Conference of the Wind Power Engineering Community

Analysis of the Effectiveness of Grid Codes for Offshore Wind Farms Connected to Onshore Grid via VSC-Based HVDC

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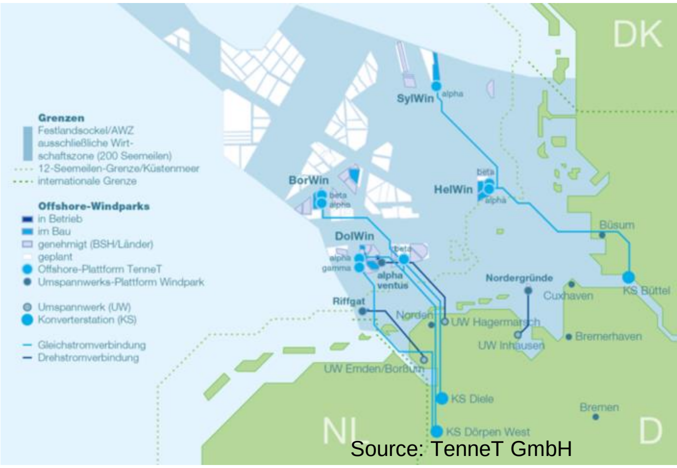
Content

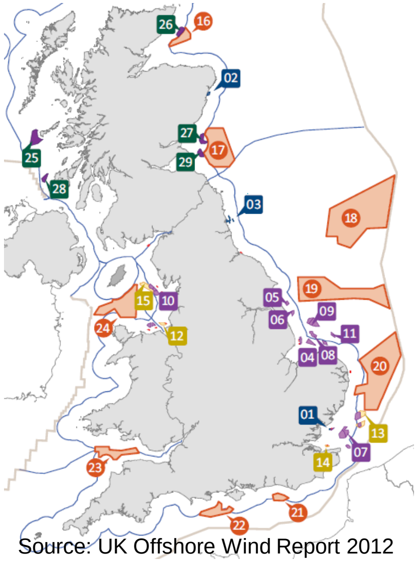
- Motivation and objectives
- Overview of relevant Grid Codes
- Model of an Offshore wind farm connected via VSC-HVDC
- Exemplary results from the stationary analysis
- Dynamic wind farm analysis under different fault cases
- Conclusion

Motivation

- High share of offshore wind power (>20 GW targeted for 2020 in German North Sea)
- Especially distant large Wind Farms are connected to Onshore-Grid via VSC-HVDC



Source: TenneT GmbH


Source: UK Offshore Wind Report 2012

- Guarantee for a reliable, but also efficient energy supply
- High Wind Farm requirements, based on the demands in Onshore-Grid, applied to Offshore Wind Farms
- Unknown effectiveness of the Grid Codes, especially in case of Offshore Wind Farms connected via VSC-HVDC

Central objectives

- Steady-State and fault behaviour investigation of a representative Wind Farm including a VSC-HVDC Model
- Presentation of the main studies on the effectiveness and possible simplifications of legal Grid Codes and requirements
- Motivation to discuss a possible modification of existing Grid Codes
- Who is responsible for System Services - Grid Operator or Wind Farm Operator?

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Overview of relevant Grid Codes

Grid Codes in Europe at a glance

Legal Framework

- Germany

German Ordinance on System Services by Wind Energy Plants (SDLWindV), Transmission Code 2007

- Spain

Operation Procedures P.O.12.1-3

- Denmark

Technical Regulation 3.2.5

- Great Britain

The Grid Code Issue 5, Revision 3 (incl. Offshore part)

Contents

- Classification of Wind Energy Units (WEU) regarding their size and connected voltage-grid level
- Requirements for the WEU in steady-state regarding e.g. Active/Reactive Power Supply
- Conditions for a disconnection from the Grid during faults
- Dynamic System Services during faults

Purpose

➔ Necessary Flexibility for Grid Operators

➔ Avoiding cascading active power loss

➔ Fast and safe Return to stable Operation Point

Overview of relevant Grid Codes

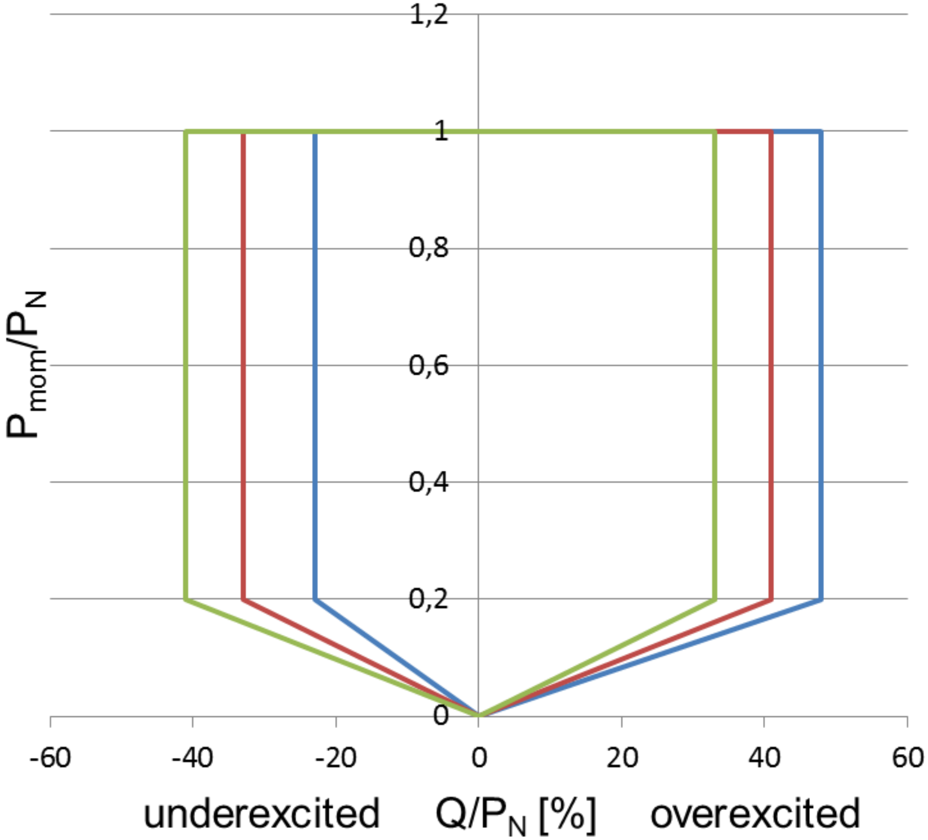
Requirements for German Offshore-WF

- Transmission Code 2007 / SDLWindV
  - Guideline of a PQ-Diagram for the Operating Points
  - Voltage- and Frequency-Control
  - LVRT-Capability, WEU have to stay connected to the Grid during faults and accomplish a contribution for system stability
  - Control of reactive current injection by the WEU in relation to significant voltage deviation
  - No specific requirements or exceptions for Offshore-WEU
- Grid Codes of the operators for a seaside connection
  - Similar to requirements for the Onshore WEU
  - Exception is only a different reactive current supply during faults

Overview of relevant Grid Codes

PQ-Diagram for the WEU-Operating Points

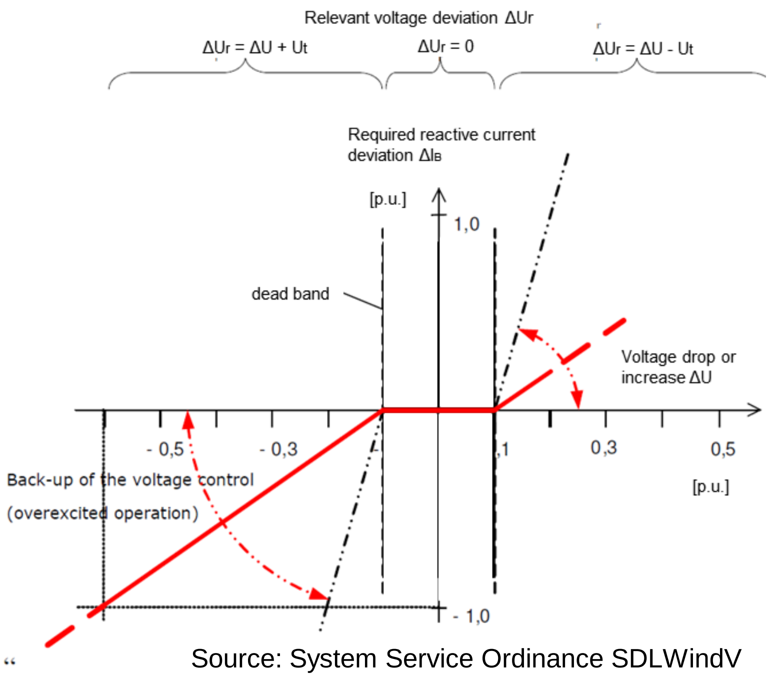
- The PQ-Diagram defines the minimum obtainable Operation Area
- Three variations of PQ-Diagrams can be forced by the Grid Operator
- PQ-Diagram depends on Grid Voltage
- Depending on the Grid situation the Grid Operator can order to operate at specific points
- Onshore: Necessary flexibility to react on deviations in the grid



Overview of relevant Grid Codes

Control of reactive current supply

- In case of a voltage deviation the WEU must back up the voltage by adjusting the reactive current I_B
- reactive current deviation (ΔI_B) must be proportional to the relevant deviation, defined by the factor k
- For 3-pole faults e.g., WEU must be able to feed in a reactive current of min. 100% of the rated current
- active current I_W can be reduced to obtain an increased reactive current
- additional time progressing requirements



Source: System Service Ordinance SDLWindV

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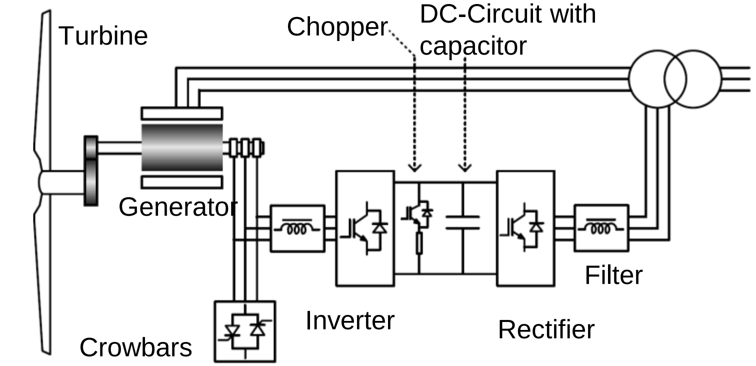
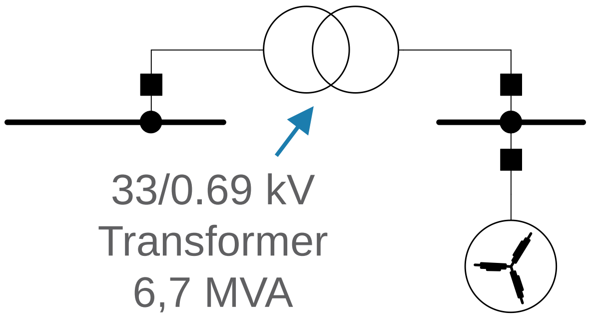
Model of an Offshore wind farm

DFIG Model

- Generic Model of doubly-fed induction generator (DFIG)
- Representation of the mechanical behaviour as a oscillating Two-Mass-Model
- Implemented pitch control, Power-Frequency Control, Protection Systems e.g. Overvoltage-Protection, Crowbar-Protection
- LVRT-Capability
- In model 50 Wind Turbines of 6 MW in 10 rows are applied
- Embedding in a 33 kV-Offshore-Grid



Source: Perdana, Dissertation Chalmers Universitiy of Technology

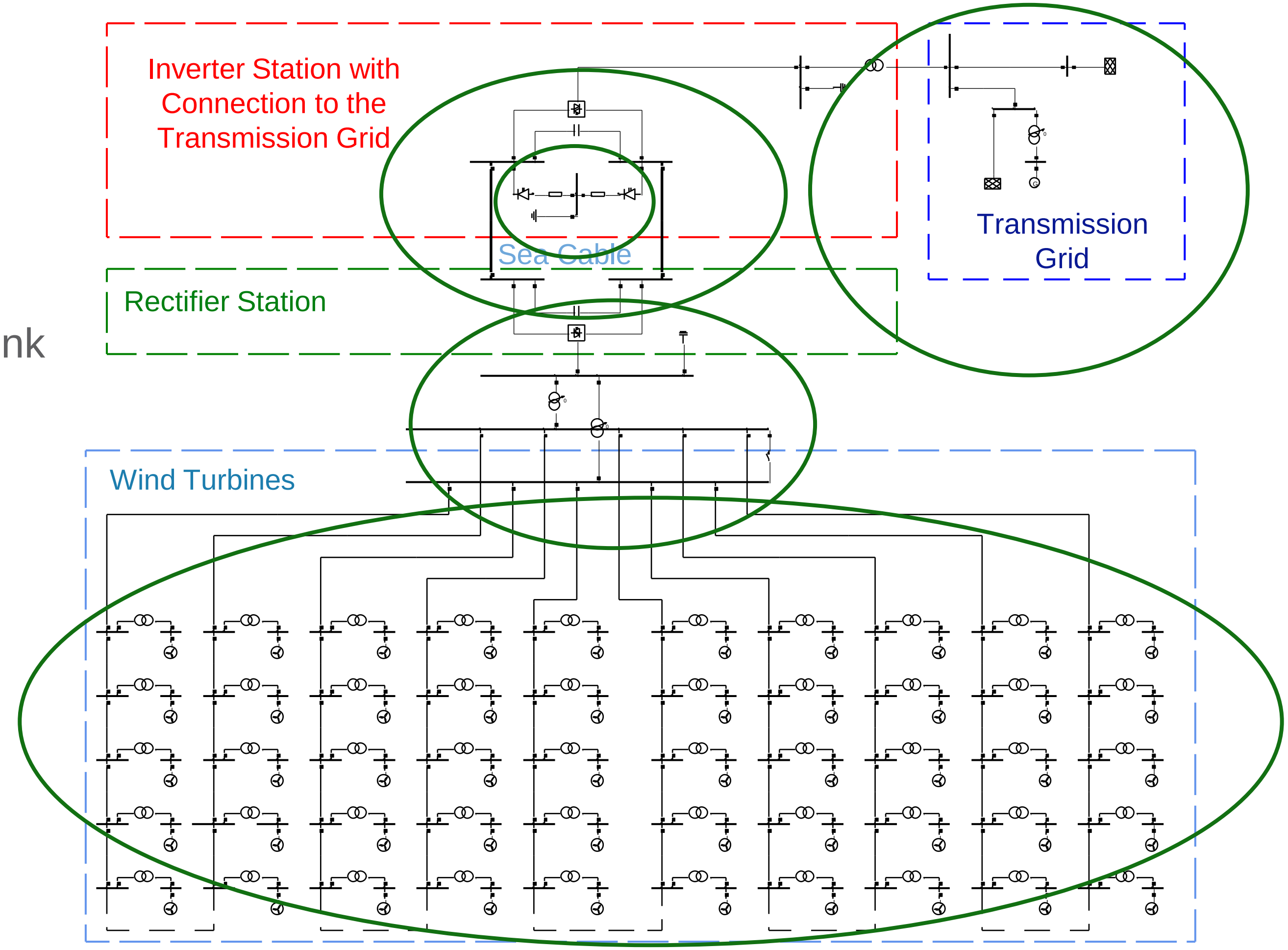


33/0.69 kV Transformer 6,7 MVA

Model of an Offshore wind farm

Overview of the model components

- Wind Turbines
- Internal grid and connection to the offshore converter
- DC-Transmission link
- Onshore converter
- AC and DC Filter systems
- Chopper
- Connection to the onshore grid, Representation by the first periphery



Model of an Offshore wind farm

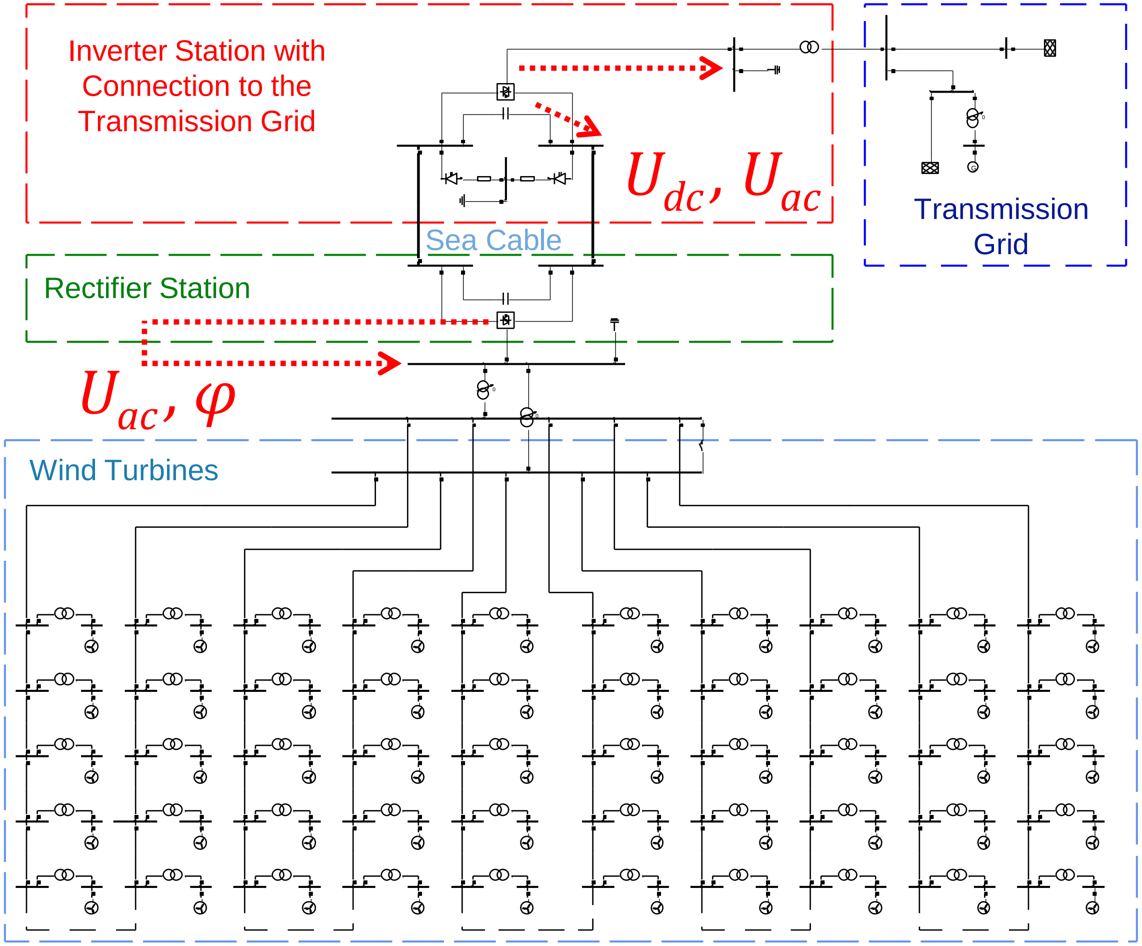
VSC-HVDC Control Scheme

Wind Farm: Weak Grid

- Rectifier controls voltage amplitude and phase
- Rectifier works as reference machine

Onshore Grid

- Inverter controls V_{DC} and V_{AC} /Q
- Control of V_{DC} and V_{AC} independently



Model of an Offshore wind farm

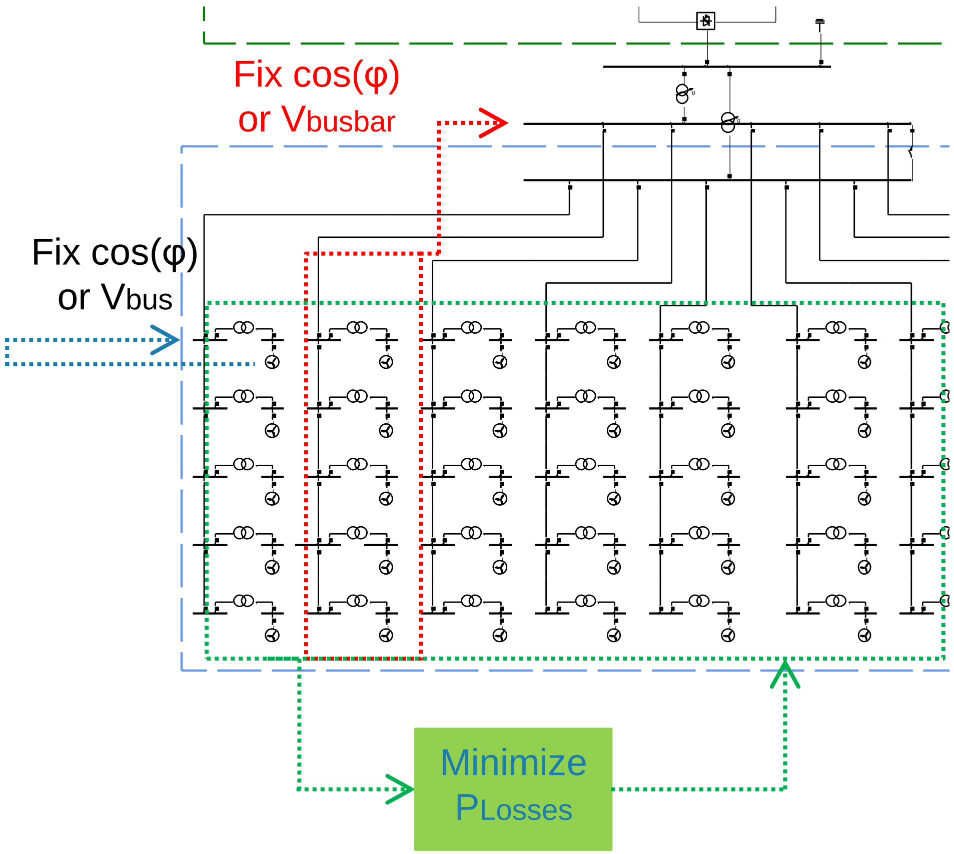
Reactive Power Control

Realised Reactive Power Controls:

- Fix voltage or power factor control by every WEU at local bus

(A power factor of cos(φ)=1 leads to an infeed of Q=0 MVAr at the 33kV Bus)

- Fix voltage or power factor control by every row at the Central Wind Farm Busbar
- Reactive Power Supply depending on the Active Power Operation Point of every WEU to minimize internal Wind Farm losses



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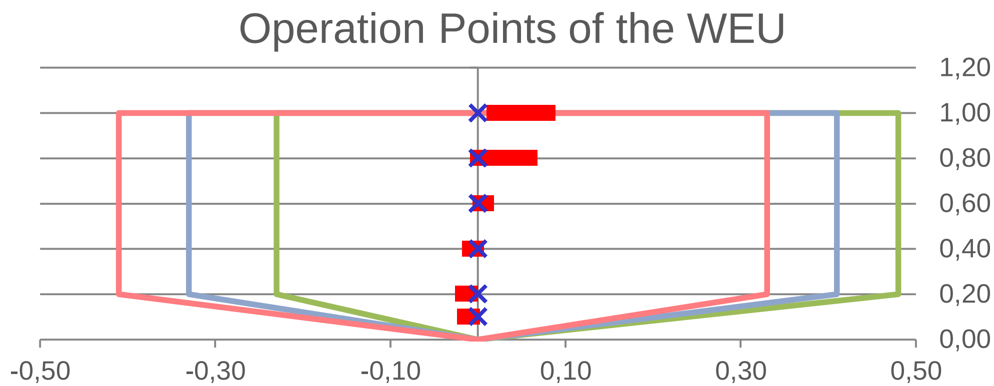
Stationary Analysis

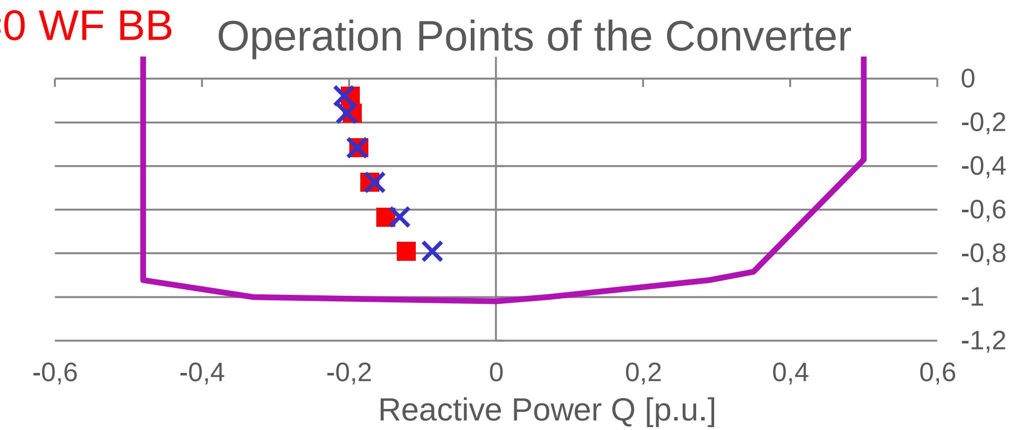
Selected control schemes

- Different control schemes disencumber the converter or the WEU electively
- Due to the VSC-HVDC the wind farm is totally decoupled from the Onshore grid regarding Reactive Power demand
- No impacts of voltage or load variations on the Wind Farm, contrary to the operation in Ohnshore grid, occur



1) x Q=0 LB

2) ■ Q=0 WF BB

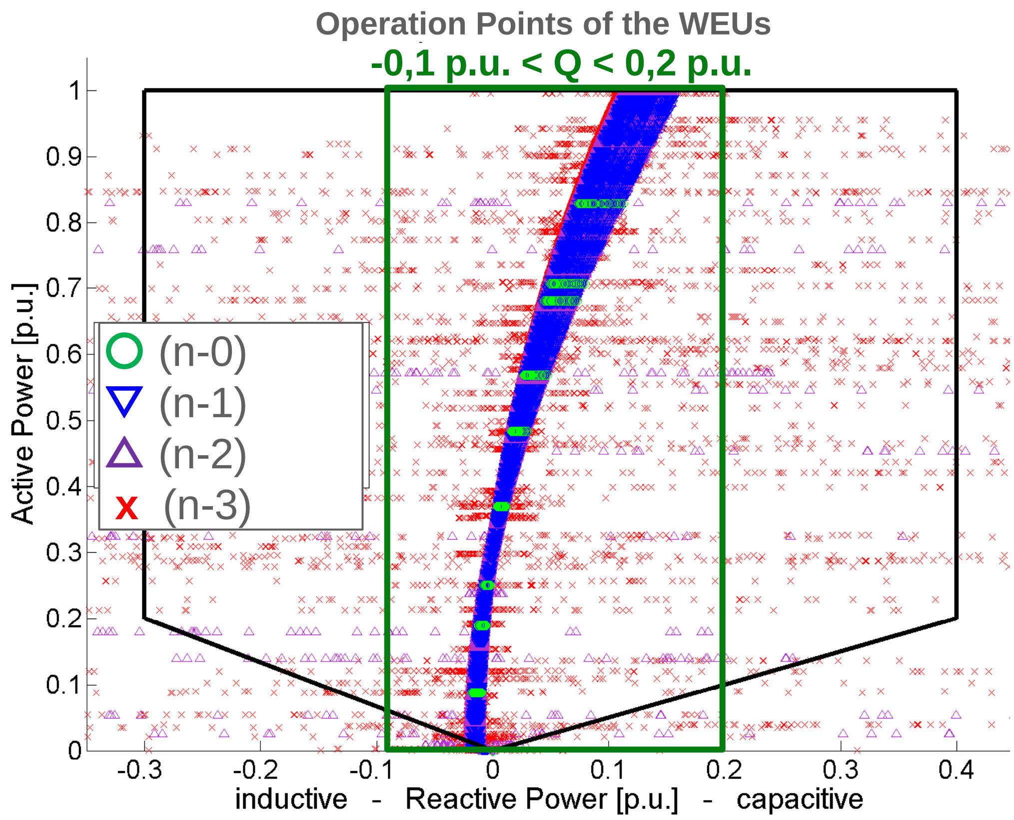


Stationary Analysis

Optimal Operation Points

- Dispersion of the given Active Power infeed P inside between the units ±5%
- Optimal power flow for minimum Losses in the Offshore wind farm
- Investigation for (n-0) as well as for any possible combination of 1-3 Wind Energy Units outages
- More than 99% of all constellations are within a range of -0,1 p.u. to 0,2 p.u.

➔ Possible downsized minimum reactive power supply range?

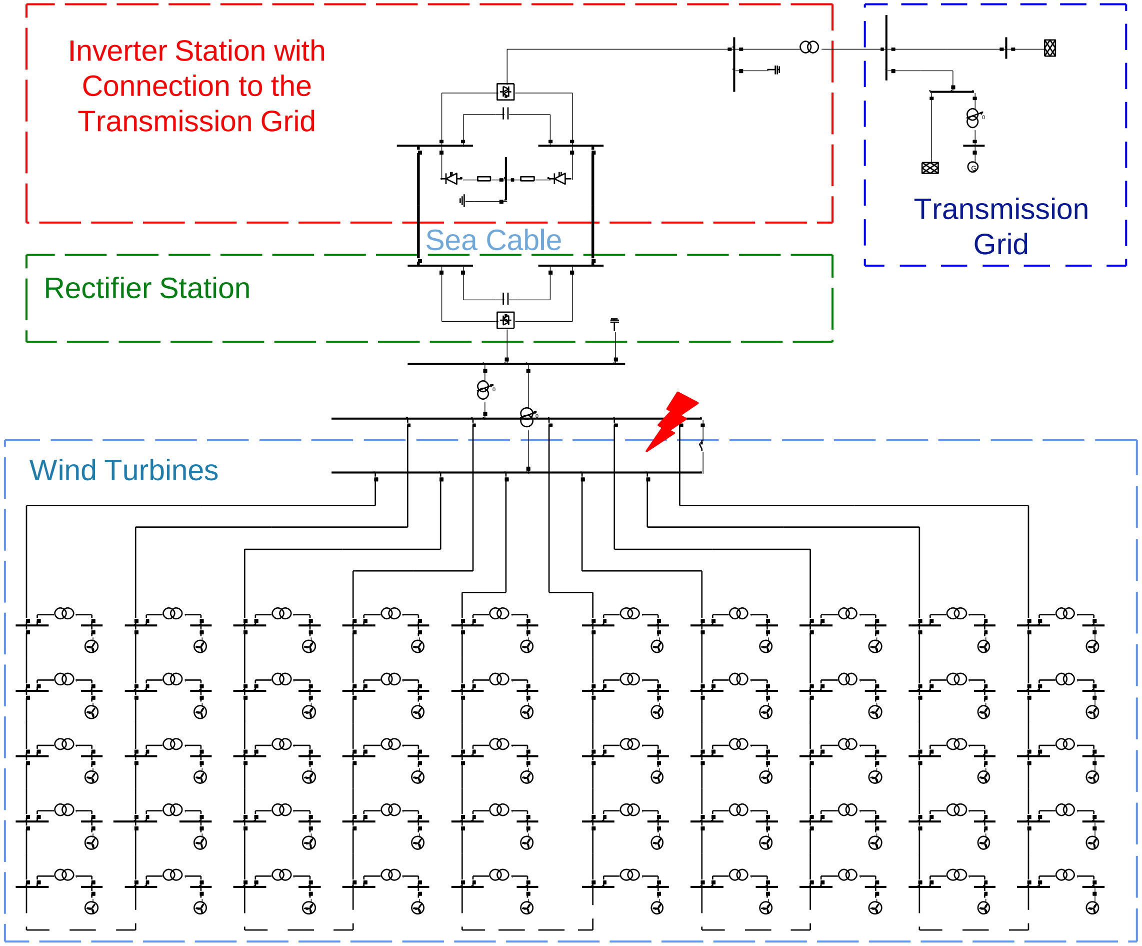


Content

Dynamic wind farm analysis

Fault in Offshore wind farm

- Fault at one Busbar in the wind farm
- Voltage drop to 40 % of nominal voltage
- Feed-in of short circuit current by converter and WEUs
- Fault clearing after 100 ms



Dynamic wind farm analysis

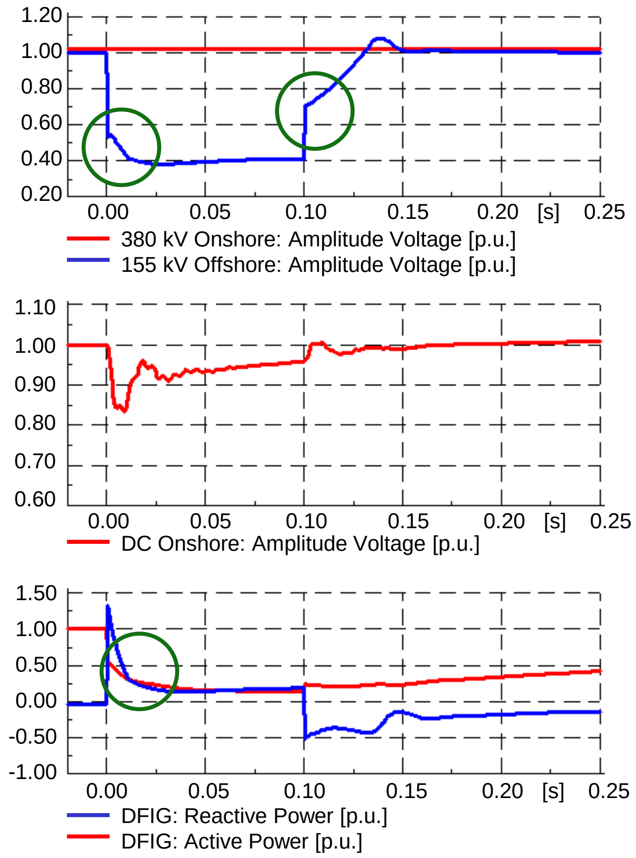
Offshore wind farm fault - Results

- Voltage drop to 40 % nominal voltage
- successful clearing after 100 ms
- Fast increase of the voltage with overshot
- Reactive current supply by the WEU according to the k-factor

➔ Voltage settling time almost independent of the previous OP (WEU)

➔ Still significant impact by the additional reactive current injection (k-factors)

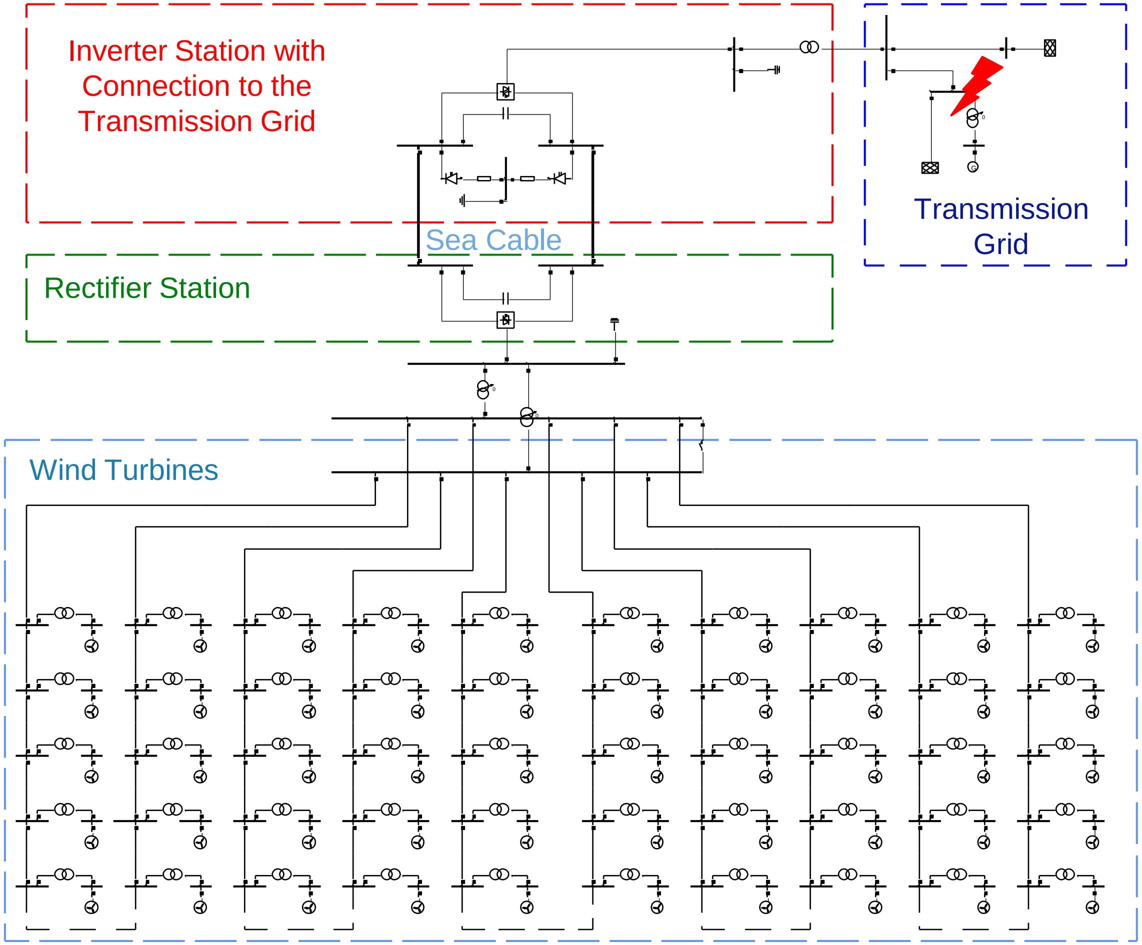
➔ Downsized DFIG current injektion has almost the same efficiency as a not downsized one



Dynamic wind farm analysis

Fault in Onshore-Grid

- Fault at a bus near to the Point of common coupling (PCC) at the Onshore Grid
- Voltage drop to 0% nominal voltage
- Feed-in of the short circuit current mainly by the Onshore Grid
- Fault clearing after 150 ms



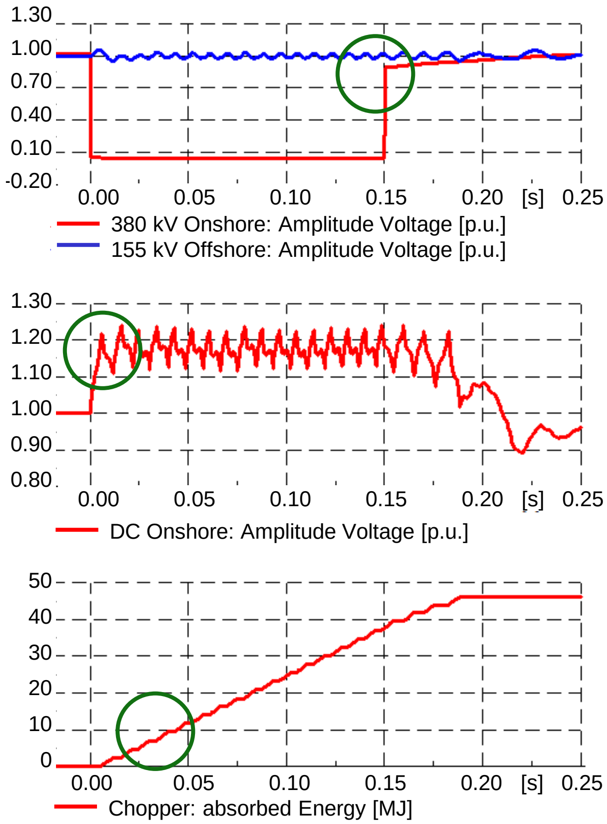
Dynamic wind farm analysis

Onshore Fault without impacts on the wind farm

- Voltage drop to 0 % at the Onshore Grid
- No more Active Power feed-in by the Inverter into the Onshore Grid
- DC voltages rises to threshold voltage
- Activation of the Chopper
- Ripple depends on chopper frequency and control, DC-capacitors and leak resistor
- Absorption of the surplus energy by the chopper of the HVDC-System
- Fault clearing after 150 ms

➔ No impact on the Wind Energy Units

➔ Absorption of the whole energy at the onshore station



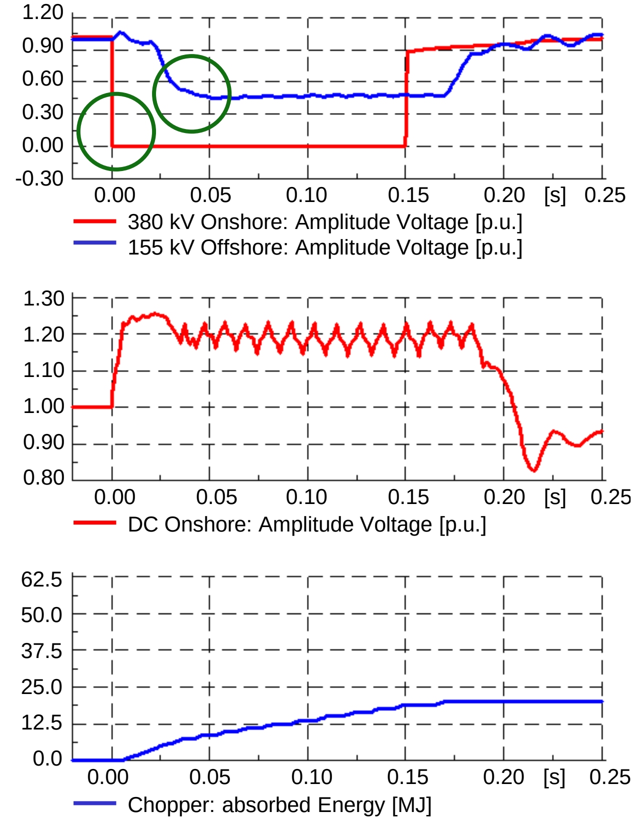
Dynamic wind farm analysis

Onshore Fault with „Fault Reflection“

- Voltage drop to 0 % at the Onshore Grid
- Controlled voltage drop at the offshore-side to 50 % nominal voltage with delay
- Reduced Active power feed-in by the WEU
- Acceleration of the generators and activation of the Pitch-control
- Delayed Re-feed-in of the whole active power due to the offshore voltage return

➔ Mechanical stress for the Wind Energy Units

➔ More than 60 % less absorbed energy by the chopper of the HVDC-System



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Conclusion and Outlook

- Presentation of a representative Model of an Offshore Wind Farm
- Examples for the application of the Grid Codes to Offshore Wind Farms connected via VSC-HVDC
- Possible modification of existing Grid Codes towards a downsized steady-state reactive power supply range for offshore wind turbine generators
- Significant contribution of a additional reactive current supply by the Wind Turbines
- Undefined Grid Codes for Offshore Wind Farms connected via VSC-HVDC leads to open question for manufactures, investors and grid operators about the need of abilities of the Wind Energy Units and the handling with faults (“Fault Reflection”)
- Special Grid Codes have to define the respective contribution to System Services by Wind Farm Operators and Grid Operators (Active power reduction)

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Thank You for Your Attention!