Experimental verification of a voltage droop control for grid integration of offshore wind farms using a multi-terminal HVDC

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Outline

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Objective

This work presents a lab-scale implementation of a voltage droop control for a multi-terminal HVDC system connecting an offshore wind farm.
Introduction

In the near future, the construction of an offshore electrical grid is expected in Europe. The objective of such a transmission framework is to facilitate large-scale integration of renewable energy and to improve the European power market.

It is widely recognized that for long-distance bulk-power delivery, HVDC transmission is more economically attractive than HVAC transmission.

A multi-terminal HVDC system presents many challenges: protection, control, and operation issues.

One of the most critical issues is the voltage control and power balance.

From http://www.friendsofthesupergrid.eu/
Introduction

Several methodologies to balance the power and control the voltage have been studied in the literature

- Master-slave control
- Voltage-margin control
- Voltage-droop control
Reference system

- Multi-terminal HVDC system composed by four terminals which aims to represent the future power HVDC in the North Sea; Norway, Germany and UK are interconnected together with an offshore wind farm.

- It is considered that the three onshore grids have a nominal voltage of 400 kV.

- HVDC system is rated at ± 320 kV and a 1200 MW offshore wind farm is considered.
Scaled experimental platform

- The set consists of **four 60 kVA VSCs**.
- **The wind farm** is emulated using a motor drive and a **55 kVA induction motor/generator-set**.
- **The strong grids** are represented by the laboratory 400 V supply.
- A **independent grid** is emulated using a **17 kVA synchronous generator**.
- **The DC line emulator** consists of variable **series resistors** to vary the length of the emulated cable.
SINTEF/NTNU smart grid lab

- DC line emulator
- Synchronous generator
- Wind emulator
- 4 VSC
The control system runs on a processor system that is embedded in **FPGA (Field-Programmable Gate Arrays)**.

For adjusting the settings, the converter is equipped with a **CAN interface** which enable receiving, sending, and controlling reference remotely.

The droop voltage control is achieved by using the **Labview programming environment**.
Voltage droop control

The voltage droop controller is a proportional control law that regulates the DC voltage and provides power sharing between the different power converters.

The mathematical expression for voltage droop control is given by

\[ V_{DC} = V_0 - \rho \left( P_{DC} - P_0 \right) \]

- \( \rho \) Droop constant
- \( V_0, P_0 \) Voltage and power set points
Laboratory case studies

Case 1: wind variations

Case 2: Disconnection of two terminals
Case 1a: Varying wind – equal droop constants

- Converters share equally the power since the droop constants and set-points are equal
- Norway is absorbing slightly less wind power since the resistance is higher due to longer cable length
Case 1b: Varying wind – different droop constants

- **Droop constants:**
  - Germany: 40 power pu/voltage pu
  - Norway: 20 power pu/voltage pu
  - UK: 10 power pu/voltage pu

- The **powers are distributed proportionally** to the **droop constants**

- The droop constant should reflect the ability of the onshore grid to absorb or provide additional power to the DC-grid

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**Diagram:**

- **Ramp up**
- **Ramp down**

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**Graphs:**

- Voltage [V] vs. Time [s]
- Power [kW] vs. Time [s]
Case 1c: Varying wind – different power set-points

- Droop constants all equal (=20)
- Power set-points are different: - 0.5 pu (Norway), 0.25 pu (Germany) and 0.25 pu (UK).
- Now, Norway exports power towards both UK and Germany
- Since droop-constants are equal, the additional wind production is shared equally among the three countries similar to case 1a
Case 2: Sudden disconnection of two converters

- Initially all countries are absorbing the same wind power. All droop constants are equal.
- At $t=0.7$ Norway is disconnected
  - The wind power initially absorbed by Norway is shared equally between Germany and UK.
- At $t=1.7$ UK is disconnected
  - Germany is now absorbing all wind power.

System response is stable and with no overshoot against these severe events.
Conclusions

- The overall goal has been to implement a voltage droop control in a down scaled model of a multi-terminal VSC-HVDC grid.
- Two scenarios have been used to test the performance of the droop-control and evaluate the stability of the system: variation in wind power production, and loss of two terminals during full wind production.
- The implemented system was able to ensure that the voltage stays within its steady state limits and to reach a stable operation point after the above disturbances were applied. Moreover, the system is able to tolerate the loss of one or two terminals. It can be concluded that the voltage-droop control scheme has been successfully implemented in this laboratory model.
- **Future work:** Secondary control, frequency reserve exchange, and DC protection and fault handling.
Thanks for the attention