

Grid Forming Control of Renewable Generation Units for Ensuring Stable Operation of Converter Dominated Power Systems

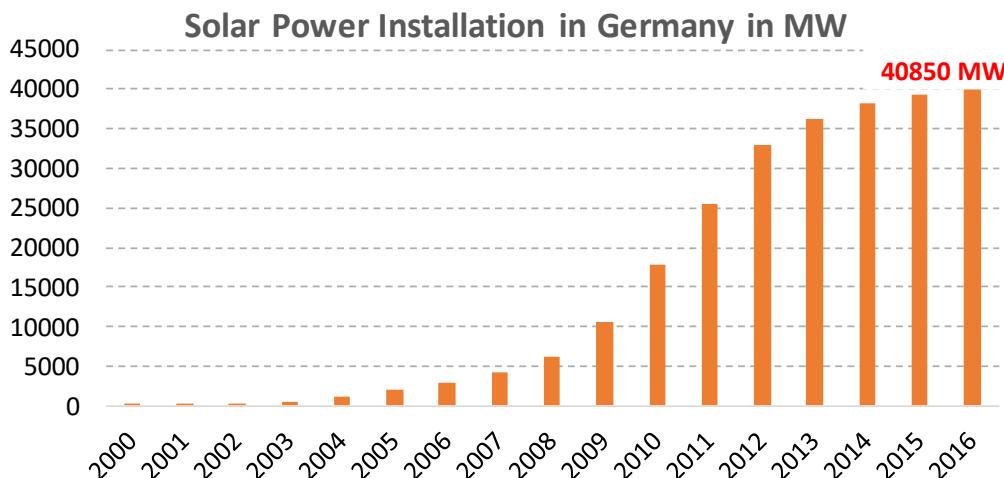
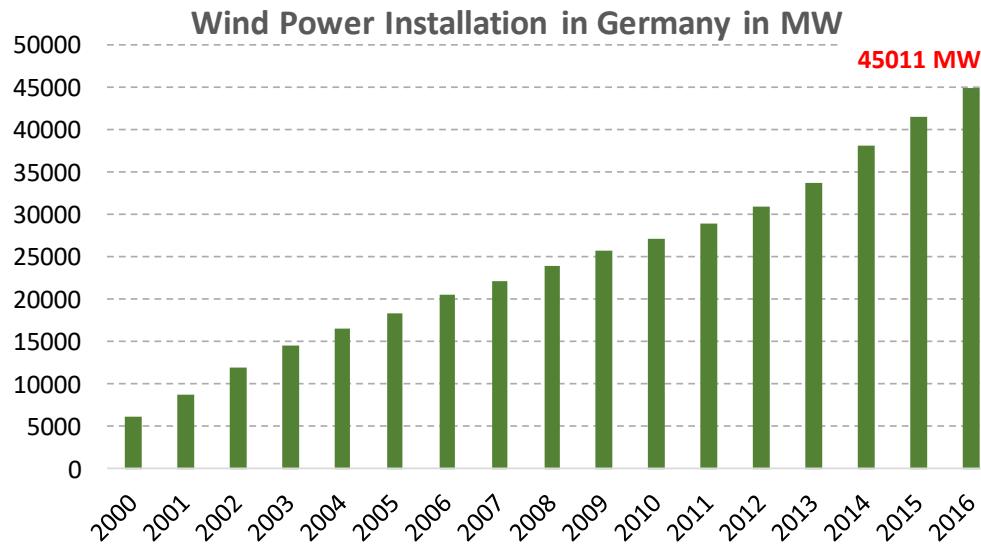
Delft, April 2018

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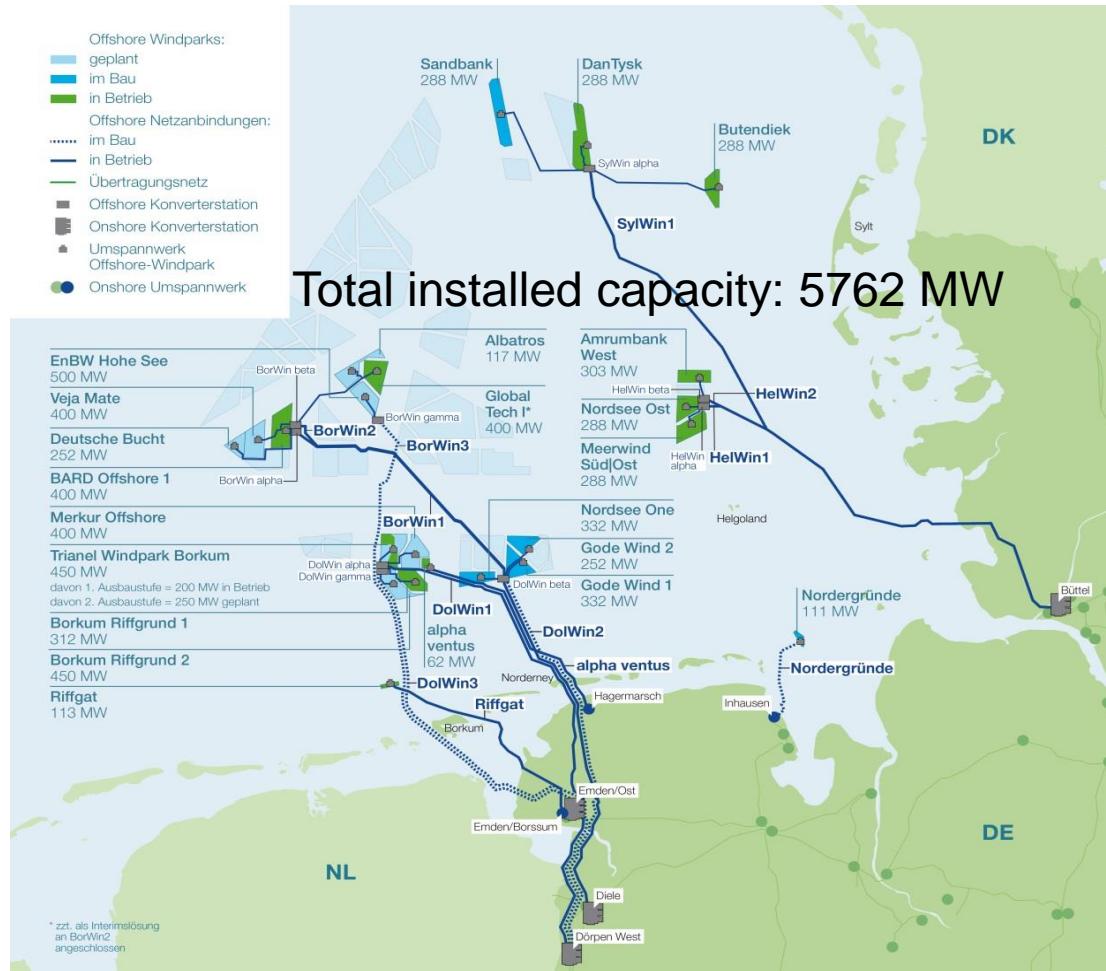
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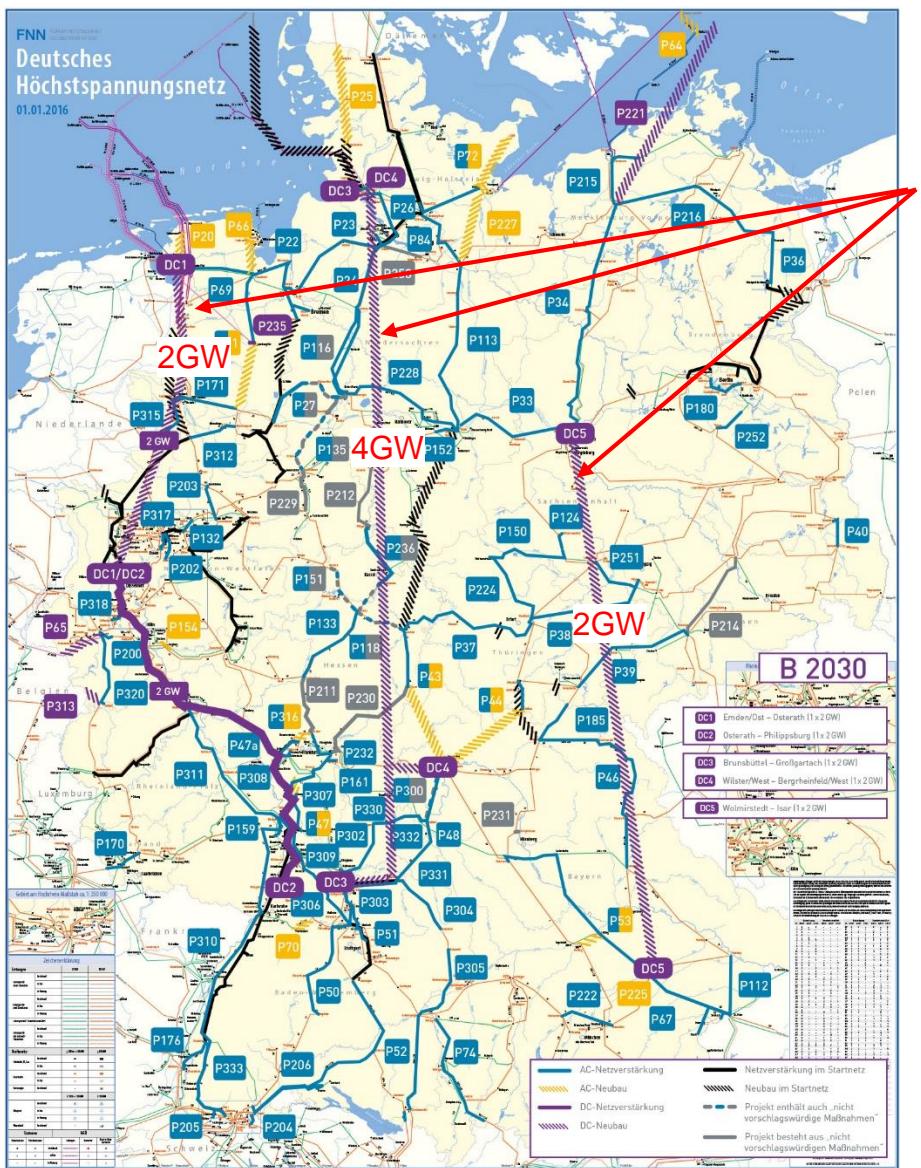
- Overview about converter application in Germany
- The Grid Separation Problem
- Var-Voltage Control
- The Current Injection Problem
- The Harmonic Stability Problem
- How much conventional generation is needed?
- Conclusions

Wind and Solar Power in Germany



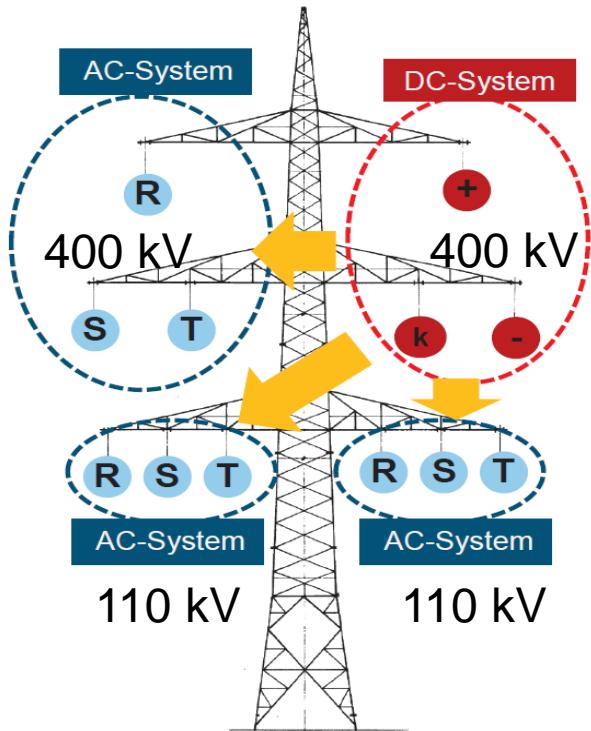
Offshore Wind Farms Projects of the TenneT TSO





Onshore point-to-point VSC HVDC Links

Hybrid AC-DC overhead line



Prospect

- As long as Germany is connected to the European transmission grid, the situation seems to be manageable
- The main concerns currently are overloaded lines and transformers forcing the operator to redispatch generation → high costs
- The new transmission links to be built in the future will use HVDC and underground cables (400 kV) → new technical challenges

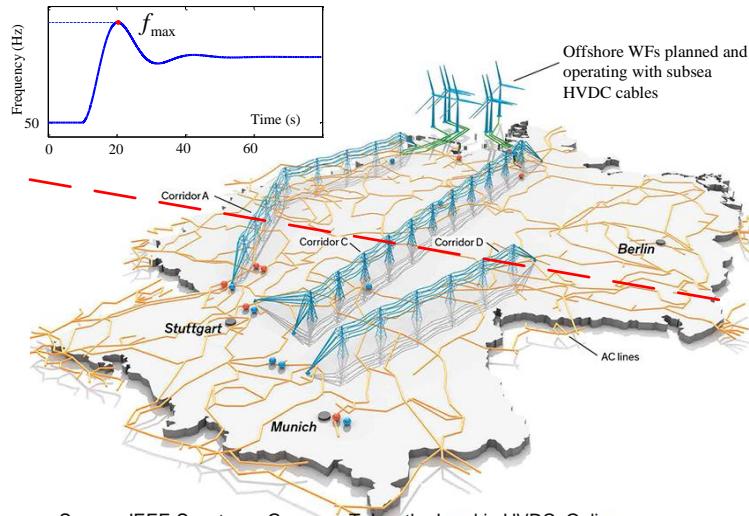
What we need in the Future

Change the philosophy from grid conform behavior to

„Grid forming Behavior“

- Direct voltage control like synchronous machines are doing (no voltage dead band, no definition thru reactive current injection)
- Participation in grid frequency control
- Damping of oscillations (frequency range 0.1 – 500 Hz)
- No mutual excitation of converter controllers (Harmonic Stability)
- Contribution to grid restoration
-

The Grid Separation Problem



Source: IEEE Spectrum: Germany Takes the Lead in HVDC. Online:
<http://spectrum.ieee.org/energy/renewables/germany-takes-the-lead-in-hvdc>

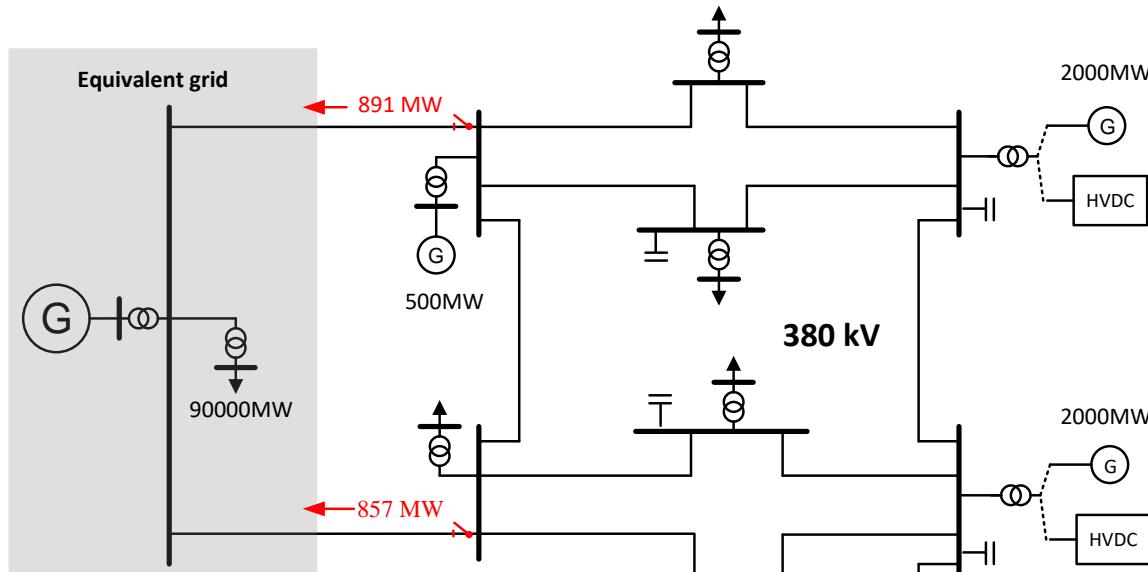
Will the North island grid survive?

- Considerable surplus of power generation
- No or little inertia
- No frequency control by converter
- No effective Var-Voltage control

Need for

- fast frequency control
- Participation of renewables in primary control
- Direct voltage control
- Stable operation of converter with small grid inertia

Test Grid for Frequency Control

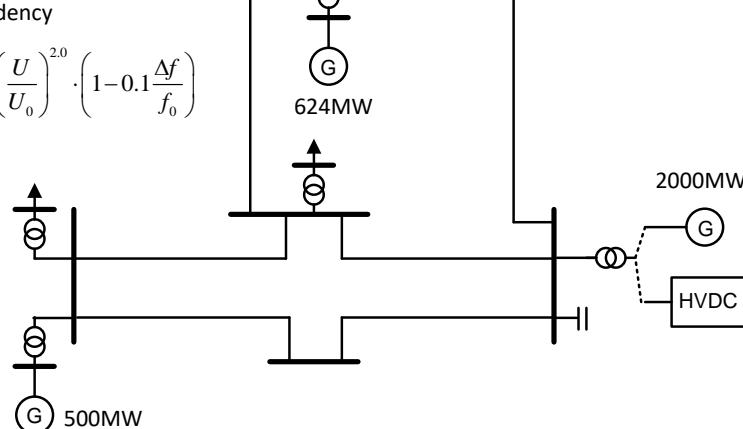


Load voltage and frequency dependency

$$P = P_0 \left(\frac{U}{U_0} \right)^{0.5} \cdot \left(1 + 0.7 \frac{\Delta f}{f_0} \right) \quad Q = Q_0 \left(\frac{U}{U_0} \right)^{2.0} \cdot \left(1 - 0.1 \frac{\Delta f}{f_0} \right)$$

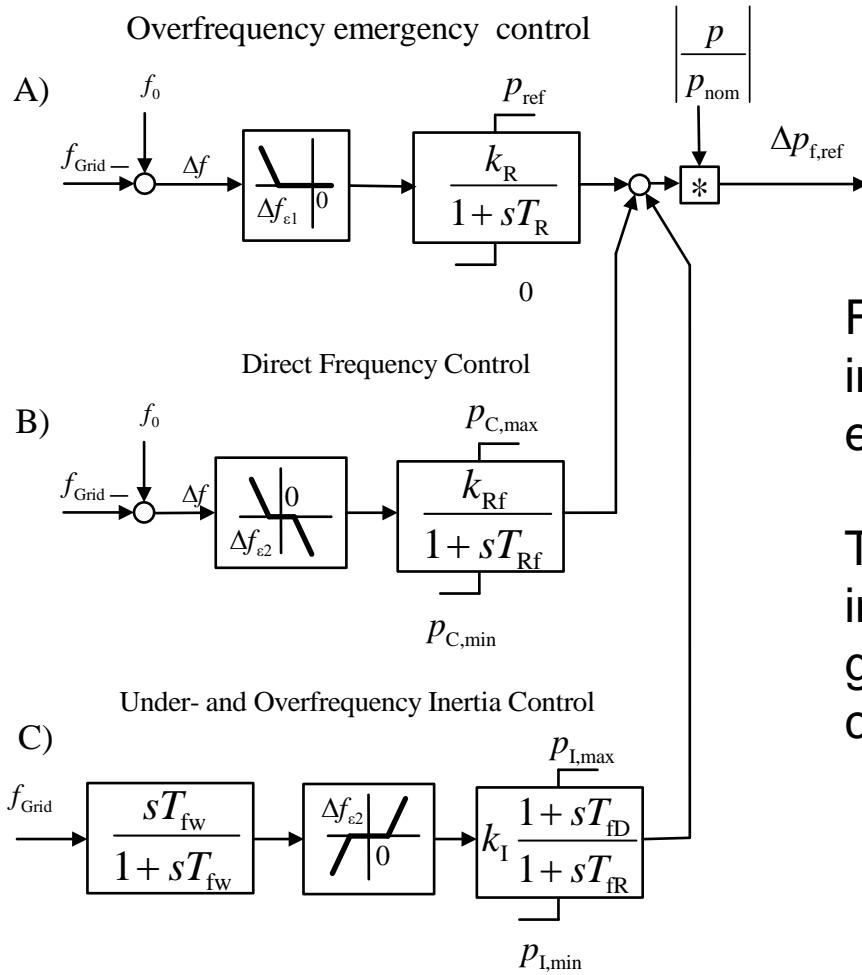
SG units without primary control

Loads: 950 MW each
 Generation total: 7624 MW
 Generation SG: 1624 MW
 Generation HVDC: 6000 MW
 Consumption total: 5700 MW
 Surplus of generation: 1924 MW (25%)
 Exchanged power: 1748 MW (23%)
 All 380 kV overhead lines are 80 km long



Options for Frequency Control

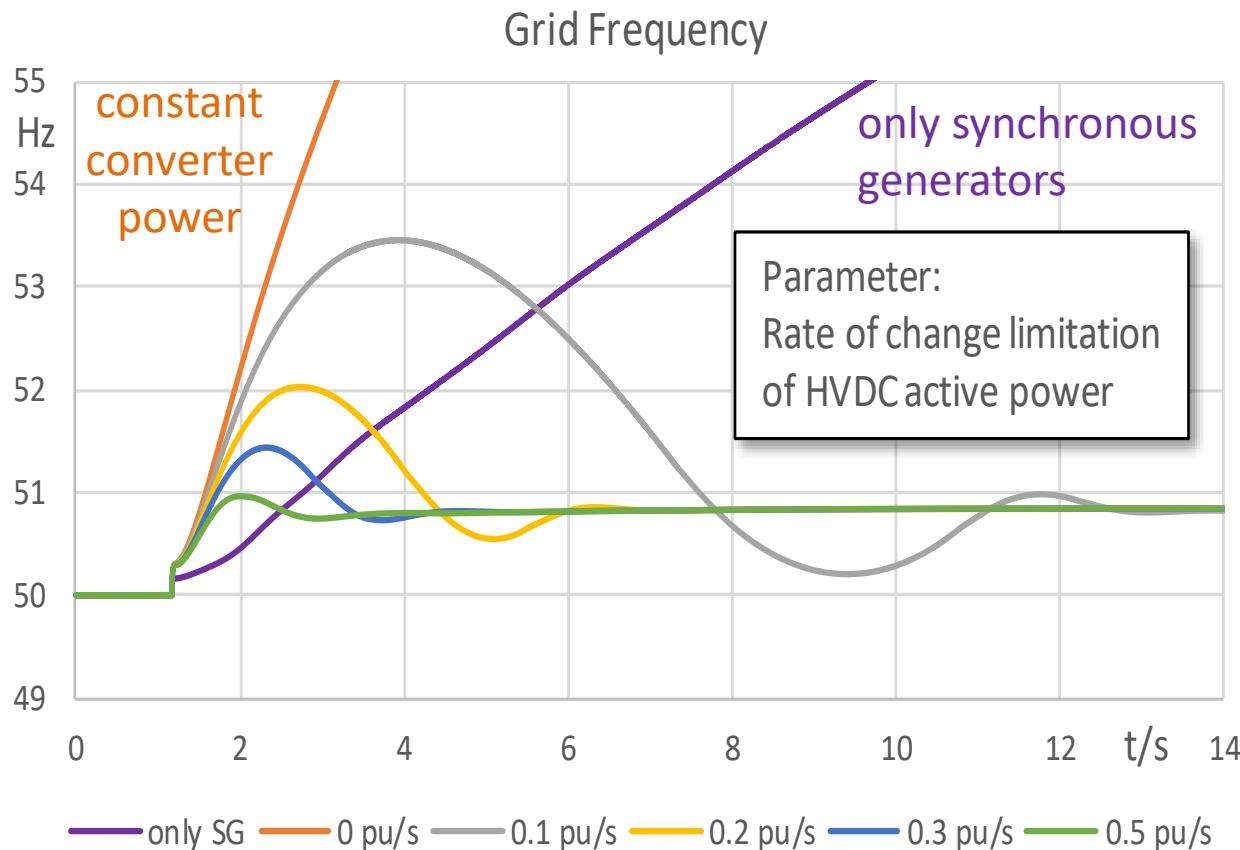
Different Options



Frequency control can be implemented in converter easily.

The challenge is rather to increase/decrease the generated power behind the converter.

Frequency Following Grid Separation



Rate of frequency change becomes approximately 5 times faster

The Var – Voltage Control Problem

Var-Voltage Control

Current Requirements
“voltage support”

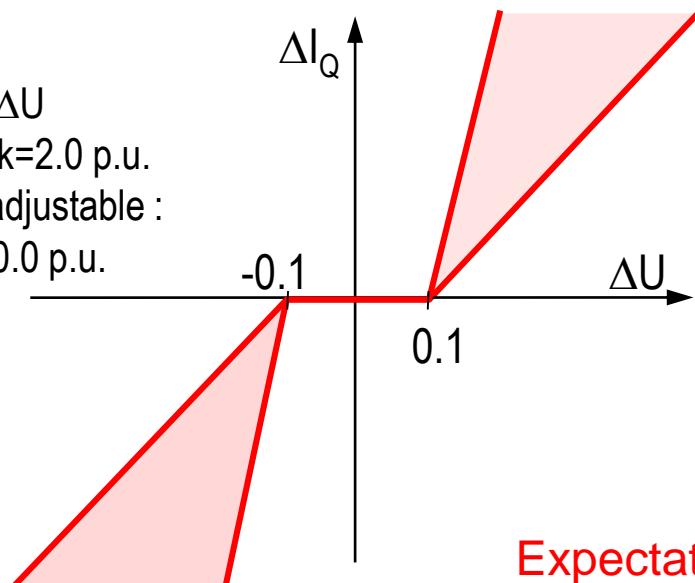
Gain:

$$k = \Delta I_Q / \Delta U$$

default: $k=2.0$ p.u.

Range adjustable :

$$k=0.0-10.0$$
 p.u.



According to current requirements converter do not contribute to voltage control under normal operating conditions.

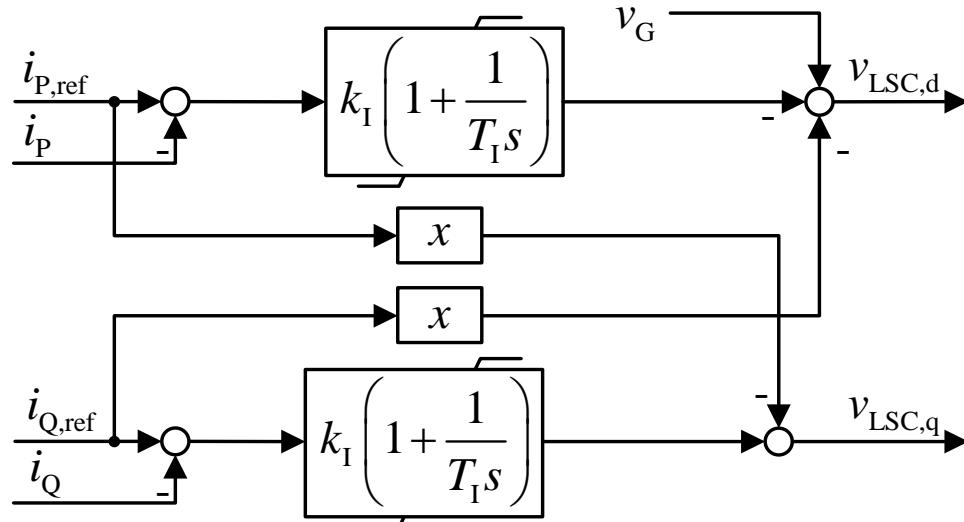
There are no clear differentiation between slow Var adaptation (control) and fast voltage control in the grid codes.

Expectation:

- Fast direct voltage control without dead band
- Slow Var adaptation

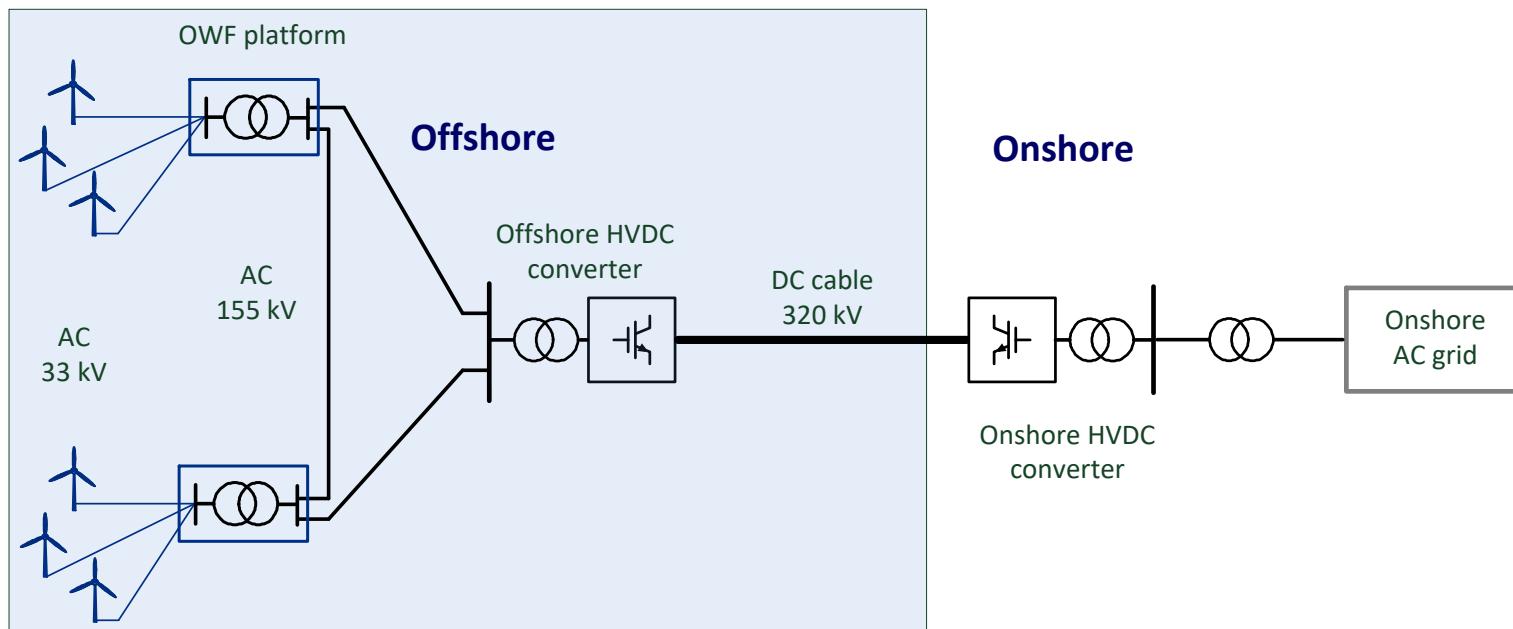
The Current Injection Problem

Current controller:
controller with PI characteristic



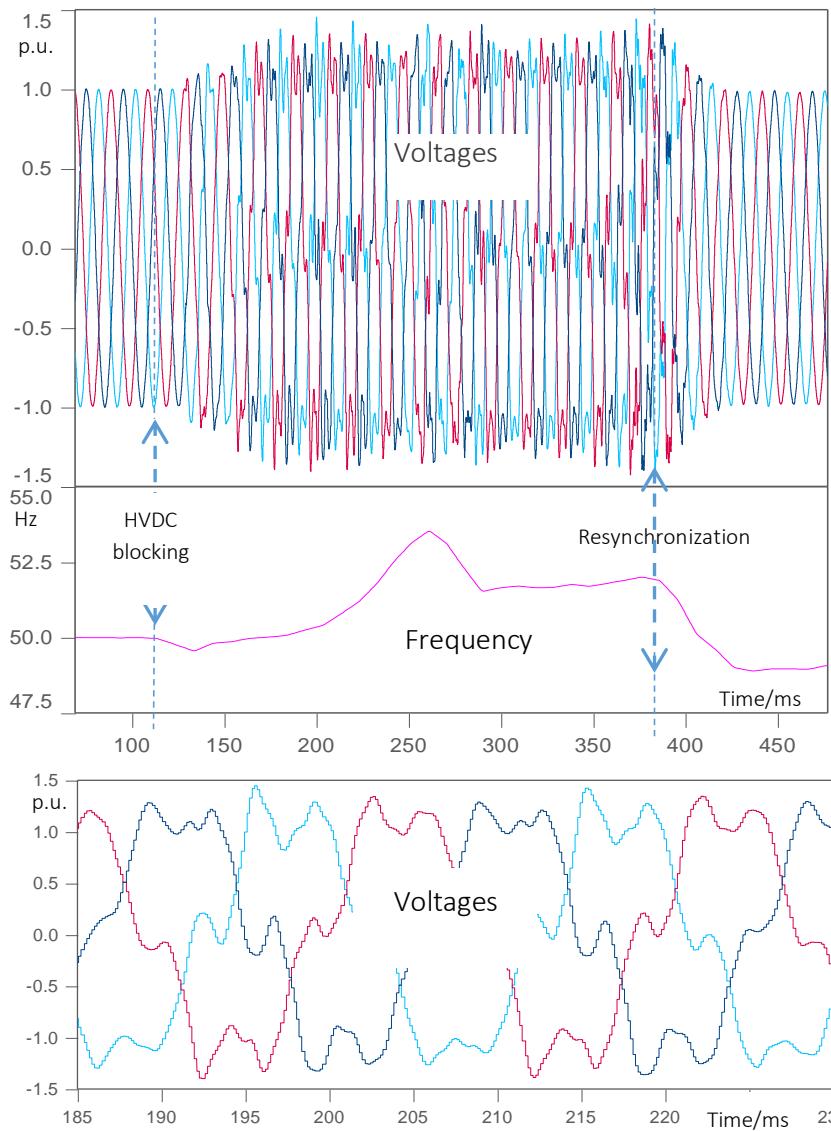
Injection of current without considering grid conditions, especially following islanding and during FRT will not work in grids dominated by converter.

Design of Offshore Grid and Power Transmission



Voltage Rise following Islanding in an Offshore Wind Farm

(measurement)



The voltage rises to ca. 1.3 pu (fundamental component) caused by the integral characteristic of the WT current controllers.

Transformer saturated resulting in transients

→ Voltage rise caused by the converter must be limited

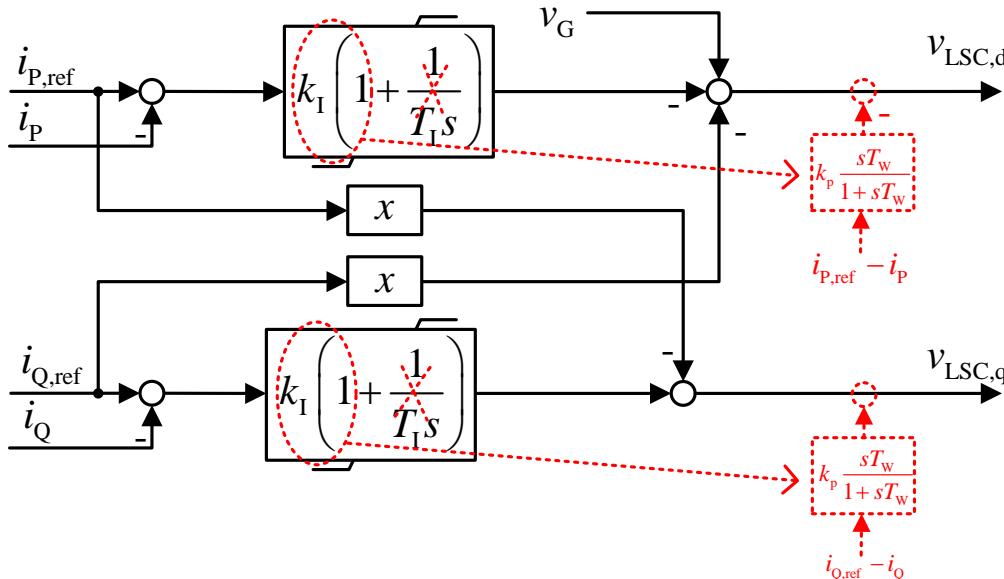
Current Injection Problem

A Simple Solution

Current controller:

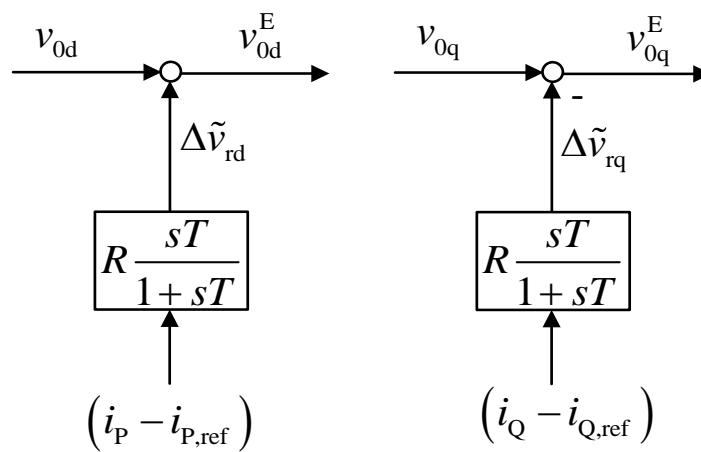
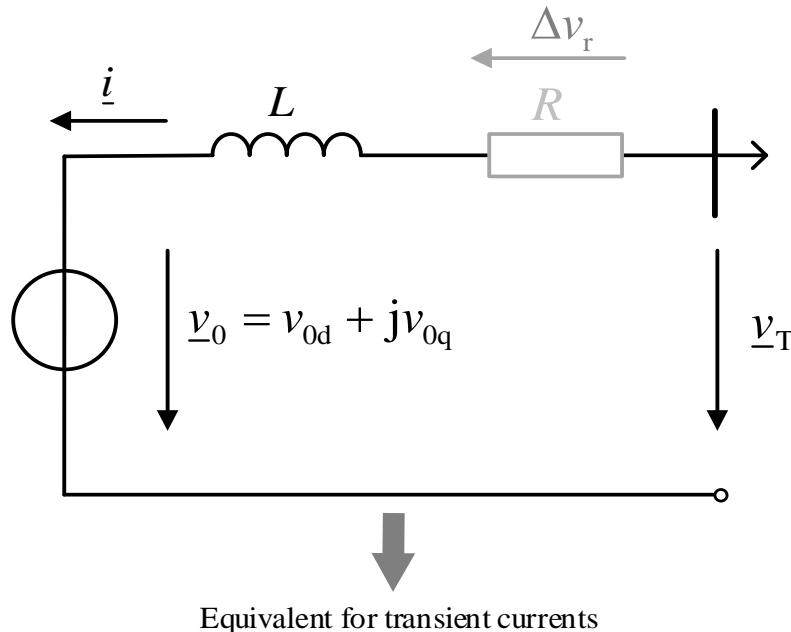
black: controller with PI characteristic

red: suggested modification



Removing the integral block in the current controller can solve the problem.

Emulation of Serial Resistance by Converter



The proportional gain in the classical PI control represents the emulation of the serial resistance
→ contribution to the damping

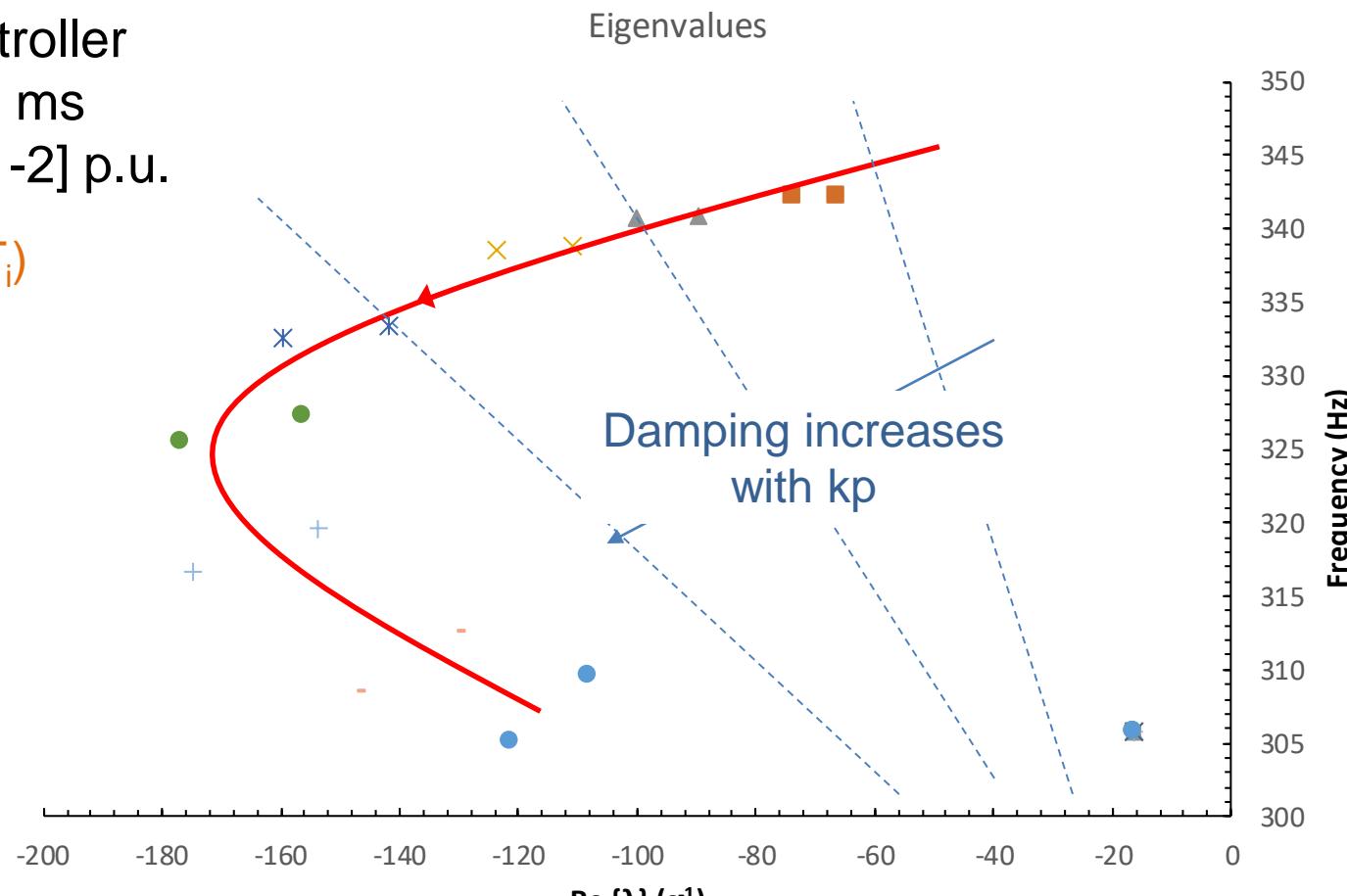
Effect of the Proportional Gain of the Current Controller on the Critical Eigenvalue

Current controller

$$T_i = 100 \text{ ms}$$

$$k_p = [0.1-2] \text{ p.u.}$$

$$(k_p + 1/sT_i)$$



■ $k_p = 0.1 \text{ p.u.}$
 ● $k_p = 0.7 \text{ p.u.}$

▲ $k_p = 0.2 \text{ p.u.}$
 + $k_p = 1 \text{ p.u.}$

✖ $k_p = 0.3 \text{ p.u.}$
 - $k_p = 1.5 \text{ p.u.}$

* $k_p = 0.5 \text{ p.u.}$
 ○ $k_p = 2 \text{ p.u.}$

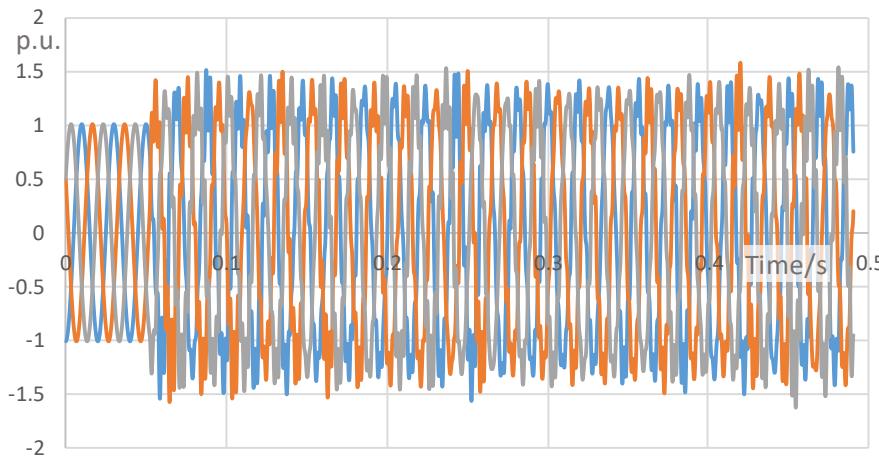
Comparison of Old and New Control

Response to sudden HVDC blocking

Max. Var supply by WT before (overexcited)

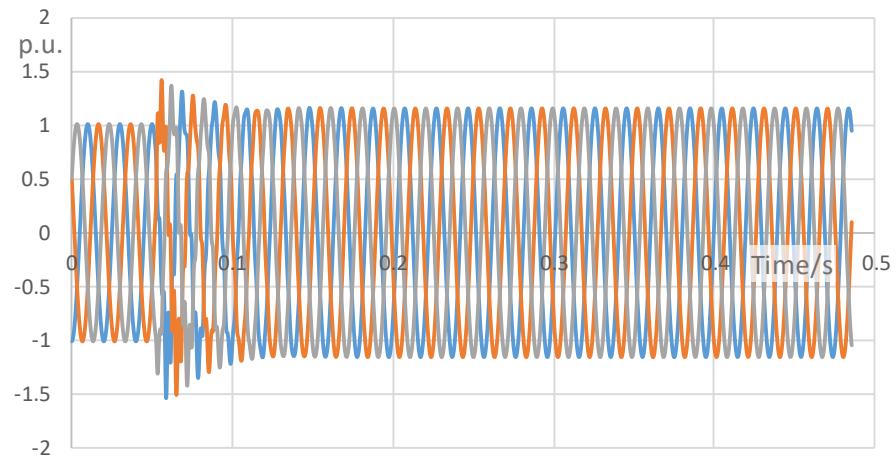
Old current control using two PI blocks

Voltage 155 kV, classical control



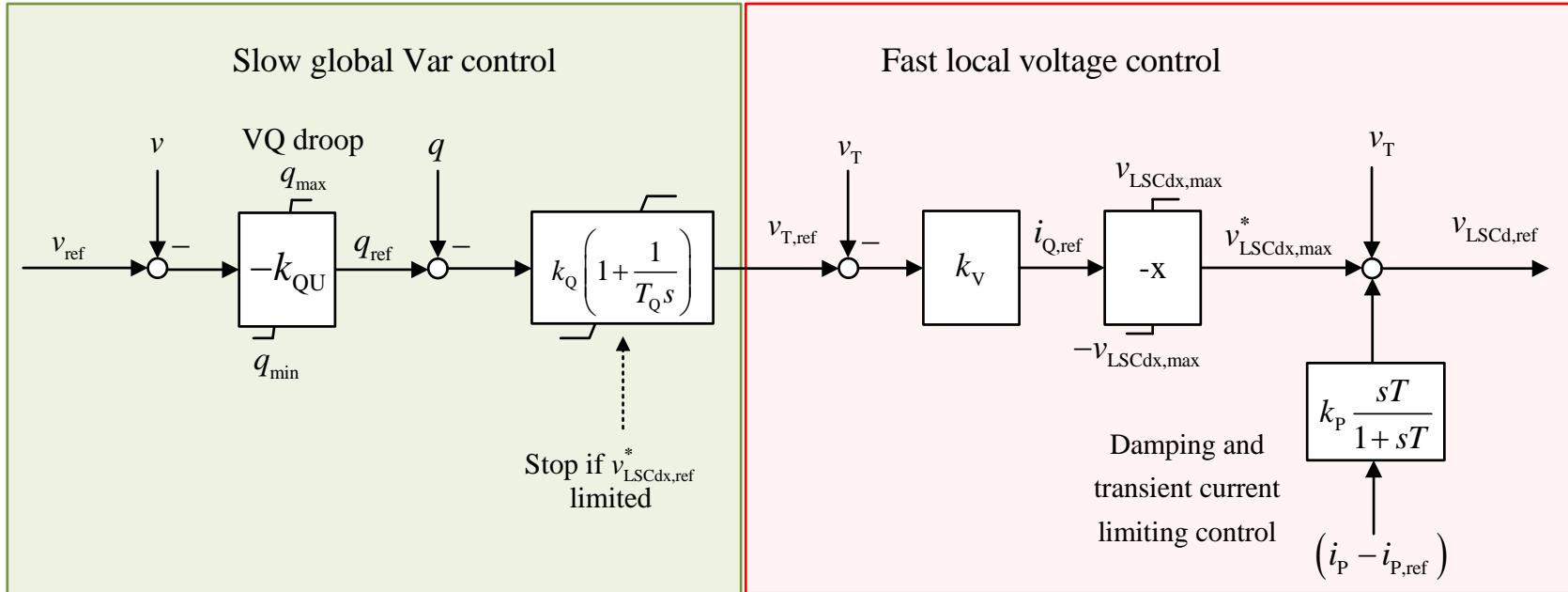
New controller without PI blocks

Voltage 155 kV, new control



Steady state voltage rise is limited to approx. 1.13 p.u.
by using the proposed new control schema

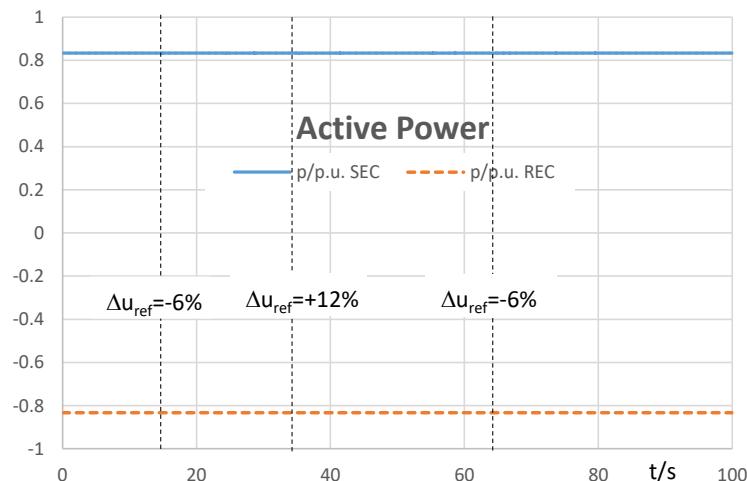
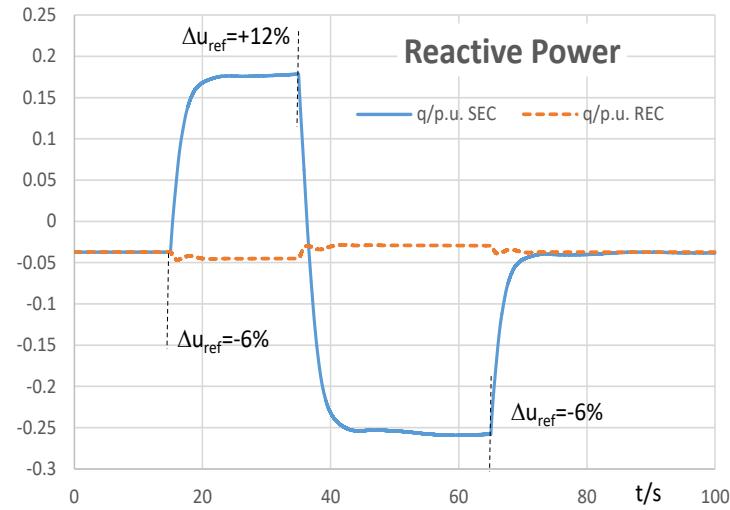
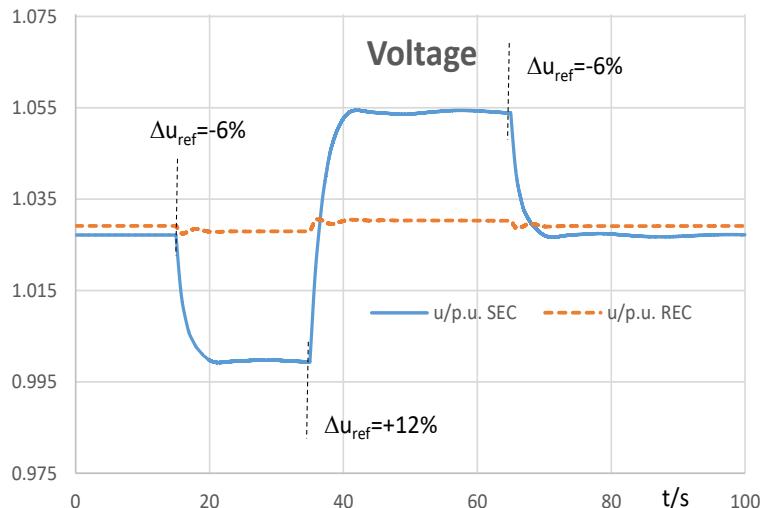
Hierarchical Var-Voltage Control



Consider: fast voltage control is not defined by reactive current injection!

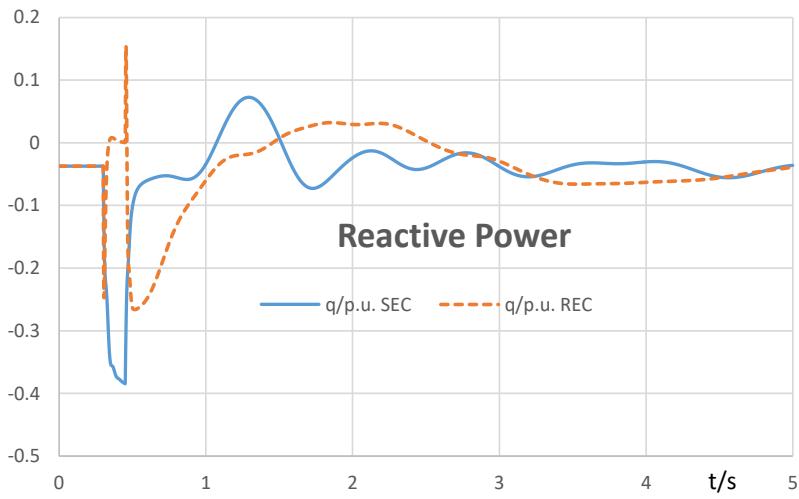
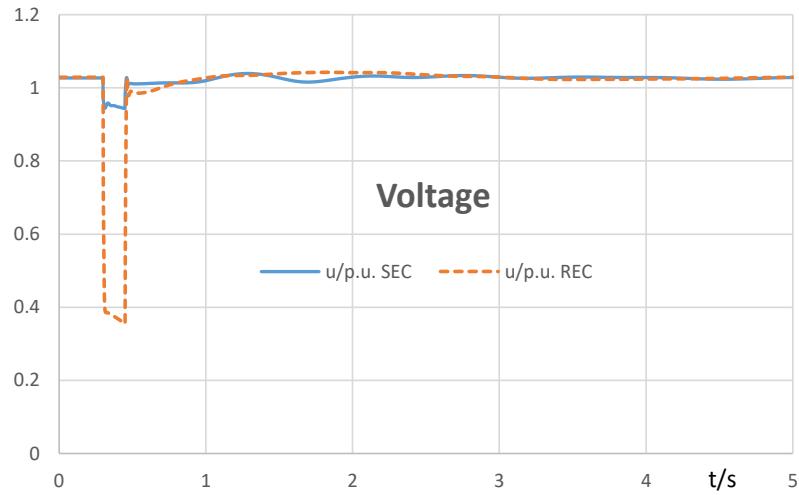
It corresponds with the classical voltage control implemented in almost all synchronous generators.

Reference Tracking Behavior

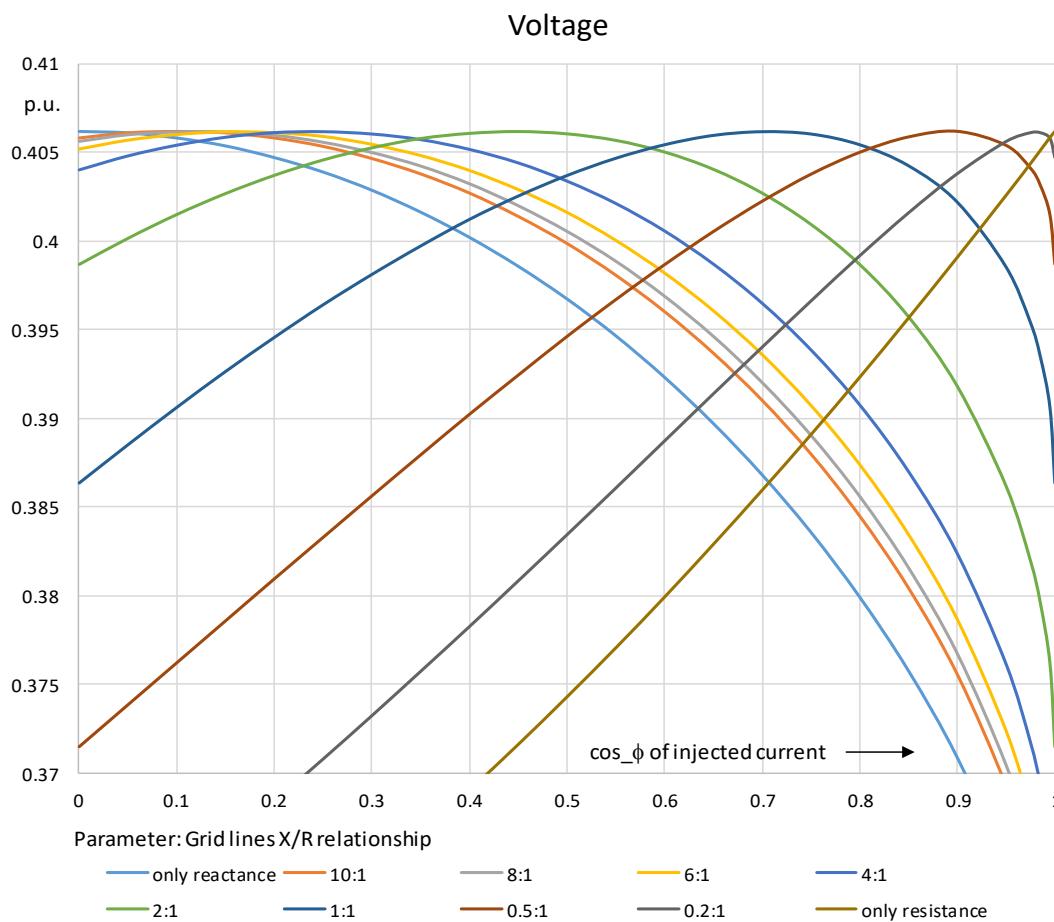


- set $\Delta u_{\text{ref}} = -6\%$ at approx. at $t = 15 \text{ s}$
- set $\Delta u_{\text{ref}} = +12\%$ at approx. at $t = 35 \text{ s}$
- set $\Delta u_{\text{ref}} = -6\%$ at approx. at $t = 65 \text{ s}$

Disturbance Behavior



Effect of the Current Injection on Voltage

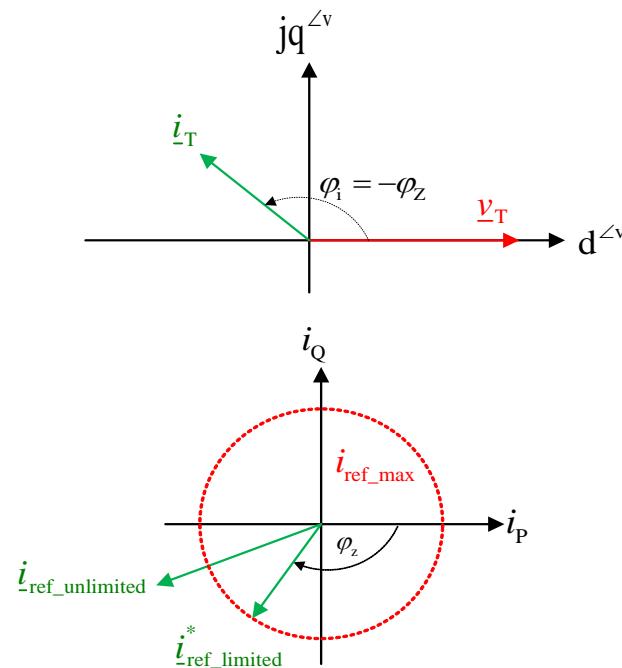
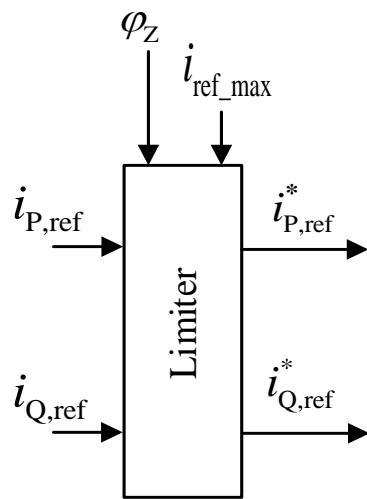


The best effect can be
achieve by injecting
current with phase angel
corresponding to the
phase angle of the grid
impedance

Current Limiting Control (1)

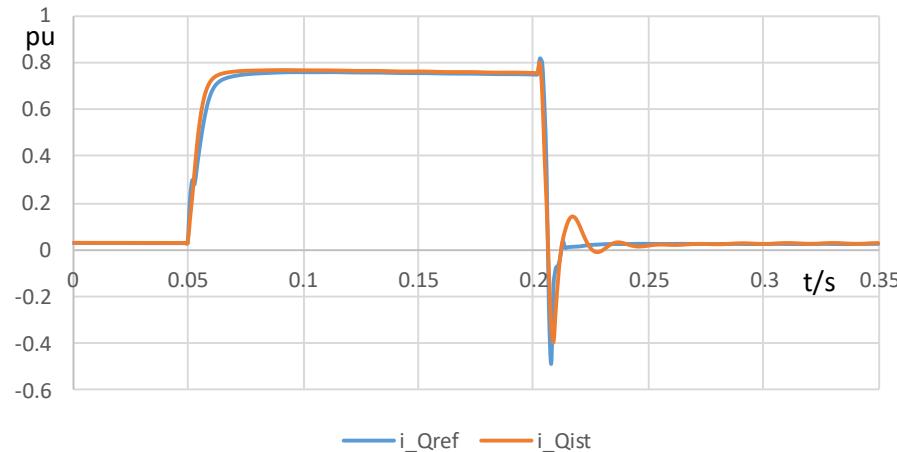
- 1) Limiting the max reference current
- 2) Phase angle of the reference current according to the phase angle of the grid impedance

$$\left(|i_d + j i_q| - i_{\text{ref_max}0} \right) > 0 \rightarrow i_{\text{ref_max}} = i_{\text{ref_max}0} - k_{\text{red}} \cdot \left(|i_d + j i_q| - i_{\text{ref_max}0} \right)$$

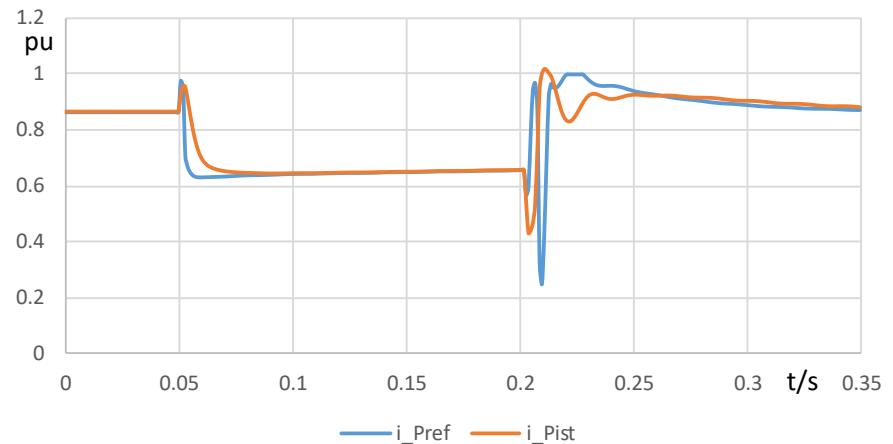


Current Limiting Control (2)

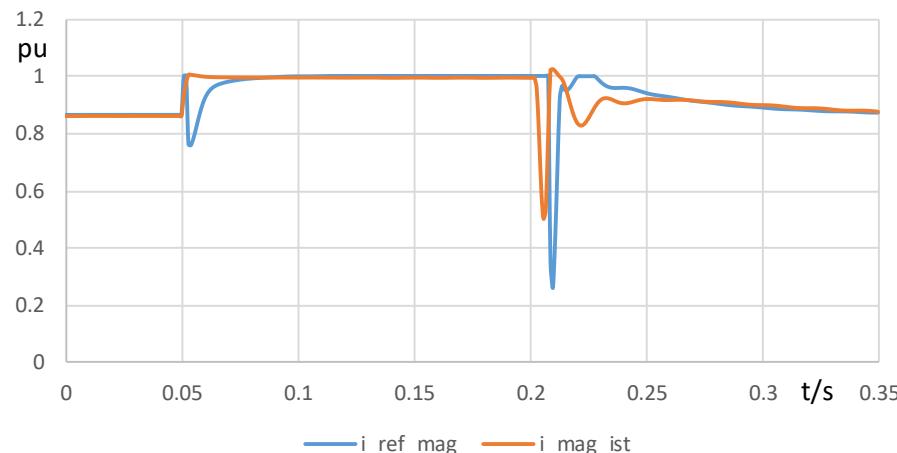
Reactive Current



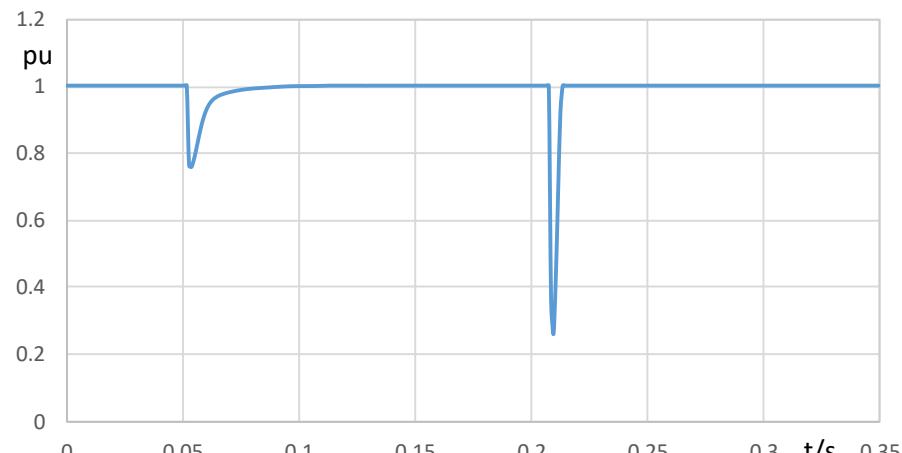
Active Current



Current Magnitude

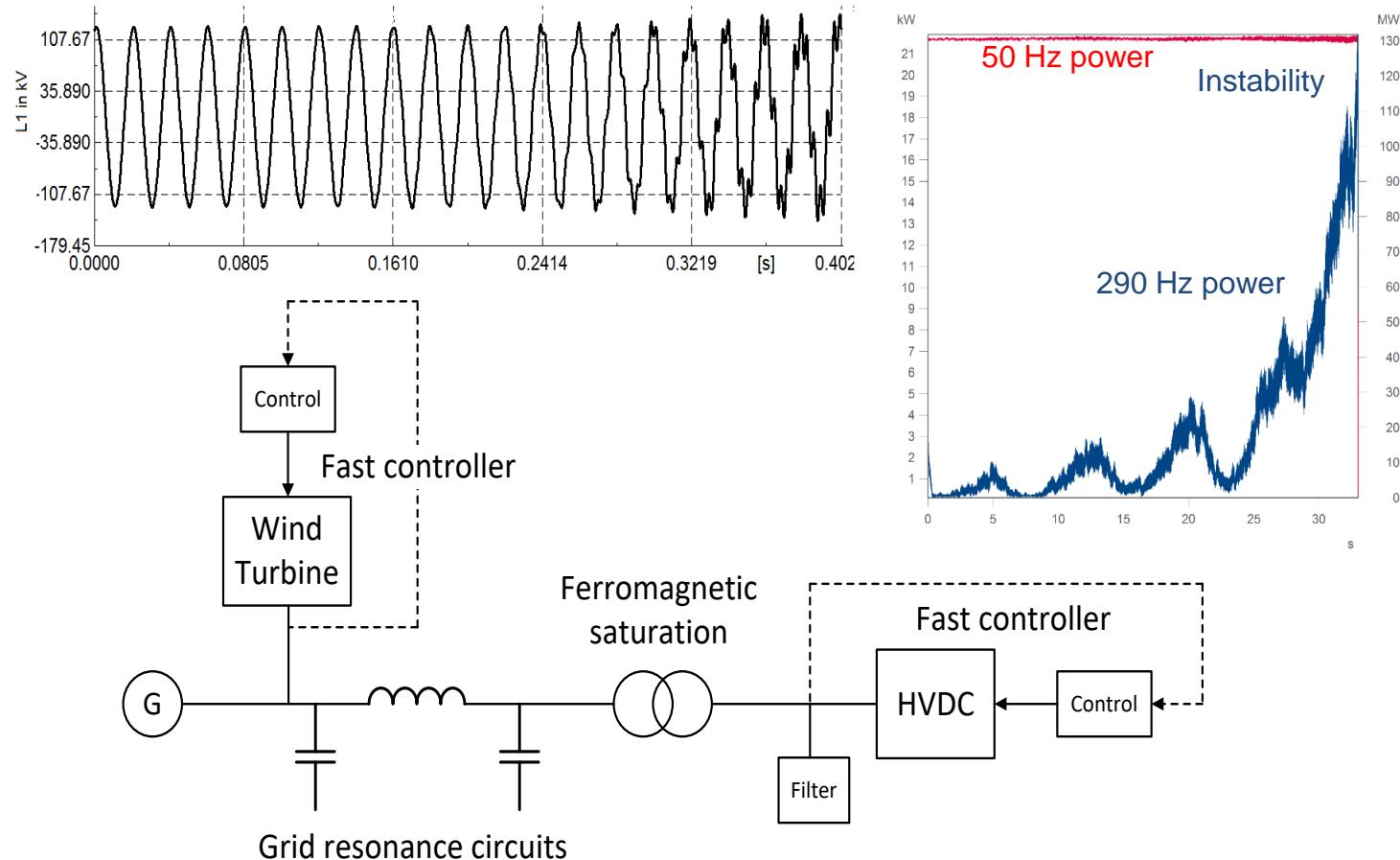


i_{ref_max}

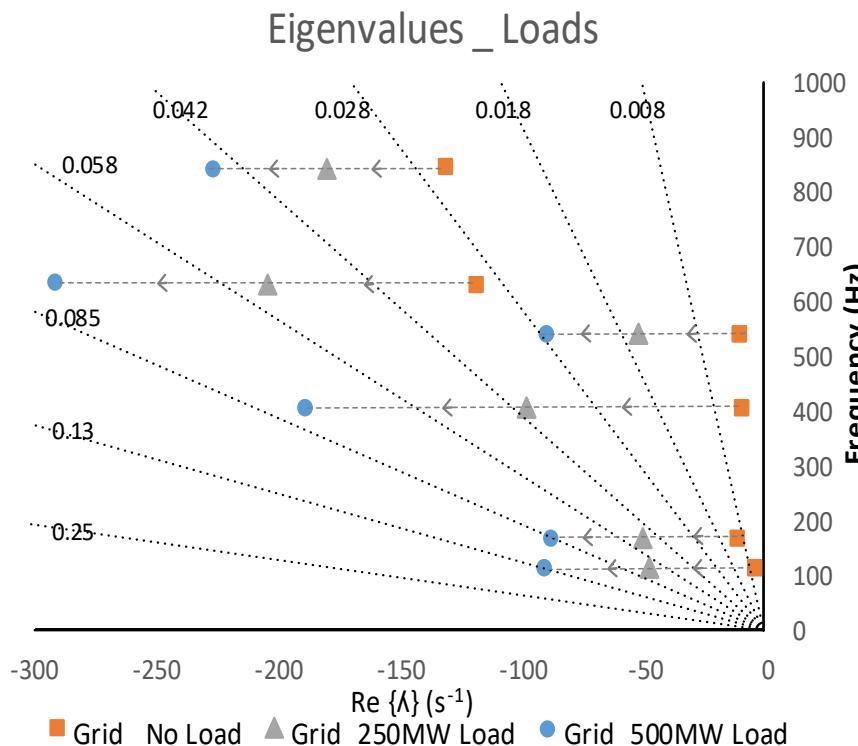
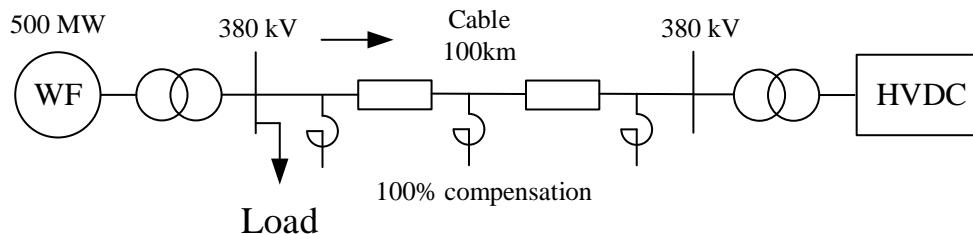


The Harmonic Stability Problem

Interaction of fast converter controllers among each other and with grid/filter resonance circuits.



Effect of Loads on Damping

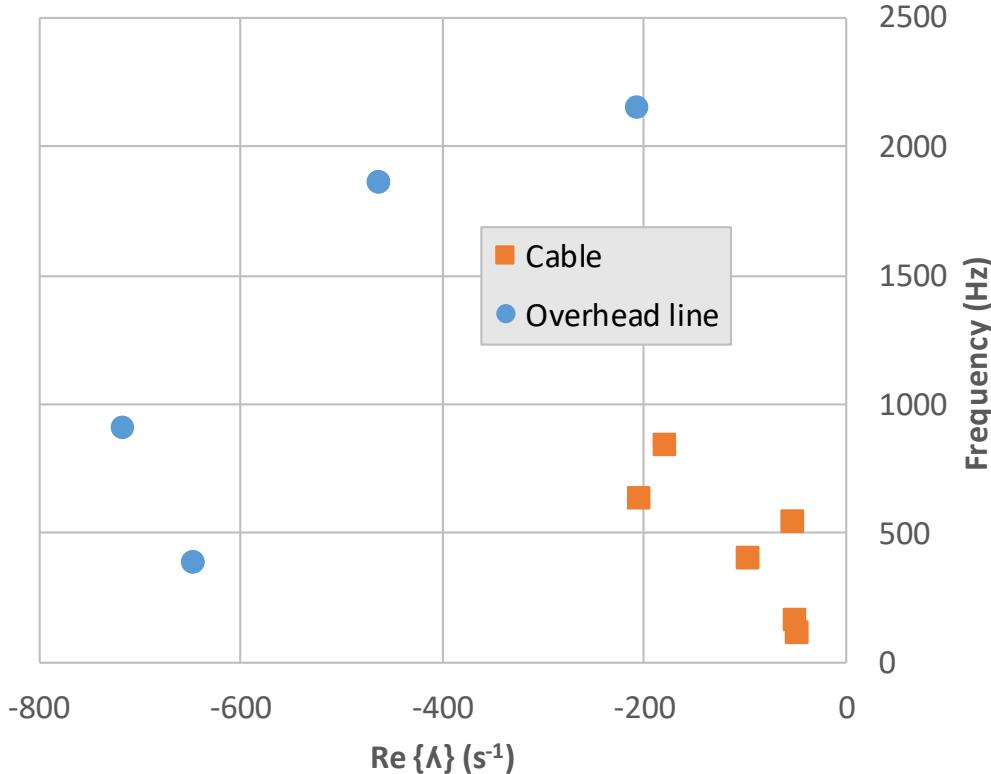


Loads contribute to better damping of resonances

Modal analysis represents a superior method for Harmonic Stability studies

Effect of Underground 400 kV Cables on Grid Resonance Frequencies

Grid - Eigenvalues - Cable/Overheadline



Cable grid resonance frequencies are in the range of the converter operating frequencies.

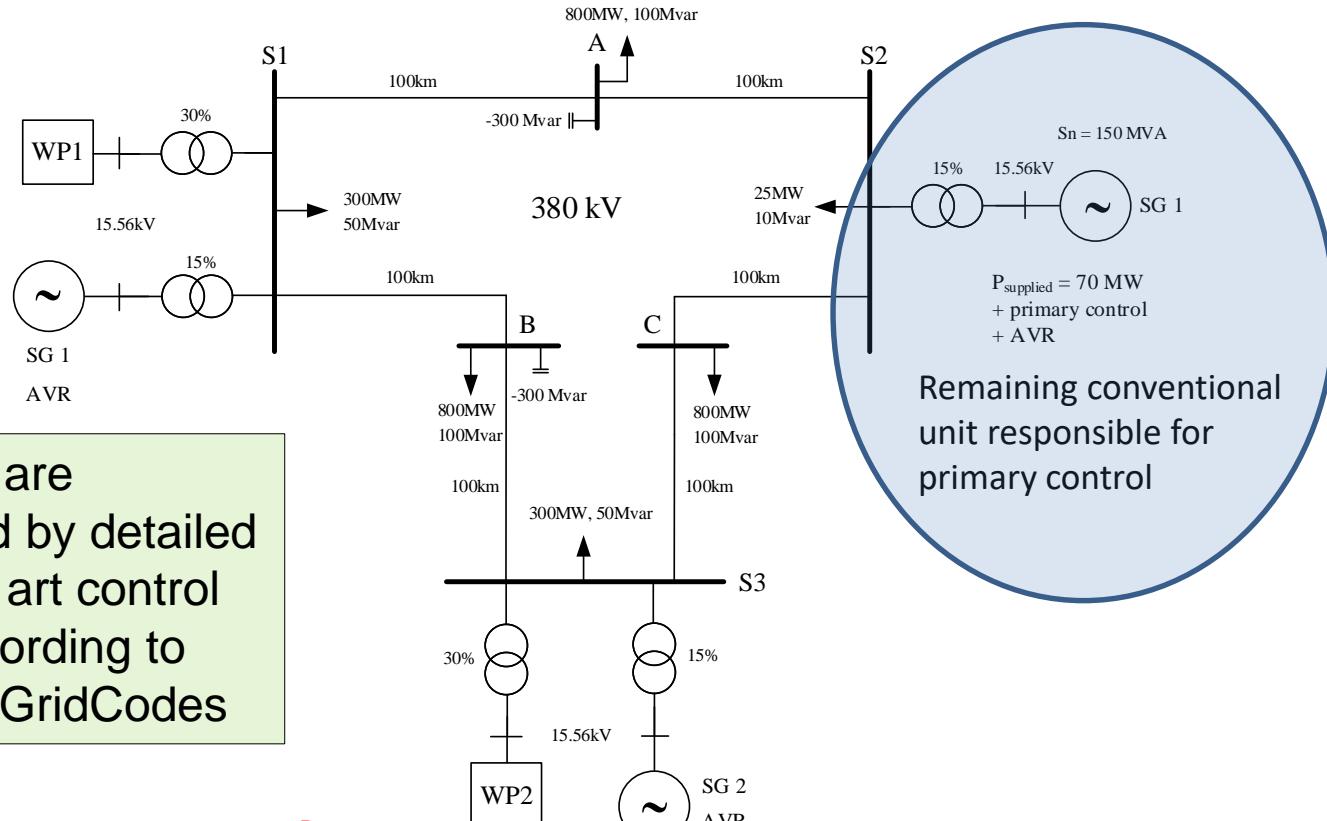
→ Risk for harmonic instability

→ Converter must be designed and tuned properly.

How many conventional generation units are needed for stable operation of converter dominated grids?

Test Grid

Power generation shifted to converter

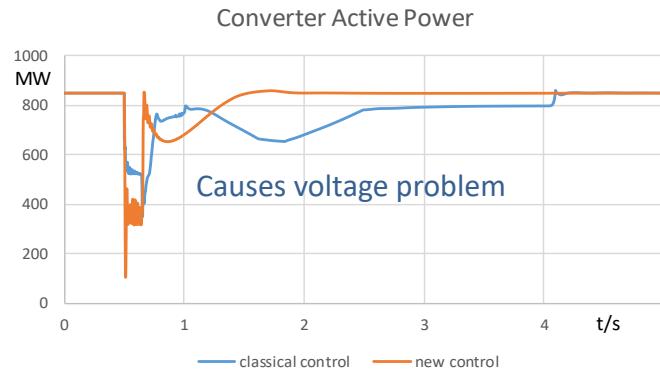


Converters are represented by detailed state of the art control models according to the current GridCodes

Power generation shifted to converter

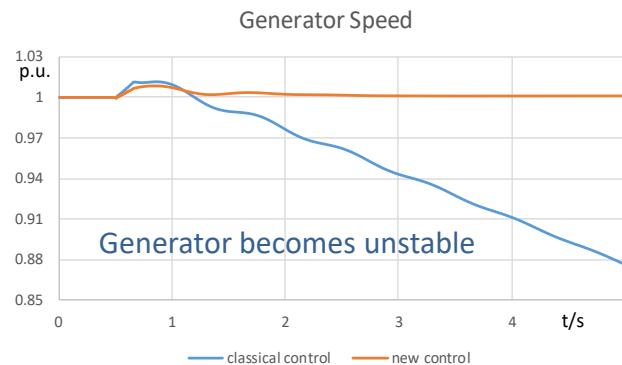
Remaining conventional unit responsible for primary control

Conclusions Based on Comprehensive Dynamic Simulation Study



Below approx. **40% conventional units** different dynamic concerns arise:

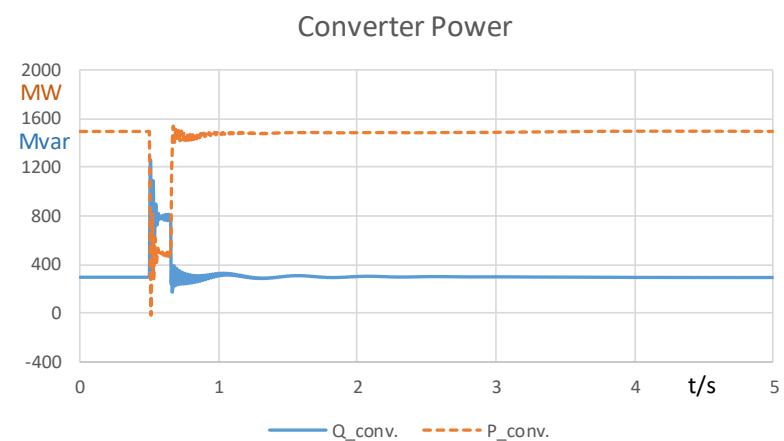
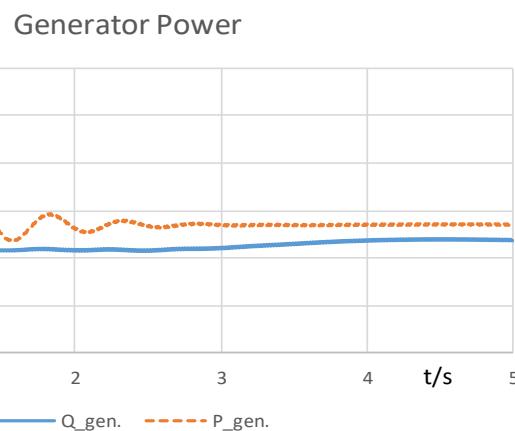
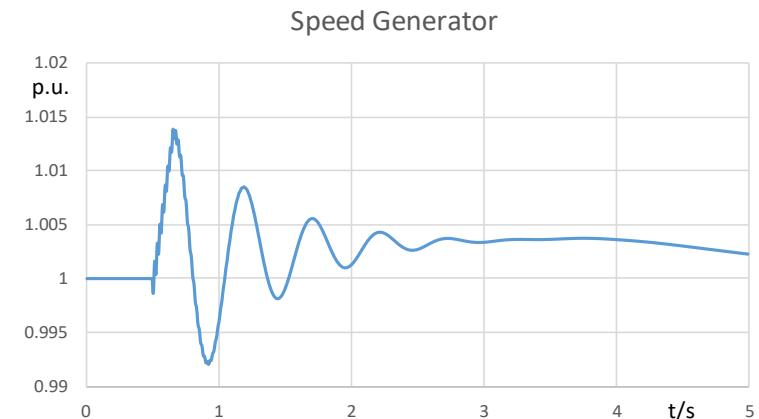
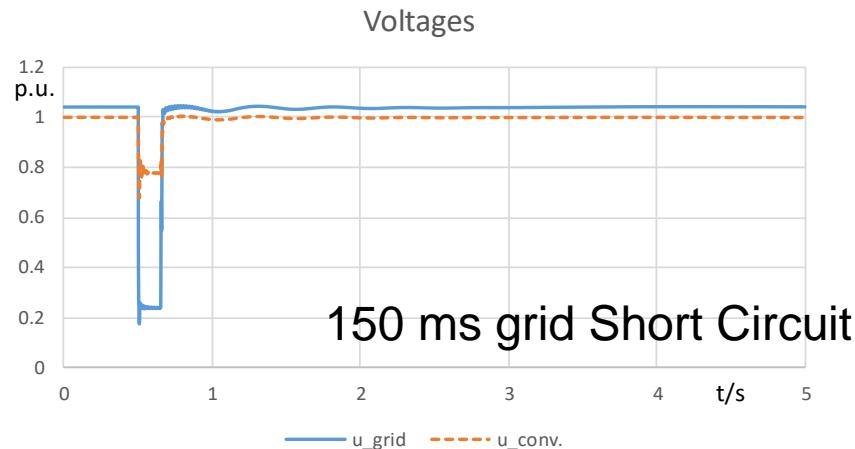
Transient stability, Voltage stability, Frequency stability, ...



However, with modified new converter control the problem can be managed

Simulation Results with New Control

only 2% conventional generation unit in the grid



→ Grid remains stable despite of low inertia 😊

The test grid including the converter control used by the University of Duisburg will be available for download on the Digsilent (PowerFactory) webpage in a few weeks.

Benchmark for Testing Converter Control

Conclusions

- Converter interfaced generation results in fundamental changes in power system operation, dynamics, control and protection.
- New phenomena arise requiring some basic research
- By using new grid forming control the system can be stabilized even though the share of converter supply will reach up to 100%

Thank you for your attention!

