVAC voltage including no-wind conditions… This may reduce the control efforts and avoid oversizing of the HVDC hubs".

The most consequent approach to take complexity out of the system and to simplify the HVDC conversion is to use diode rectifiers. Indeed the diode rectifier is the most simple and robust AC/DC converter the electrical engineer can think of.

Using diode rectifiers for HVDC was already suggested back in the 70ies [2]. But for onshore applications controllability and bidirectional power flow are considered to be more important than the advantages in costs and robustness the diodes pro-vide. In 2010 Ramon Blasco-Gimenez et al proposed to utilize the capabilities of the converters of state of the art wind turbines to realize distributed voltage and frequency control of off-shore wind farms connected with a diode based HVDC Link [3].

I. System Overview

Figure 1 shows a simplified single line diagram of the proposed grid access system.

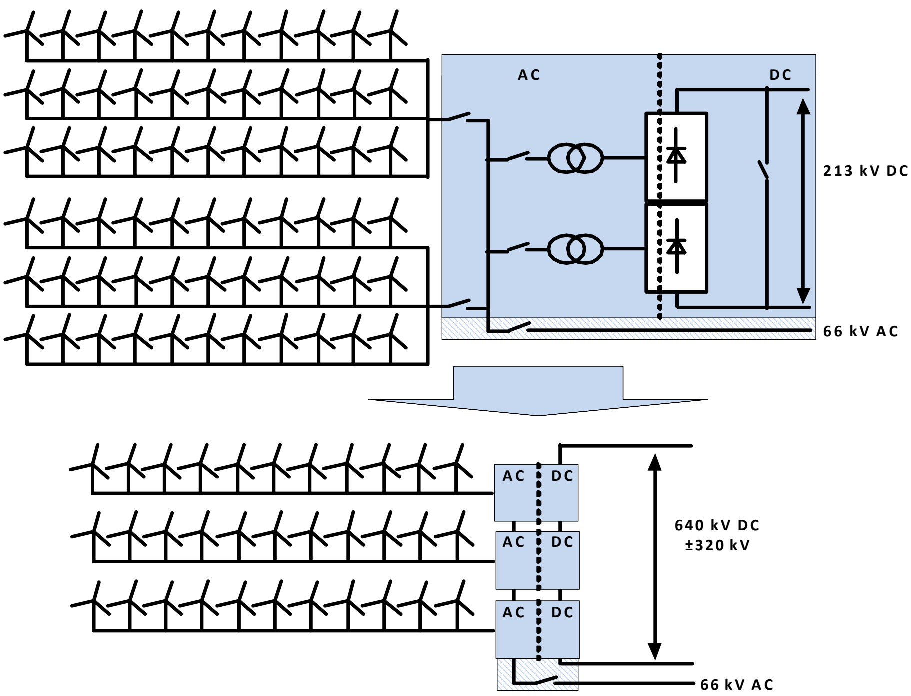


Figure 1. Simplified single line diagram on one platform

The system utilizes a modular approach: 6 rectifiers are placed on 3 platforms. This modular approach provides the following benefits:

- Stepwise erection of the DC platforms is feasible

- In case of maintenance or failure a platform can be bypassed while the other platforms continue to operate. This results in a high availability of power transmission capacity.
- Equipment and platform sizes and weights are in a range good to handle (transport and installation)
- The DC platforms can be distributed to optimize the wind farm layout and minimize array cable length and losses

During no wind situations auxiliary power is provided by an auxiliary power cable, which can be commissioned in advance of and completely independent of the DC link. This cable can be connected to the onshore grid or to a neighbouring existing OWF or VSC platform.
Each of the rectifiers provides a DC voltage of 106.7 kV DC resulting in a DC voltage of +-320 kV as state of the art.

II. THE DIODE RECTIFIER UNIT

Traditional HVDC converters are air insulated and have therefore limitations in reducing their size due to the weak voltage withstand capability of air.
Liquid insulation as used in power transformers instead of air can dramatically reduce the required insulation distances up to 80%.
Furthermore years of experience with traditional HVDC converters have shown that simple solutions are more robust due to their decreased number of electric components. The simplest solution that can be done is a diode rectifier.

The Diode Rectifier unit combines the active component of a transformer together with a 12-pulse diode rectifier and DC smoothing-reactors in a common tank filled with synthetic ester (regarding the pulse choice see our reasoning in [4]).
The insulation liquid allows the reduction of the size of the complete unit and is also used for cooling of the diodes and their RC-circuit. That can be done with a single cooling system for both, transformer and rectifier.
The reduced number of electric components especially on high potential on the one hand and the lack of auxiliary equipment that needs power supply on other hand leads to very low-maintenance and meets the requirements for harsh offshore environment conditions. Therefore a diode rectifier is ideal when it comes to the reduction of parts that could cause failures and system trips. Compared to thyristors. diodes do neither need protection against steep rise of current when fired and are not susceptible for failure events within the recovery time nor do they require for firing and monitoring electronics.
The electrical circuit of the diode rectifier itself consists of four simple components per diode-level: A snubber RC-circuit, a grading resistor and of course the diode with its heat sink itself. That decreased number of components increases MTTF values dramatically.
By providing enough redundant diode-levels continuous operation can be achieved for up to 30 years without diode replacement and a minimum of maintenance. Regularly checks can be reduced from monitoring every single semiconductor to a simple pass/fail decision.

The nominal DC voltage of one DRU is 106.7 kV. The rated power is 200MW. With 6 units in series the DC sums up to +-320kV and a total transmission capacity of 1200MW. AC input voltage can be 33kV, 66kV or 155kV.

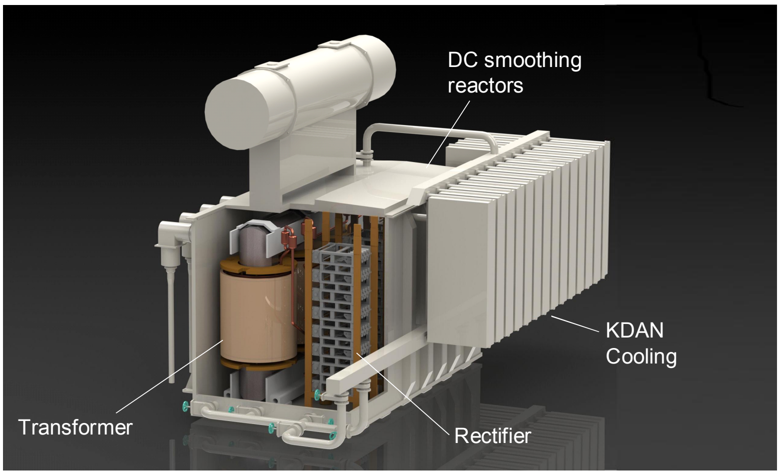


Figure 2. Diode Rectifier Unit

The integrated approach as shown simplifies the interconnection between transformer, rectifier and reactor. The assembly and interconnection is done in the factory. The integrated unit can be fully tested there providing highest quality and reliability.
All 6 units used are identical. The voltage withstand capability vs. ground is always designed for the full DC voltage of +-320kV, although not really needed for the middle units. By doing so only a single spare unit has to be kept ready for replacement purposes.
As insulation liquid a ester is used. Due to its higher flash point and the fact that it is recognized as biodegradable, it is an appropriate choice for an environmentally sensitive maritime environment.
Diode rectifiers also feature low losses. The total full load losses are about 3% (for 115km cable length). This 20% below the losses of the conventional VSC approach.

III. The DC switchgear

The DC switchgear (i.e. bypass switch, earthing switches, disconnectors and measurement devices) is encapsulated as well, so there is no high voltage in open air at all any more.
This means no costly and maintenance intensive large air conditioning systems are required like for a VSC and an air insulated DC switchyard. Space savings are around 90%.
The DC switchgear is design based on proven AC GIS technology.

Figure 3. DC compact switchgear

IV. THE DC PLATFORMS

The use of encapsulated diode rectifiers and compact DC switchgear allows to reduce platform size and weight substantially and to provide small, modular and flexible DC platforms easy to install and maintain.
The new DC grid access concept does not require any AC Offshore Substations. The turbine strings can directly be connected to one out of three DC platforms. These are of similar size than today's AC Offshore Substations. The total top side weight is reduced from approx. 26.000 tons to only 9.000 tons.
The operation costs are reduced as well since there is no complex control and no maintenance intensive auxiliary equipment like large air conditioning.
Finally the small platform size allows fast erection of approx. 30 month form order till commissioning of the first DC platform and start of power transmission. Aux power supply for the turbines can be commissioned even faster, if the cables are in place. The platforms can be erected step by step following the turbine installation progress.

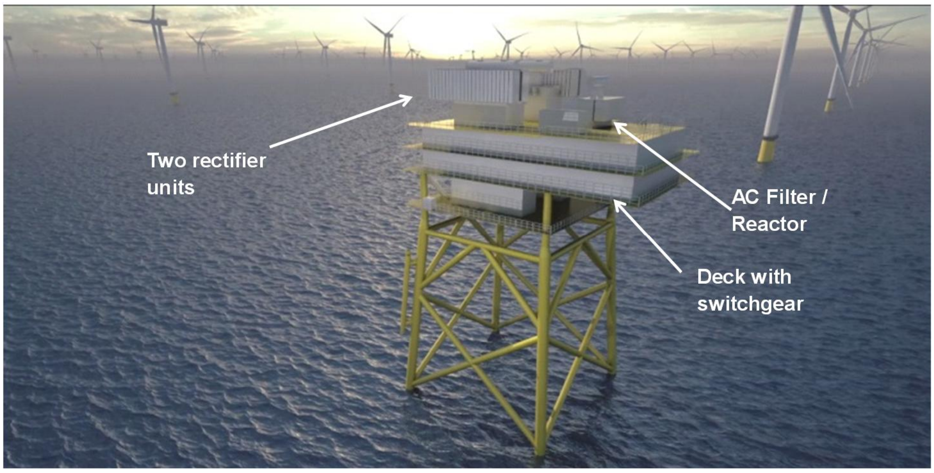


Figure 4. The new DC platform

The resulting offshore topology is shown in Figure 5 and for comparison the old topology we refer to in Figure 6.

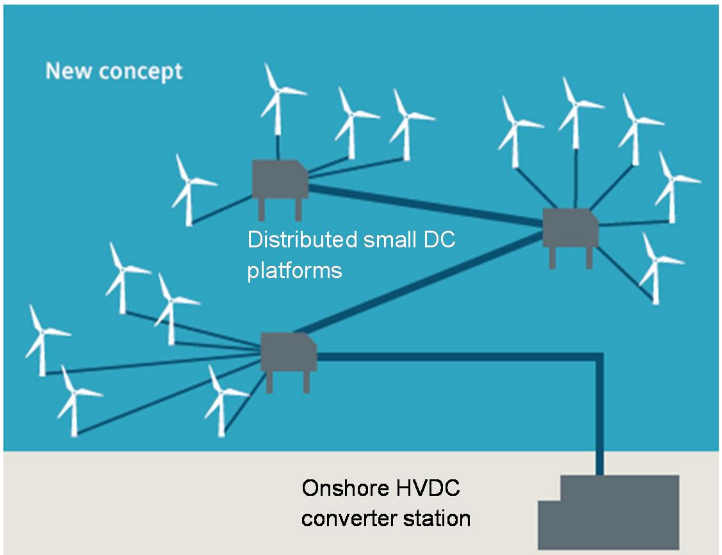


Figure 5. New DC Grid Access Topology

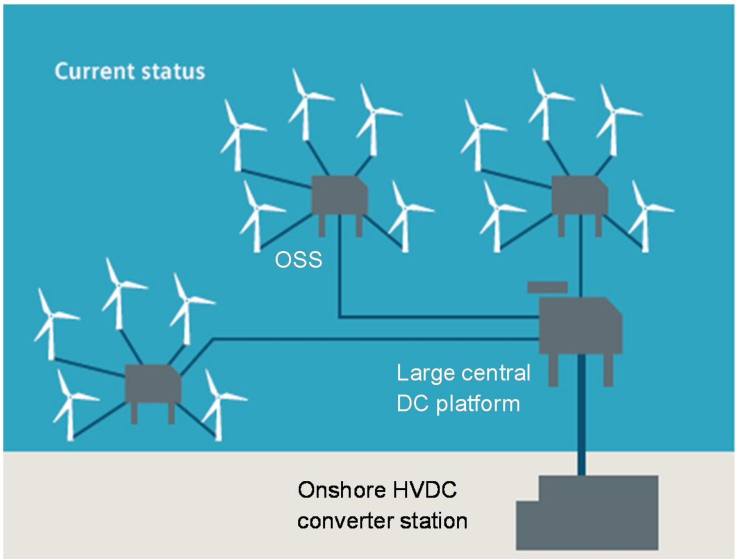


Figure 6. Current approach for comparison

V. THE TURBINE CONTROL

Since the rectifier is a purely passive device the WTG have to maintain voltage and frequency once the umbilical cable which provides initial auxiliary power is disconnected. This is a novelty, but taking out the offshore VSC with its redundant, complex and proprietary control features simplifies the sys-tem and makes it actually easier to handle. This is especially true for Germany, where WTG and HVDC link are built by different companies. System responsibility is difficult to define and the exchange of confidential technical information is a challenge.
Replacing the offshore VSC by a rectifier simplifies the interface between OWF and TSO. The assignment of responsibilities is easier. The HVDC converter becomes much more predictable. It is just a rectifier that behaves like a rectifier does. No VSC "black-box". No surprises.
The principal control objectives for the network bridge control of the WTG are:

- Balance power generated by wind farm with that transferred to onshore grid via HVDC link and / or Umbilical cable.
- Provide support to offshore system voltage and frequency

To do so, the WTG control has to fulfil the following tasks:

- Providing reactive power when the park is energized via the auxiliary power cable
- Adjust the voltage magnitude within the allowed voltage range to control DC power flow
- Control frequency when the umbilical cable is disconnected

The concept is designed so that a full converter WTG type is able to fulfil these tasks without hardware change. Only control firmware needs to be adopted. Details on the proposed WTG control concept which is compatible with a diode rectifier HVDC, a VSC HVDC and an AC grind connection can be found in [6].
The ability to operate DFIG ETGs with diode rectifiers was e.g. investigated by Peña et al [5].

VI. CONCLUSIONS

The new approach for DC grid access of offshore wind farms as presented in this paper provides a number of benefits:

- Robust offshore AC grid control
- Encapsulated, rugged equipment
- Bio degradable and low flammable insulation
- Simple and robust power electronics

- Easy transport and installation
- High reliability, minimal maintenance
- No offshore DC converter as single point of failure
- Shorter delivery times
- Stepwise offshore installation feasible
- Fast commissioning of WTG aux power
- Up to 1200MW DC
- Flexible offshore installation options due to modular rectifier concept

This makes the new DC grid access concept a major contribution to the economic viability of large scale far shore offshore wind farms.

ACKNOLEDGEMENT
The authors would like to thank the German Ministry of Economics and Energy for providing R&D funding support.

BIBLIOGRAPHY

[1] P. Sandeberg, P. Moran, A. Lombardi, A. Hernandez, C. Feltes, D. Ramsay, G. Nichol, G. Drobnjak, G.Q. Varela, J. Palle, J. MacEnri, M. Dhesi, M. Aten, M.E. Crespo, M. Ono, N. Singh, P. Knol, T. Schlüter, T. Kobayashi, A. Neumann, G. Hentschel, J. Finn, M. Osborne, R. King, S. Wijnbergen, T. Boehme, V. Akhmatov, "CIGRE-WG B3.36-Special Considerations for AC Collector Systems and Substations associated with HVDC connected Wind Power Plants". TB612, Electra No. 280 - June 2015

[2] J.P. Bowles, "HVDC System Developments and concepts – The diode rectifier." CIGRE SC14, Meeting and Colloquium, Winnipeg, Canada, June 1977

[3] R. Blasco-Gimenez, S. Añó-Villalba, J. Rodrígez-D`Derlée, F. Morant, S. Bernal-Perez. "Distributed voltage and frequency control of offshore wind farms connected with a diode-based HVDC link". IEEE Transactions on Power Electronics, vol. 25, no. 12, pp. 3095-3105

[4] S. Seman, T.Christ, R. Zurowski, "Investigation of DC Converter Nonlinear Interaction with Offshore Wind Power Park System, EWEA Offshore Conference 2015

[5] R. Peña (University of Concepción, Chile), S. Añó-Villalba, R. Blasco-Gimenez (Polytechnical University of Valencia, Spain), "Control of DFIG-Based Off-Shore Wind Power Plants for the Connections to HVDC Diode Rectifiers", 14th Wind Integration Workshop, Bruxelles, October 2015.