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

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Outline

- Introduction
- Reference system
- Scaled experimental platform
- Voltage droop control
- Laboratory case studies
- Conclusions

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

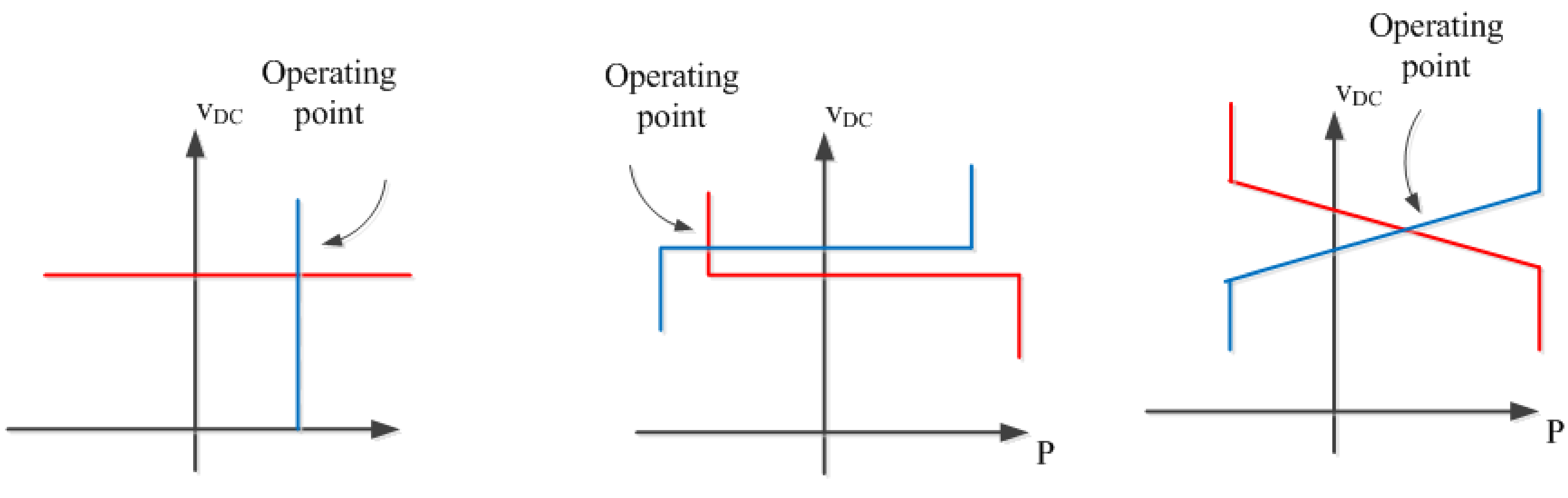
- **A multi-terminal HVDC** system presents many challenges: **protection, control, and operation issues**.
- One of the most critical issues is the **voltage control and power balance**

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



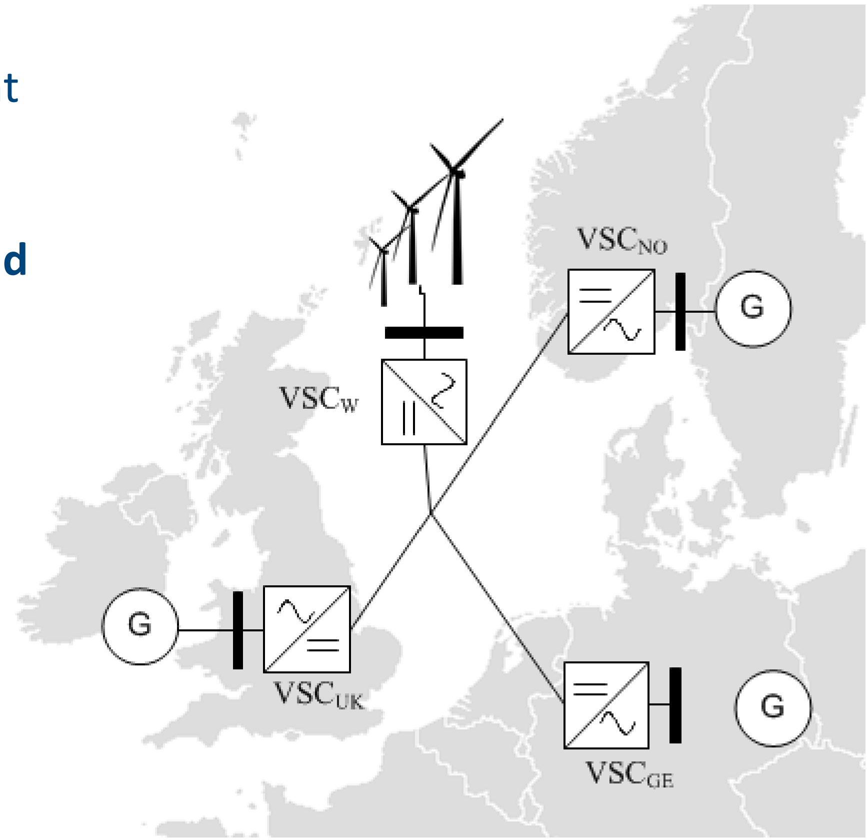
a) b) c)

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 inter-connected together with an **offshore wind farm.**

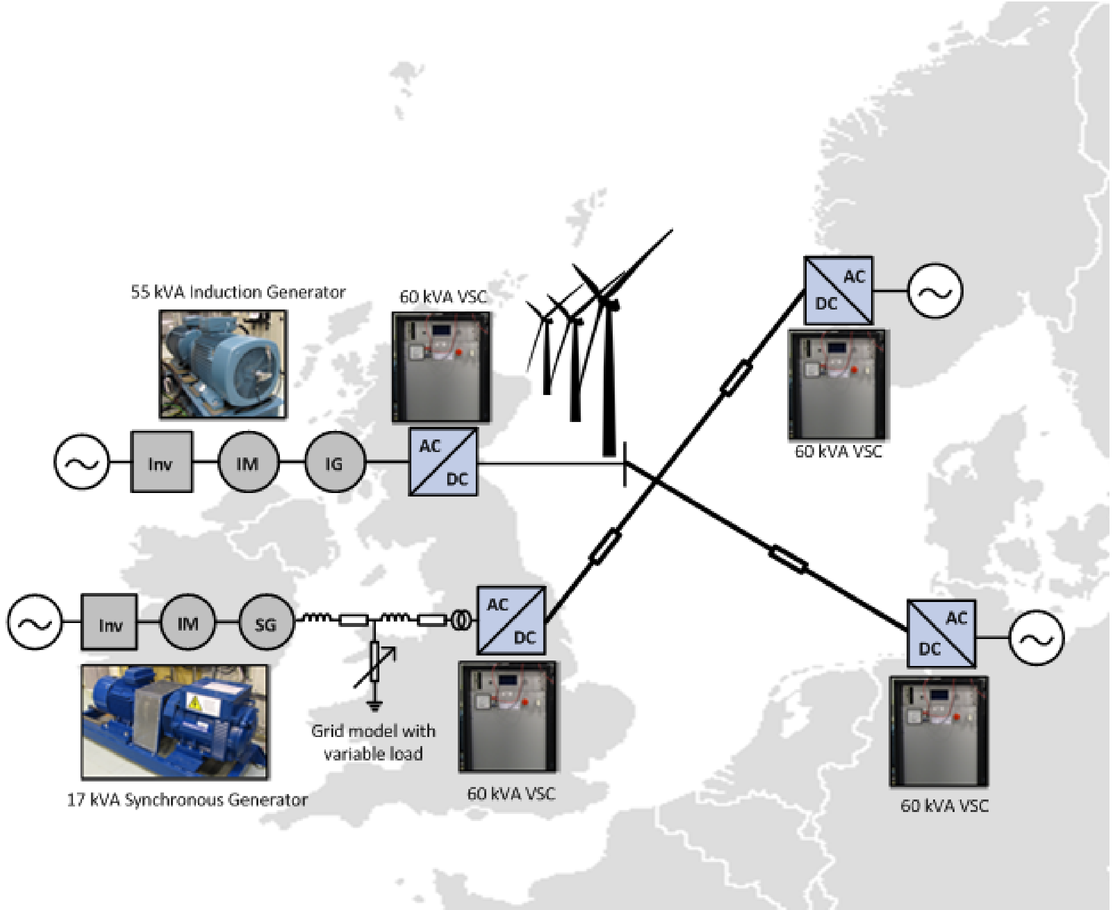
- It is considered that the **three onshore** grids have a nominal voltage of **400 kV**.

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

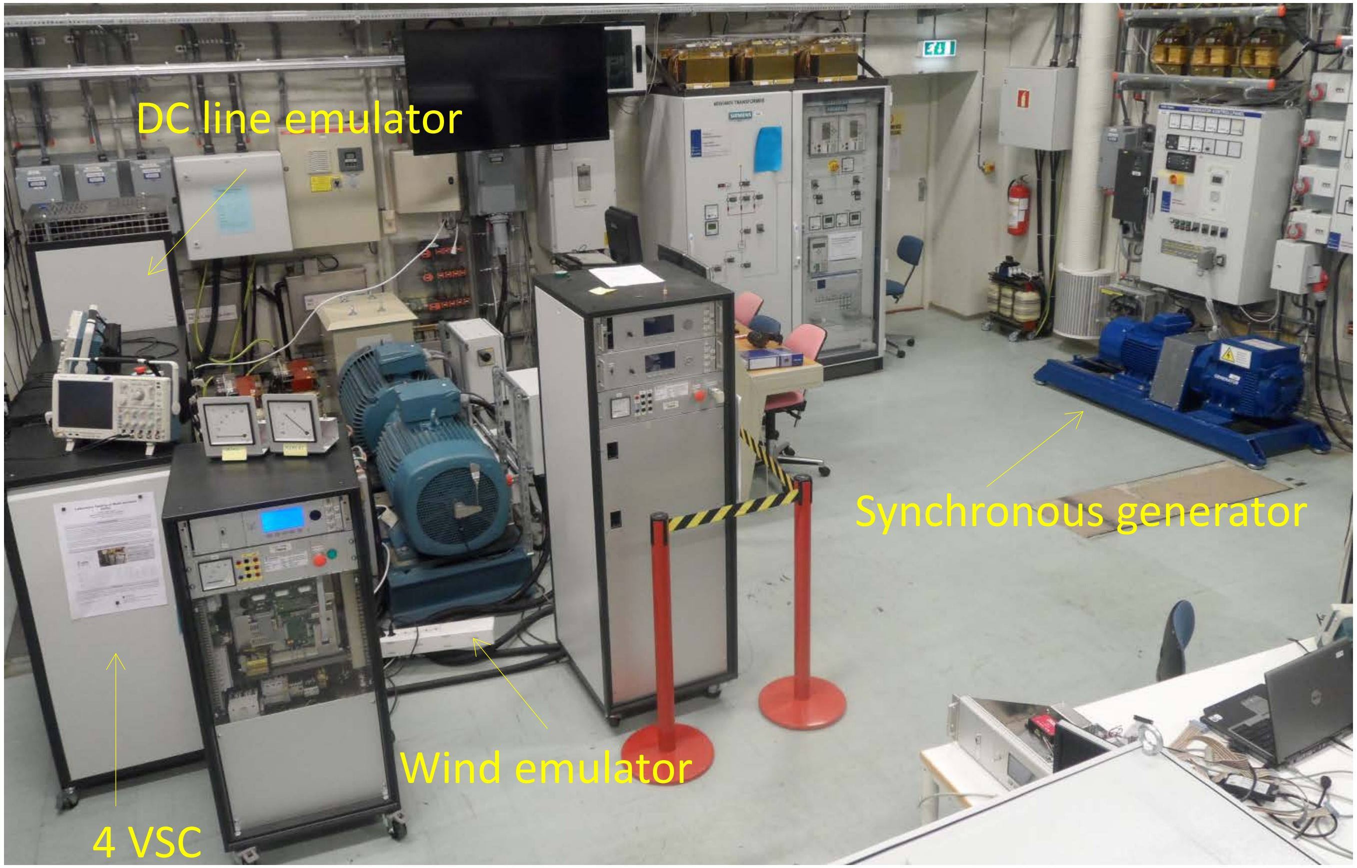


Scaled experimental platform

- 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.

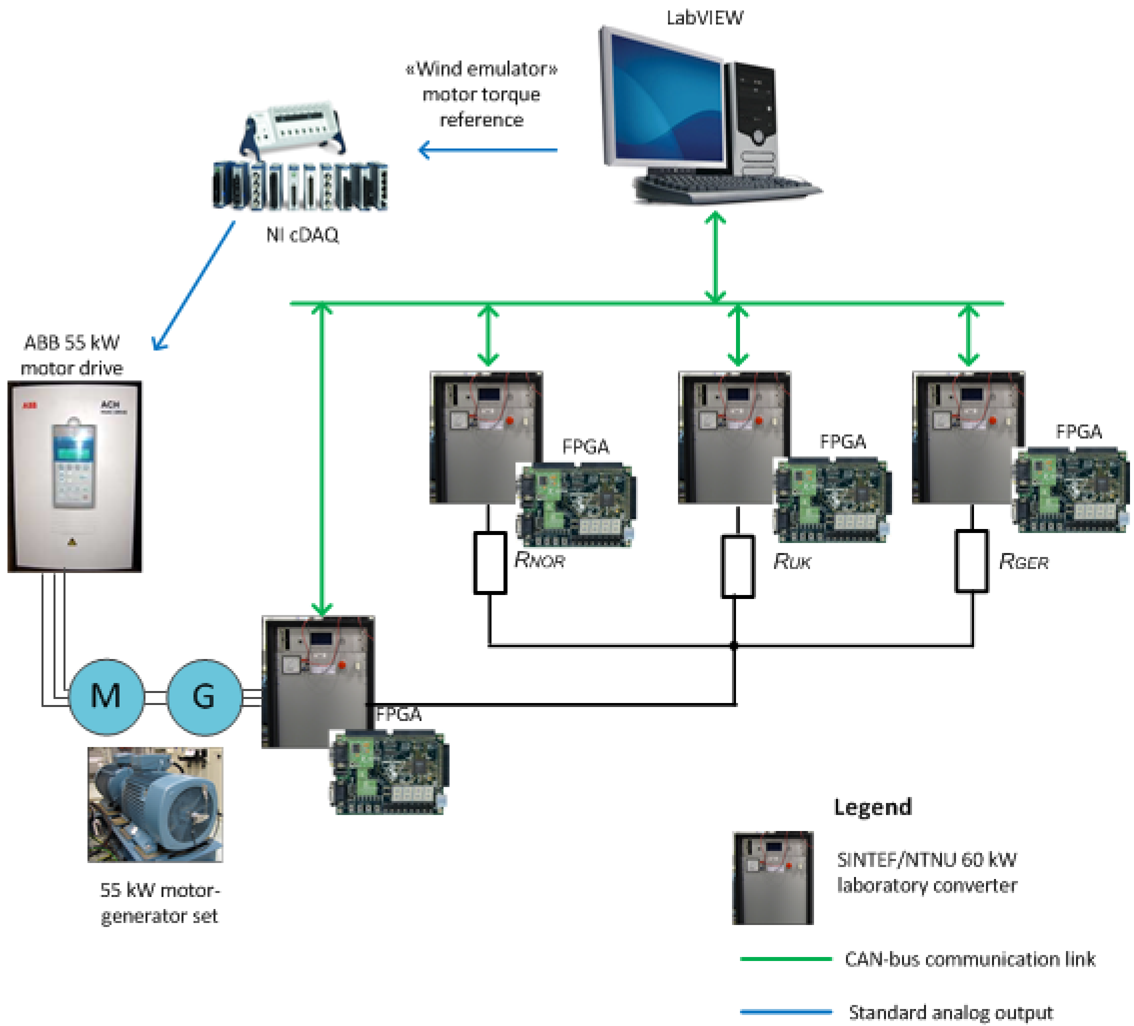


SINTEF/NTNU smart grid lab



Scaled experimental platform

- 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.

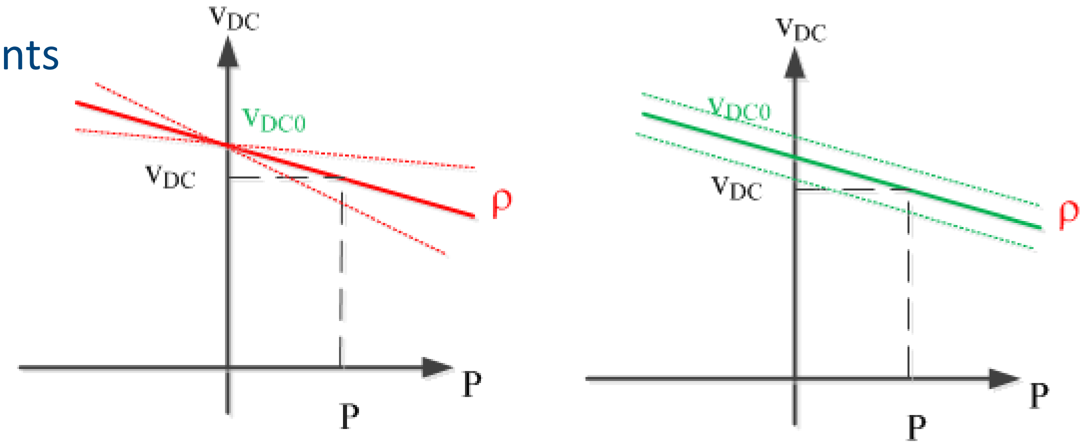
The mathematical expression for voltage droop control is given by

$$V_{DC} = V_0 - \rho\,(P_{DC} - P_0)$$

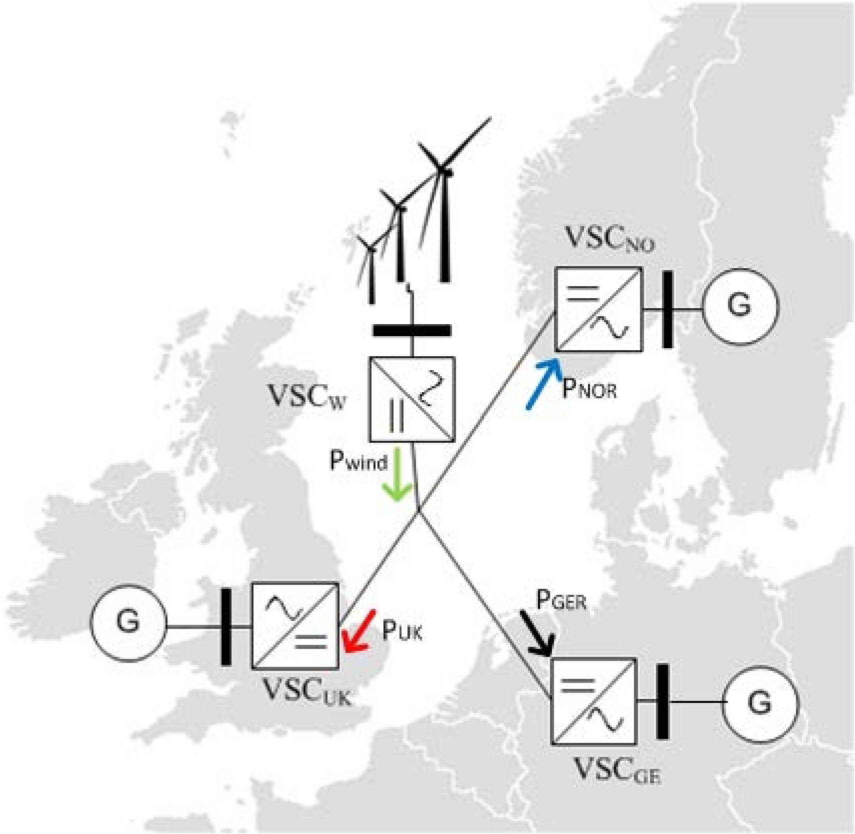
ρ Droop constant

V_0, P_0 Voltage and power set points

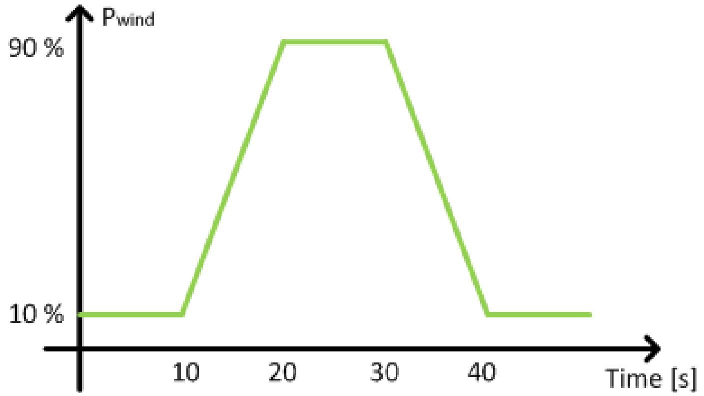
DC voltage droop characteristic.



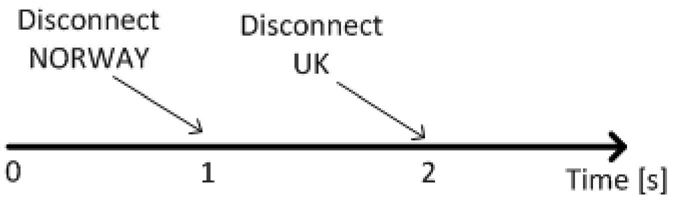
Laboratory case studies



Case 1: wind variations

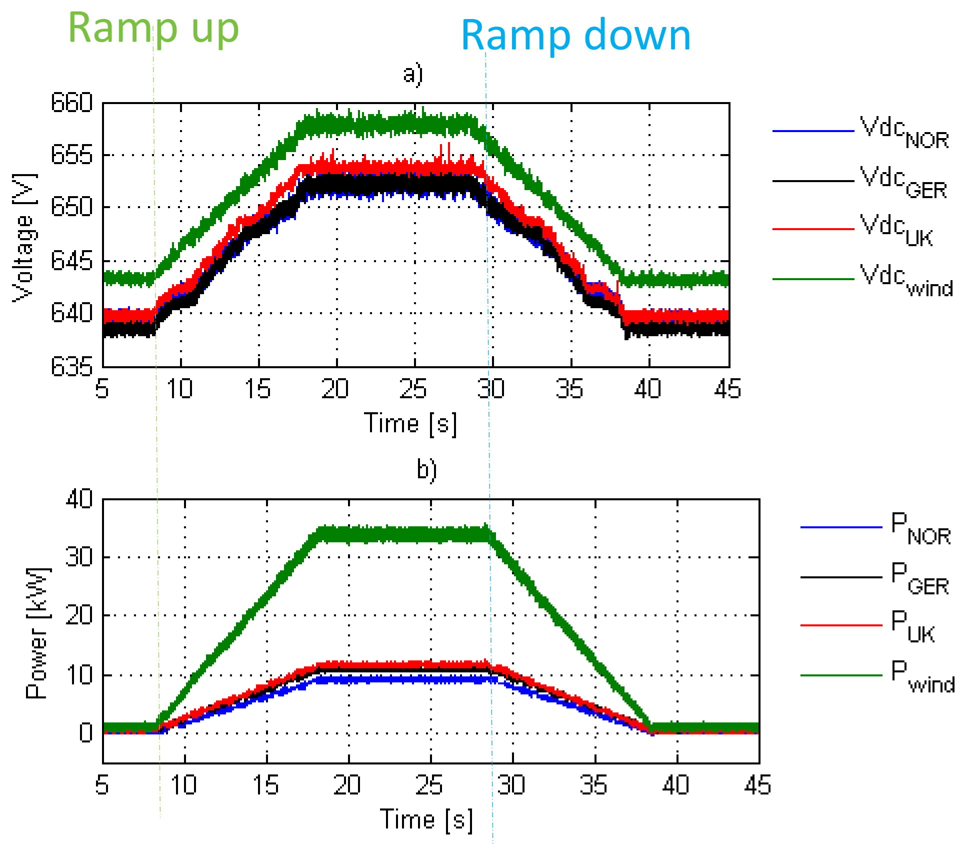


Case 2: Disconnection of two terminals



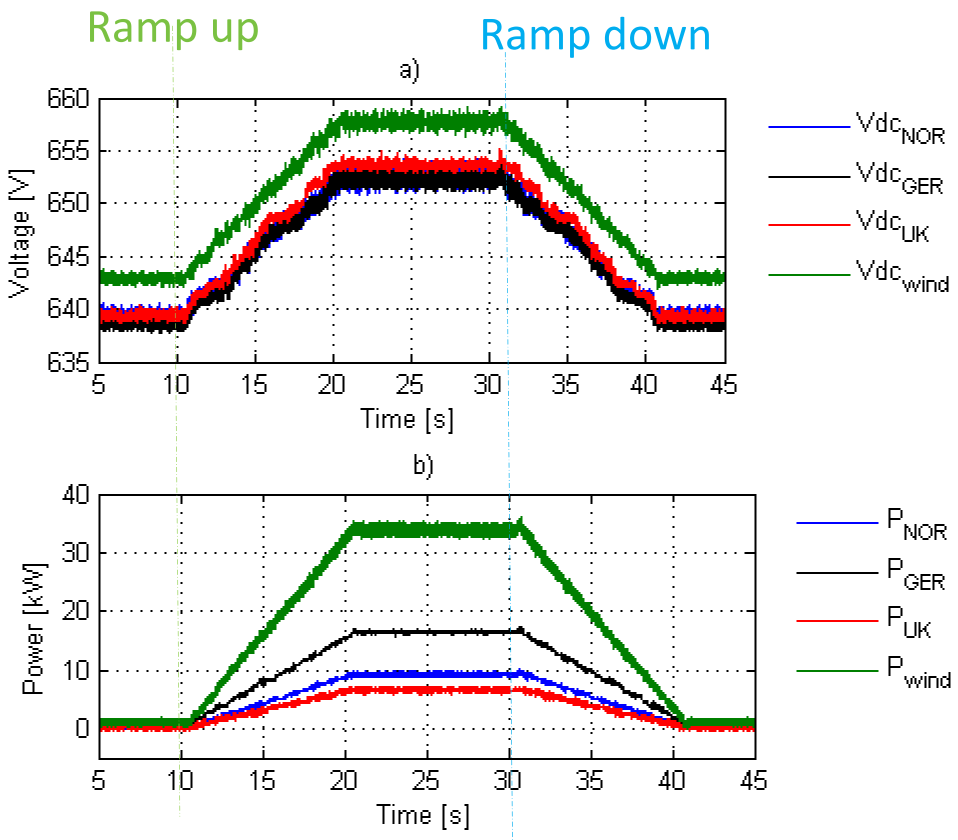
Case 1a: Varying wind – equal droop constants

- 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

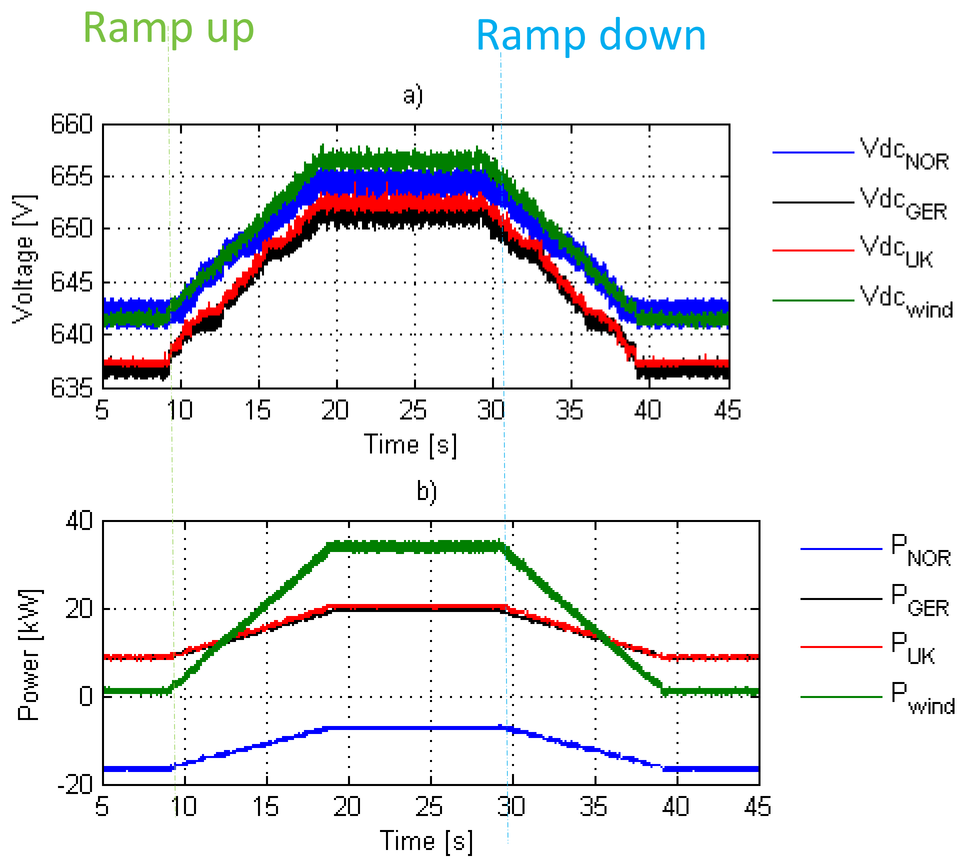
- Droop constants:
  - Germany: 40 power pu/voltage pu
  - Norway: 20 power pu/voltage pu
  - UK: 10 power pu/voltage pu
- The **powers are distributed proportionally** to the **droop constants**
- The droop constant should reflect the ability of the onshore grid to absorb or provide additional power to the DC-grid



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**

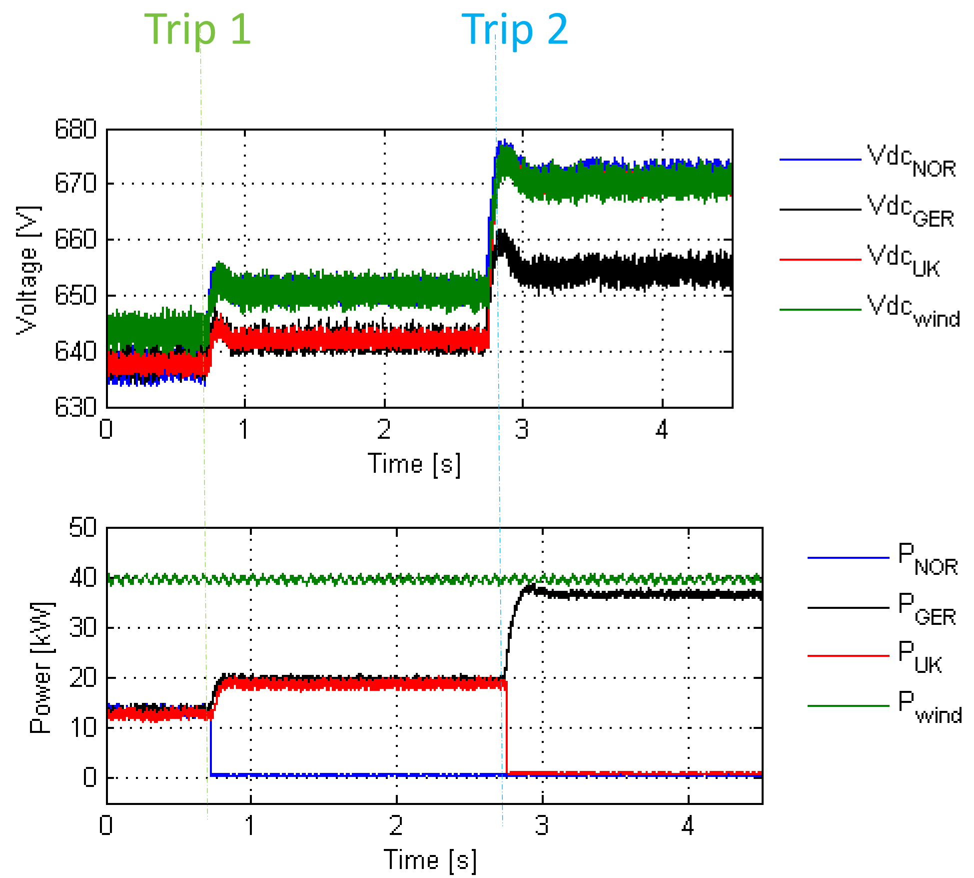
- Since droop-constants are equal, the additional wind production is shared equally among the three countries similar to case 1a



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**

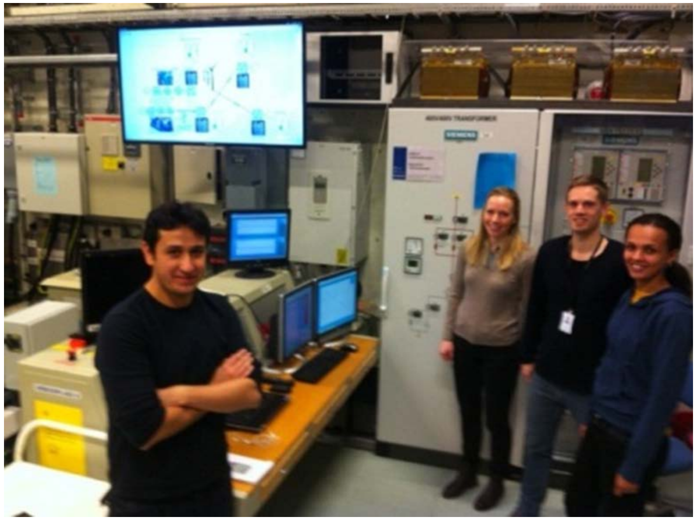
System response is stable and with no overshoot against these severe events



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



Picture by John Olav Tande