IEEE ENERGY CONVERSION CONGRESS & EXPO | PITTSBURGH, PA, USA | SEPTEMBER 14-18, 2014

Influence of Harmonic Grid Resonance on the Operation of Grid-Connected Converters

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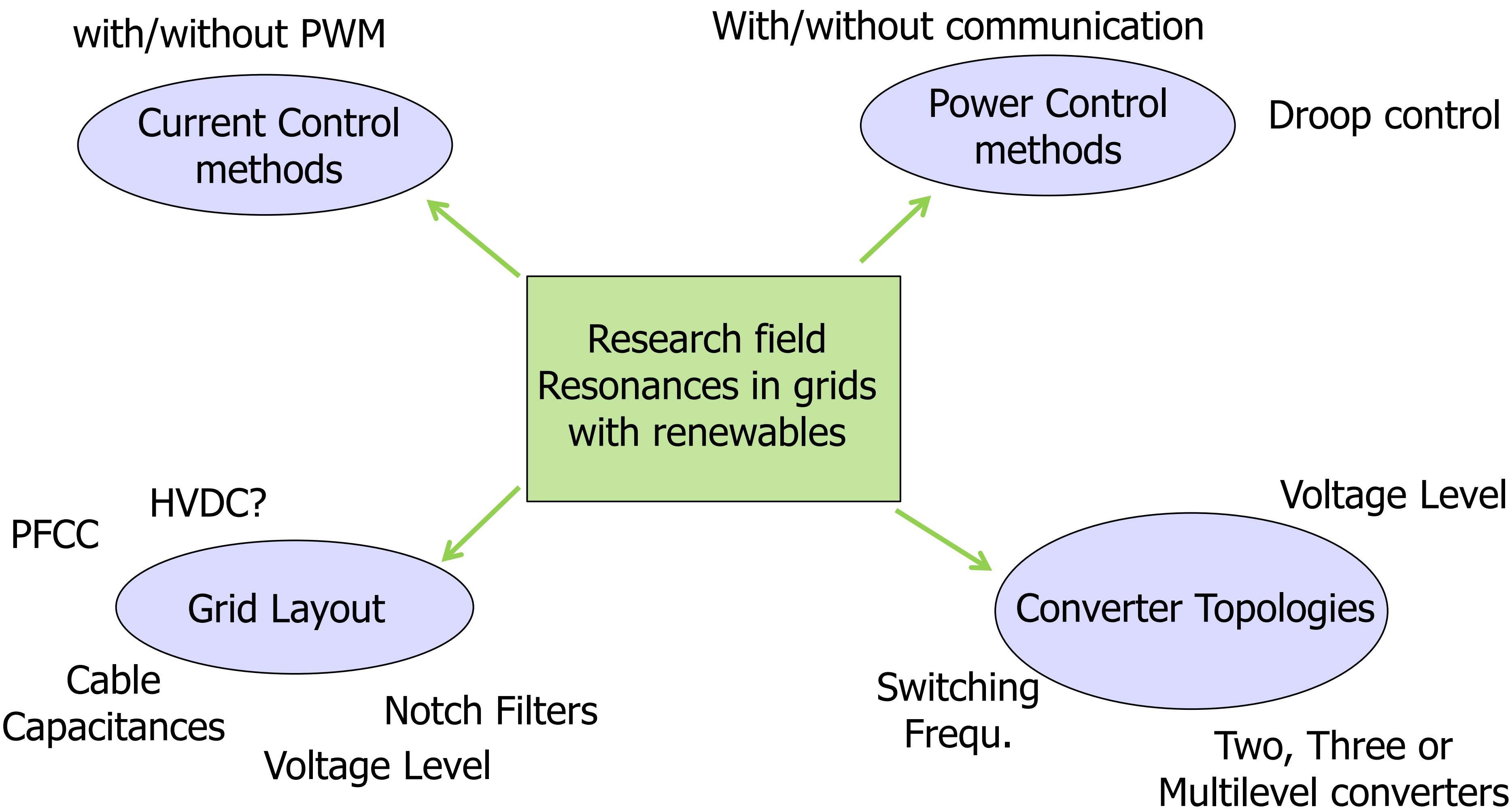
Presentation at ECCE 2014 in Pittsburgh, PA, USA

Overview on Presentation

- Introduction
- Emulation of a Variable Grid Resonance
- Wind Turbine and Laboratory System
- Transfer Function Based Analysis
- Experimental Validation

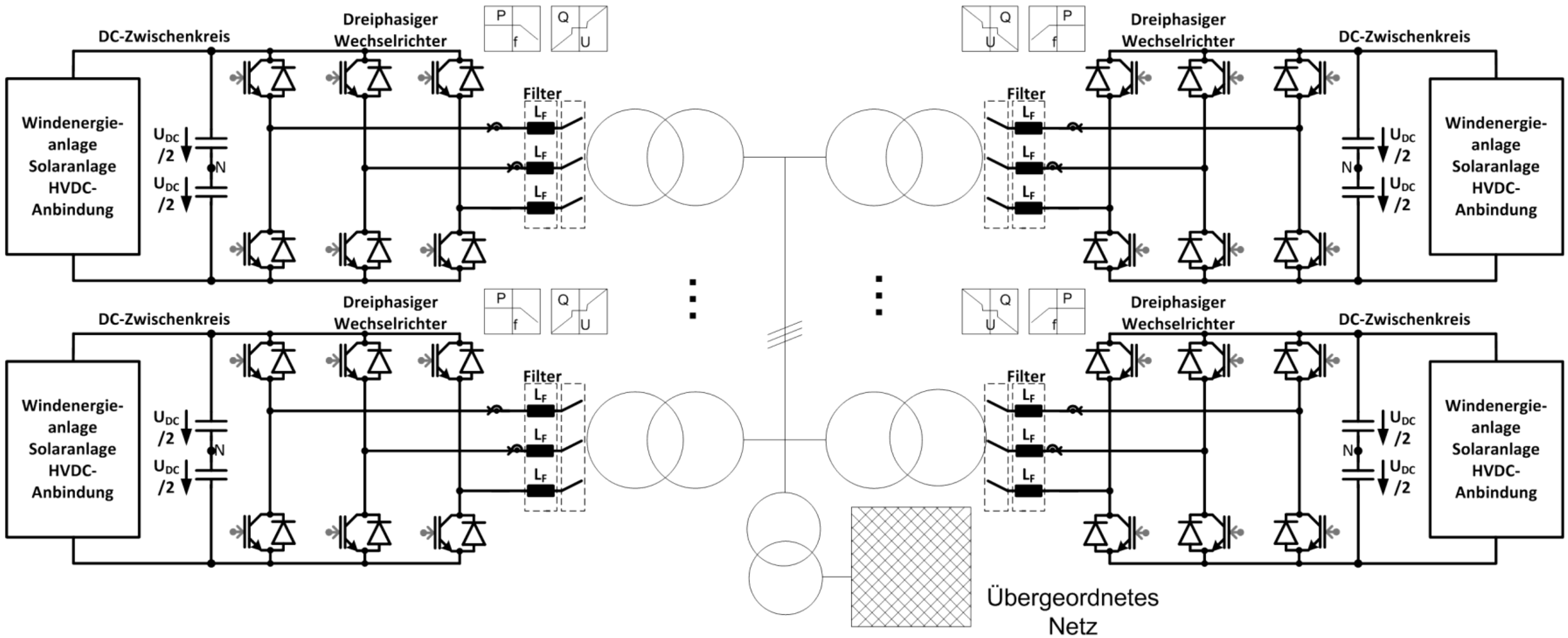
Introduction



In the following: Examples of Resonance Analysis in Hannover

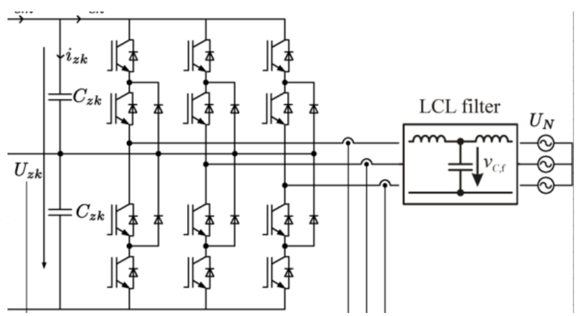
Introduction

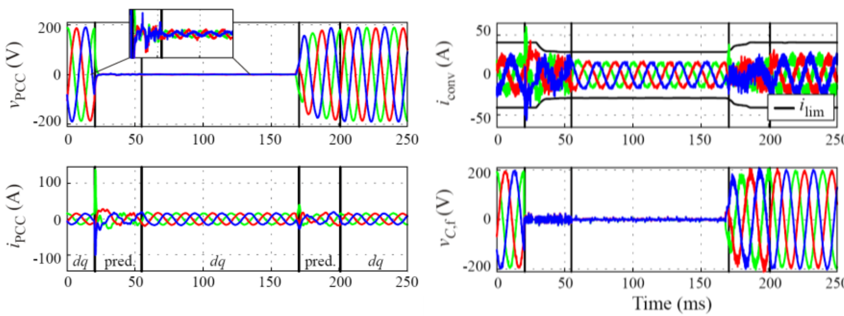
- Laboratory setup for grid-connected converters in Hannover
  - Resonances in cower control
    - Two level converters: several test benches ready to use
    - Microgrid control // Power control methods // high switching frequencies (8-16 kHz)



Introduction

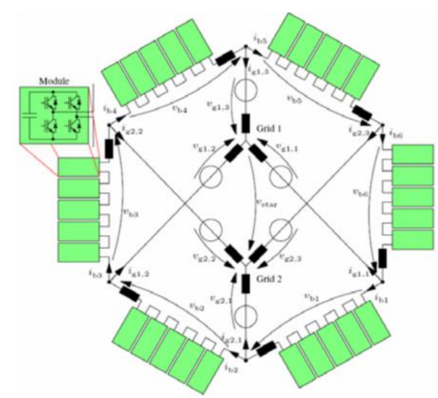
- Laboratory setup for grid-connected converters in Hannover
  - Slow switching (825 Hz) grid-connected NPC converter with LCL filter
    - Doctoral thesis in Hannover in 2014 on LVRT control and LCL filter design





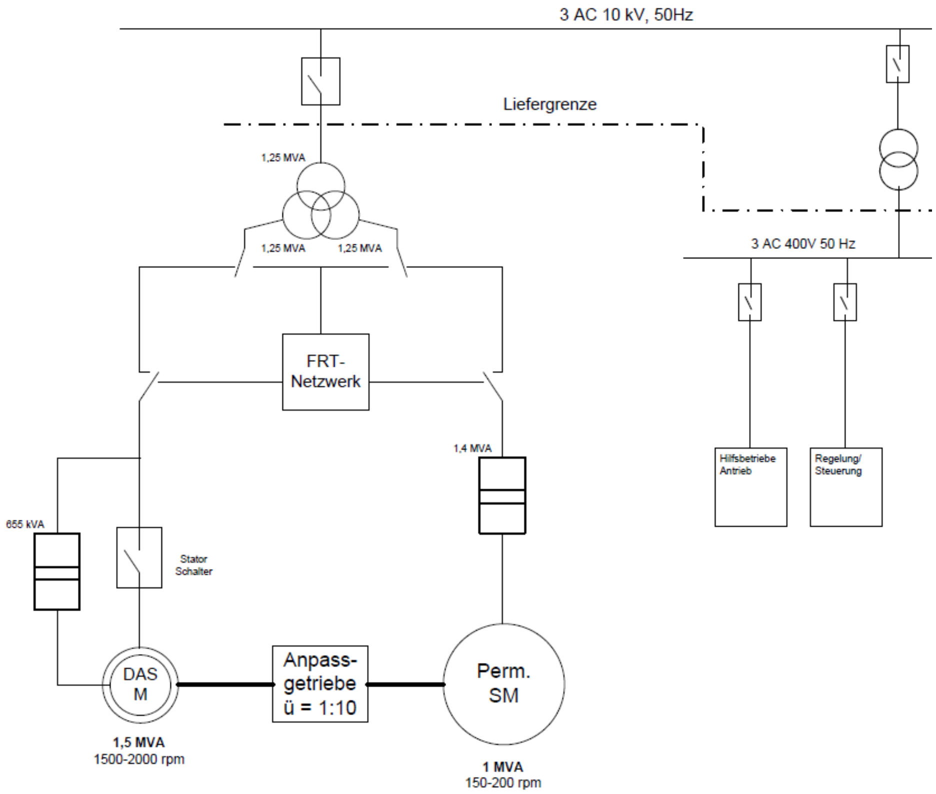
  - Multilevel research group: promising concept ‚Hexverter' (patented)
    - Complexer control in combination with resonances in wind park

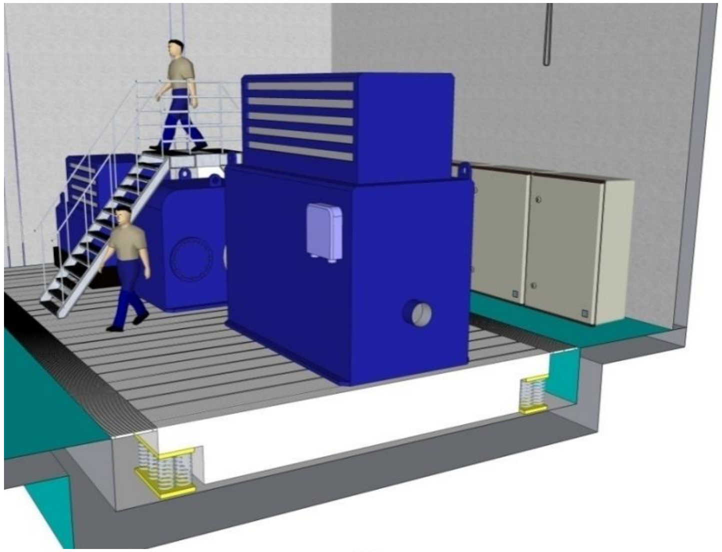
Hexverter as multilevel converter option for high power wind turbines

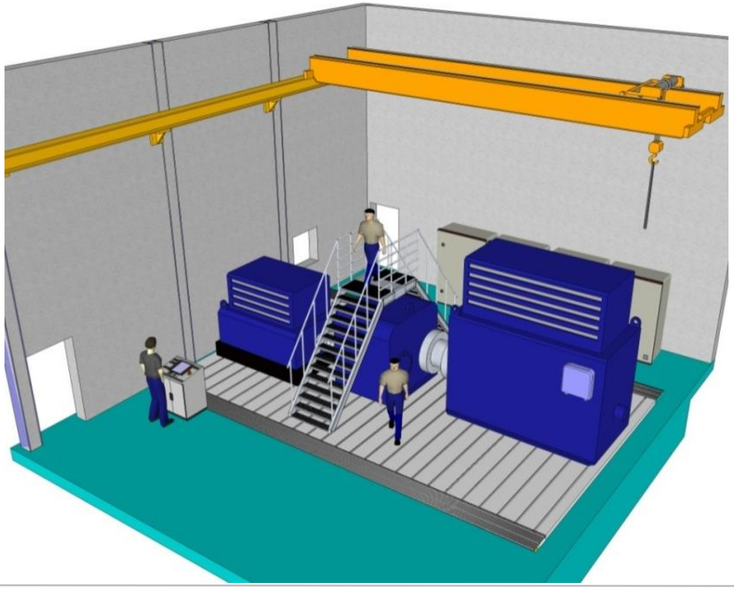


Introduction

- High Power Test Bench (scale 1:10)
  - GeCoLab in Hannover going in operation at the end of 2014: 1.2 MW converter generator test bench including a 690 V grid emulator



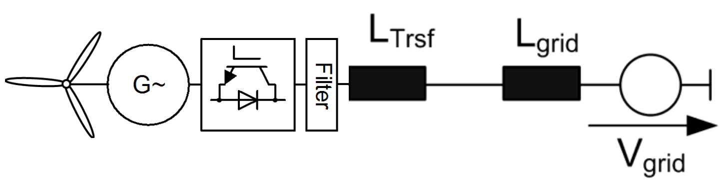


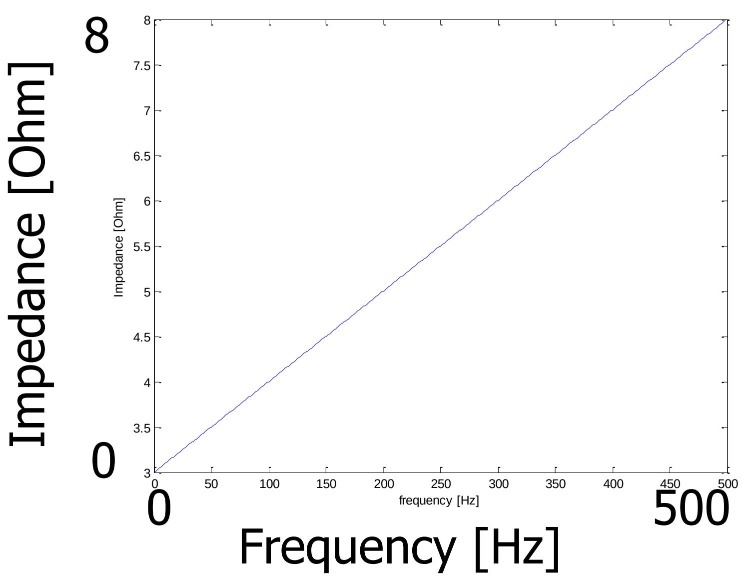


Overview on Presentation

Variable Grid Resonance: Emulation

- Grid impedance seen by the converter is time varying and not only inductive [1] :





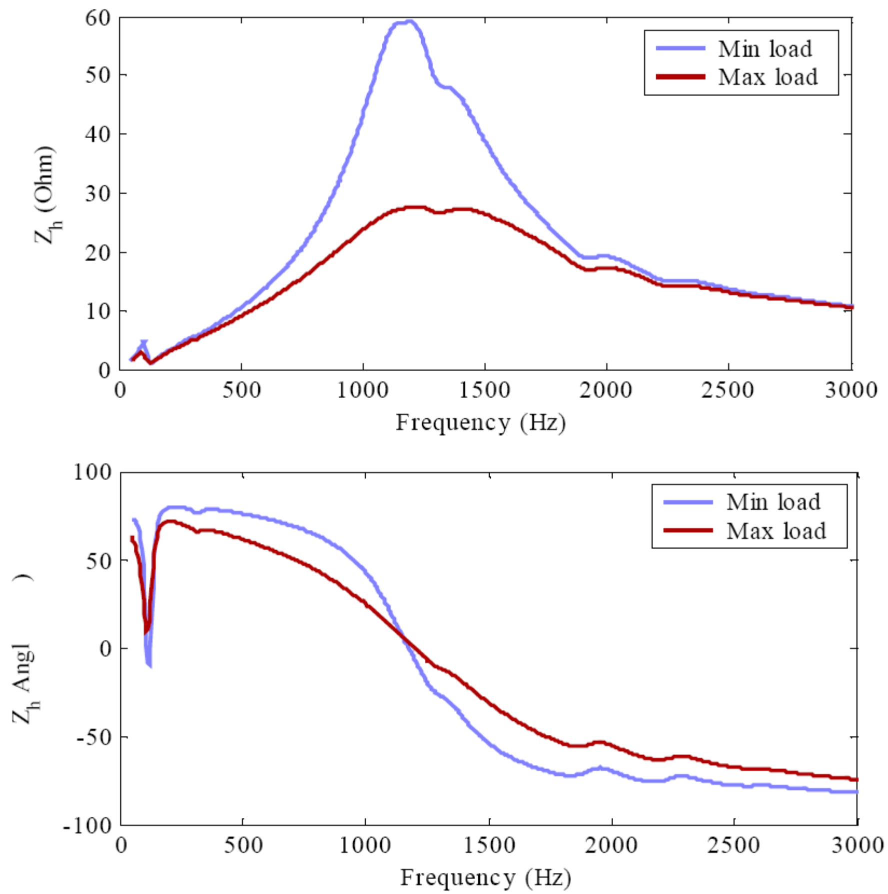


Figure 5. Magnitude and angle of the harmonic impedance at the PCC of the wind farm (Argostoli 15 kV busbars), for maximum and minimum load conditions.

[1] Papathanassiou, S.A; Papadopoulos, M.P., "Harmonic analysis in a power system with wind generation," *Power Delivery, IEEE Transactions on* , vol.21, no.4, pp.2006, 2016, Oct. 2006

Variable Grid Resonance: Emulation

- Grid impedance seen by the converter is time varying and not only inductive [2] :

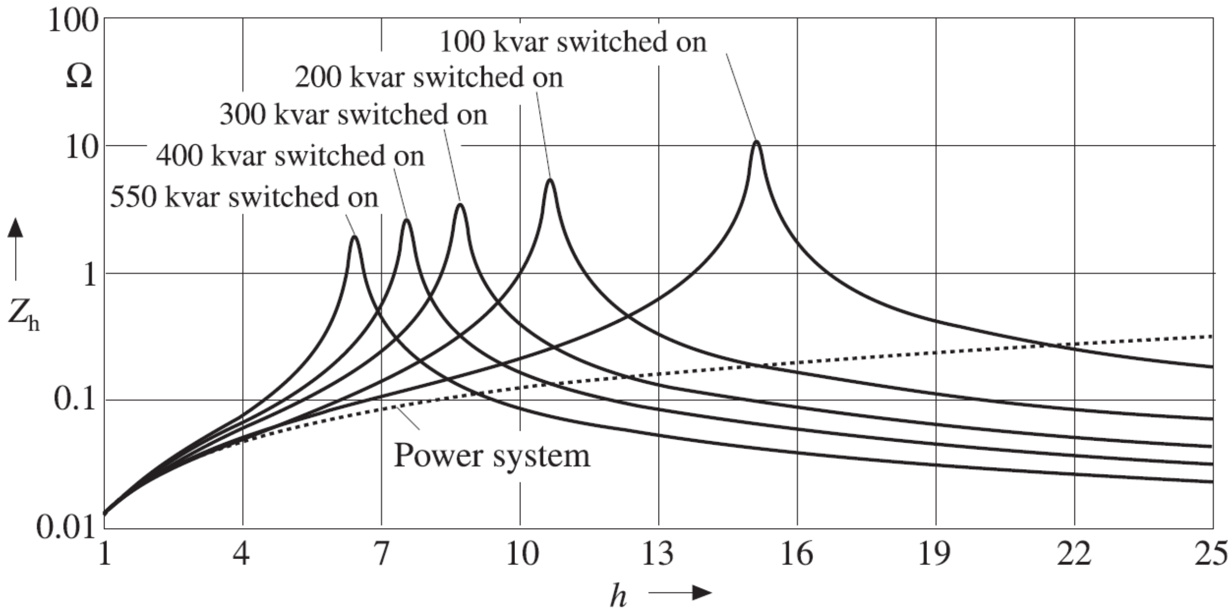


Figure 2.18 Impedance versus harmonic order at the point of common coupling (PCC) of an industrial system
$S''_k = 23.8$ MVA; switched capacitors $Q_C = 100$ kvar . . . 550 kvar (5 steps)

[2] Schlabbach, Jürgen, Dirk Blume, and Thomas Stephanblome, eds. *Voltage quality in electrical power systems*. No. 36. IET, 2001.

– -> sudden change of resonance frequency due to switchable capacitance possible

Variable Grid Resonance: Emulation

- Grid impedance seen by the converter is time varying and not only inductive [3] :

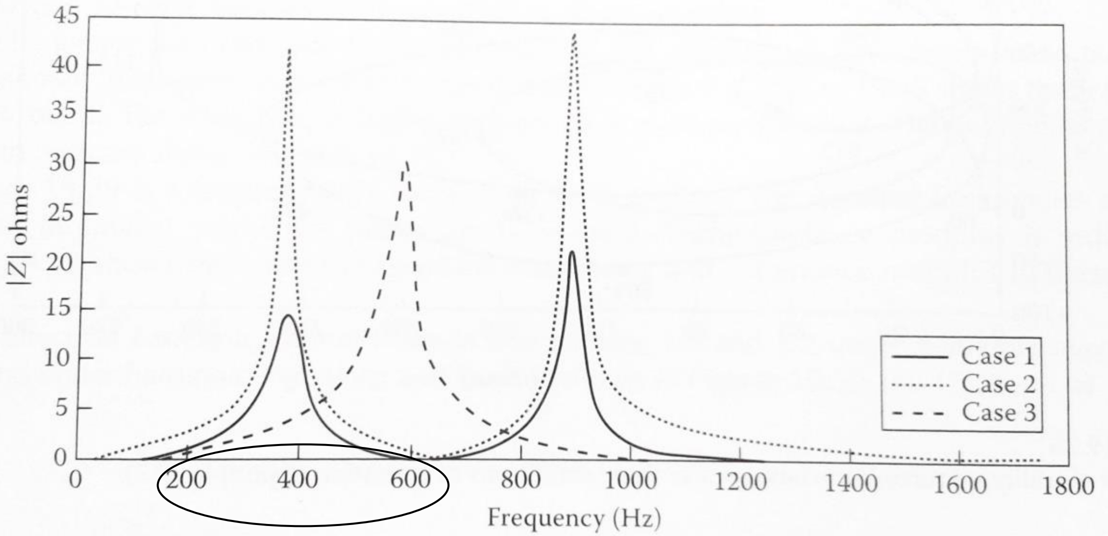


FIGURE 19.25
Impedance modulus versus frequency plot for three conditions of operation, 12.47 kV bus 3 (Example 19.2).

[3] Das, J.C. *Power system analysis: short-circuit load flow and harmonics*.CRC press, 2002.

- Large Industrial Distribution system
- Case 1: all loads, sources and PFCC are operating an nominal value
- Case 2: Some loads, sources and PFFC are are not operating
- Case 3: Additional 30 MVA and 18 MW converter load connected by long cable

Variable Grid Resonance: Emulation

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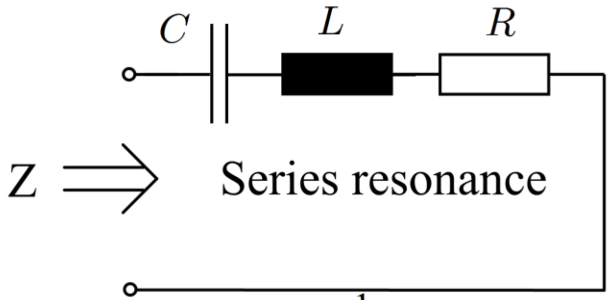
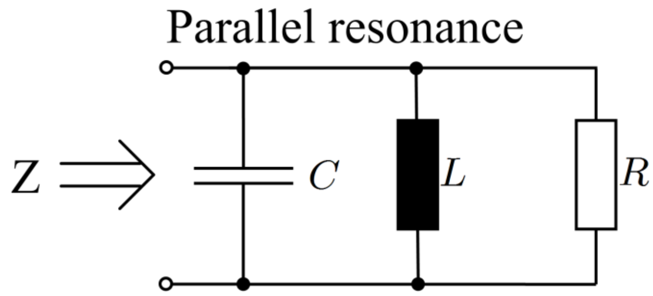
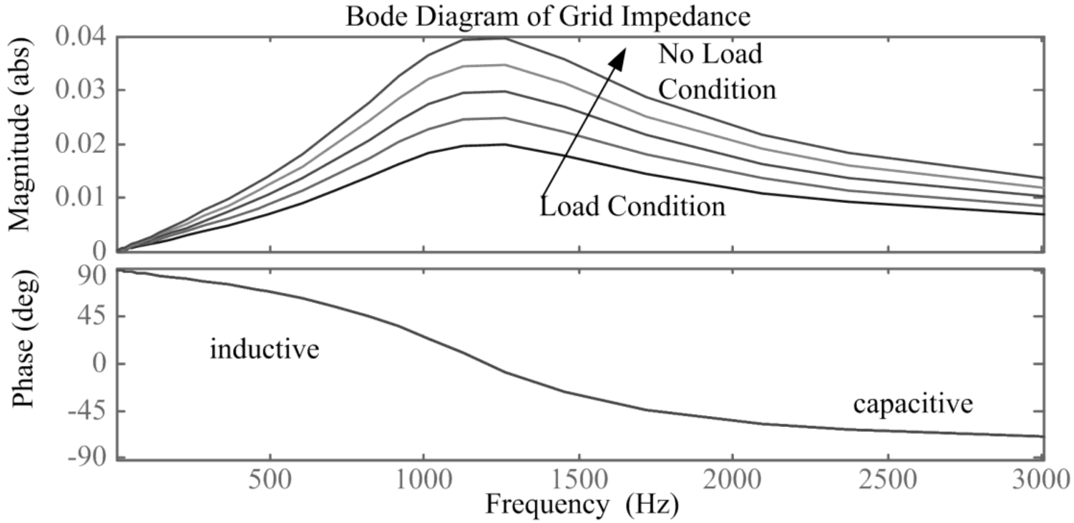
- Is there a general possible range for grid impedance seen by the converter ?



$$f_0 = \frac{1}{2\pi\sqrt{LC}}$$



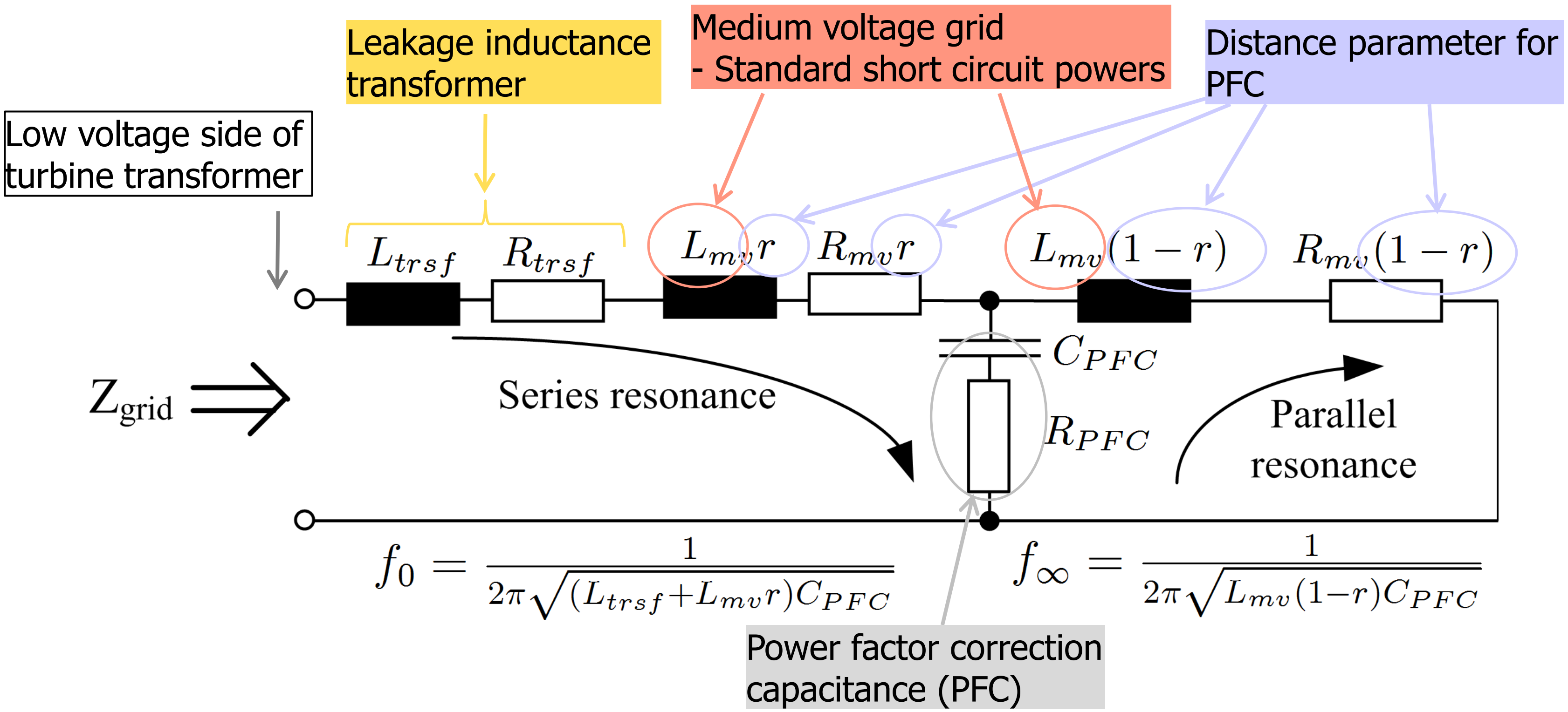
$$f_\infty = \frac{1}{2\pi\sqrt{LC}}$$



Example:
Parallel resonance

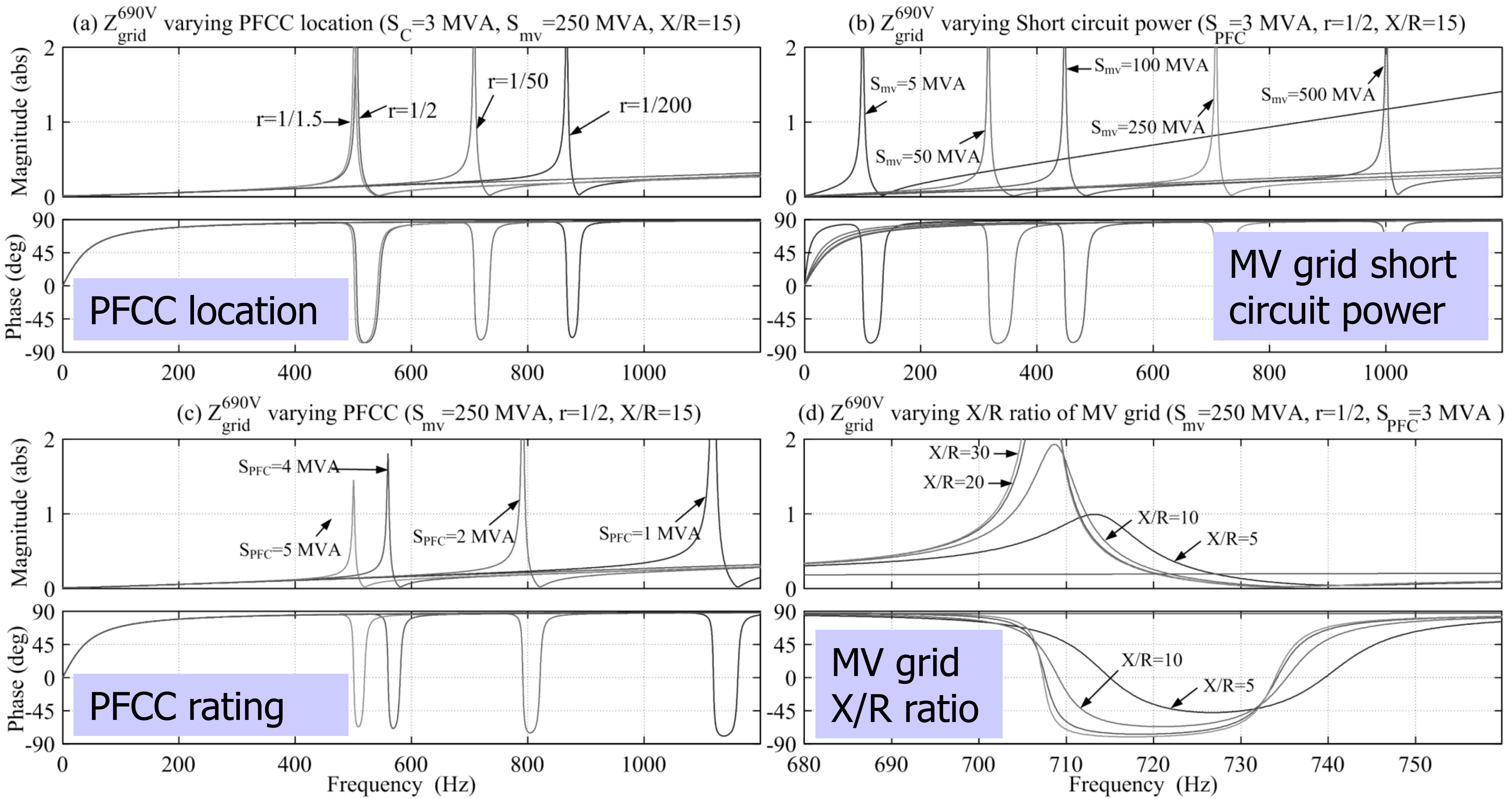
Variable Grid Resonance: Emulation

- Is there a general possible range for grid impedance seen by the converter ?
  - Simple approach to emulate a series and parallel resonance:
    - All Impedances are transformed to the low voltage level



Variable Grid Resonance: Emulation

- Influence factors on grid impedance emulation



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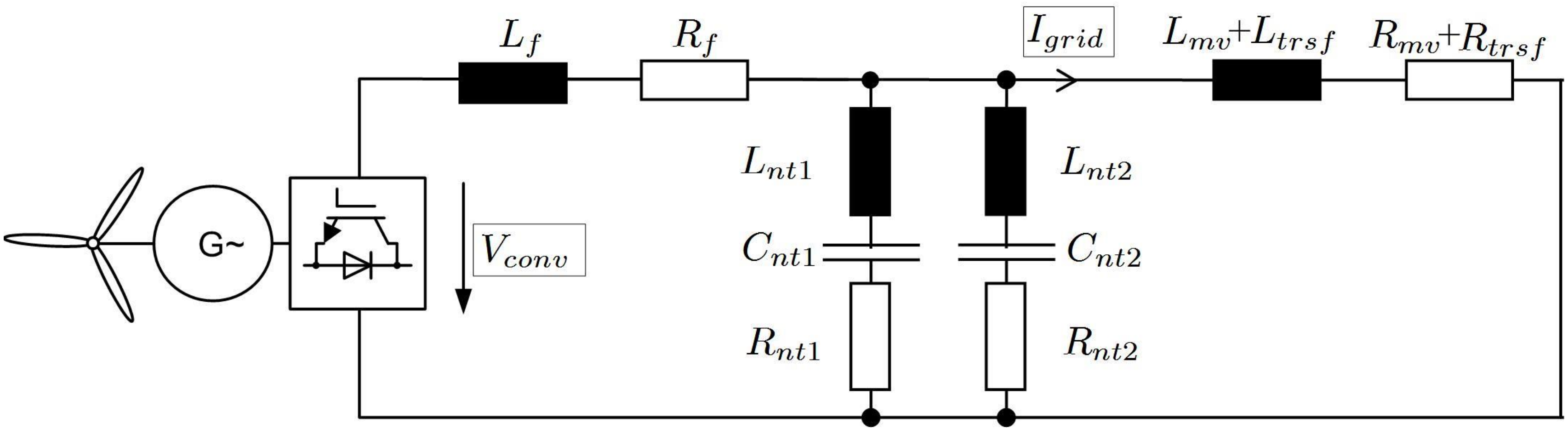
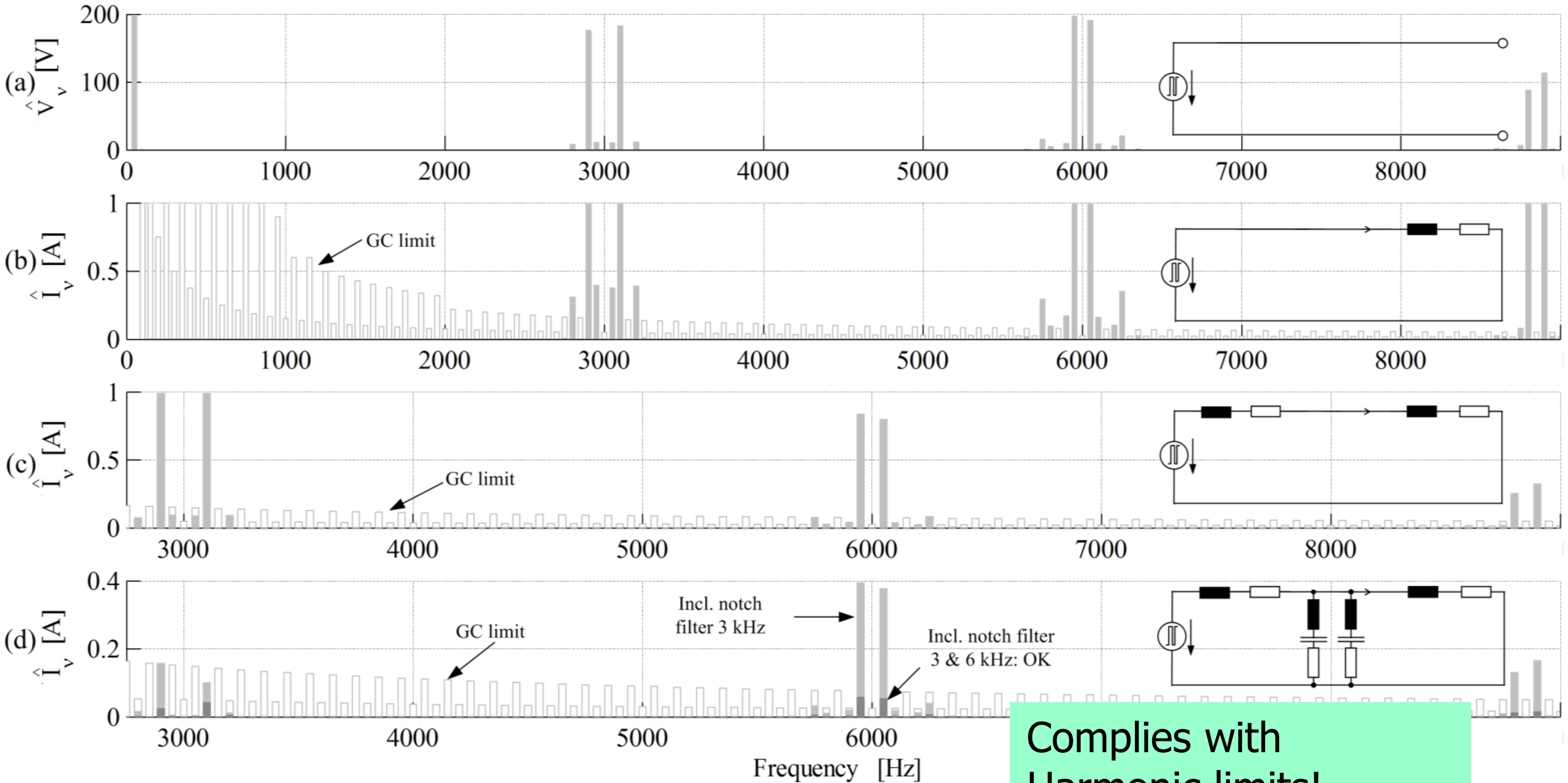
Wind Turbine and Laboratory System

- Fully Sized 2 MW wind turbine
- All data is provided within the paper
- Design of grid filter according to the grid codes :



Wind Turbine and Laboratory System

- Filter design according to grid codes



Complies with Harmonic limits!

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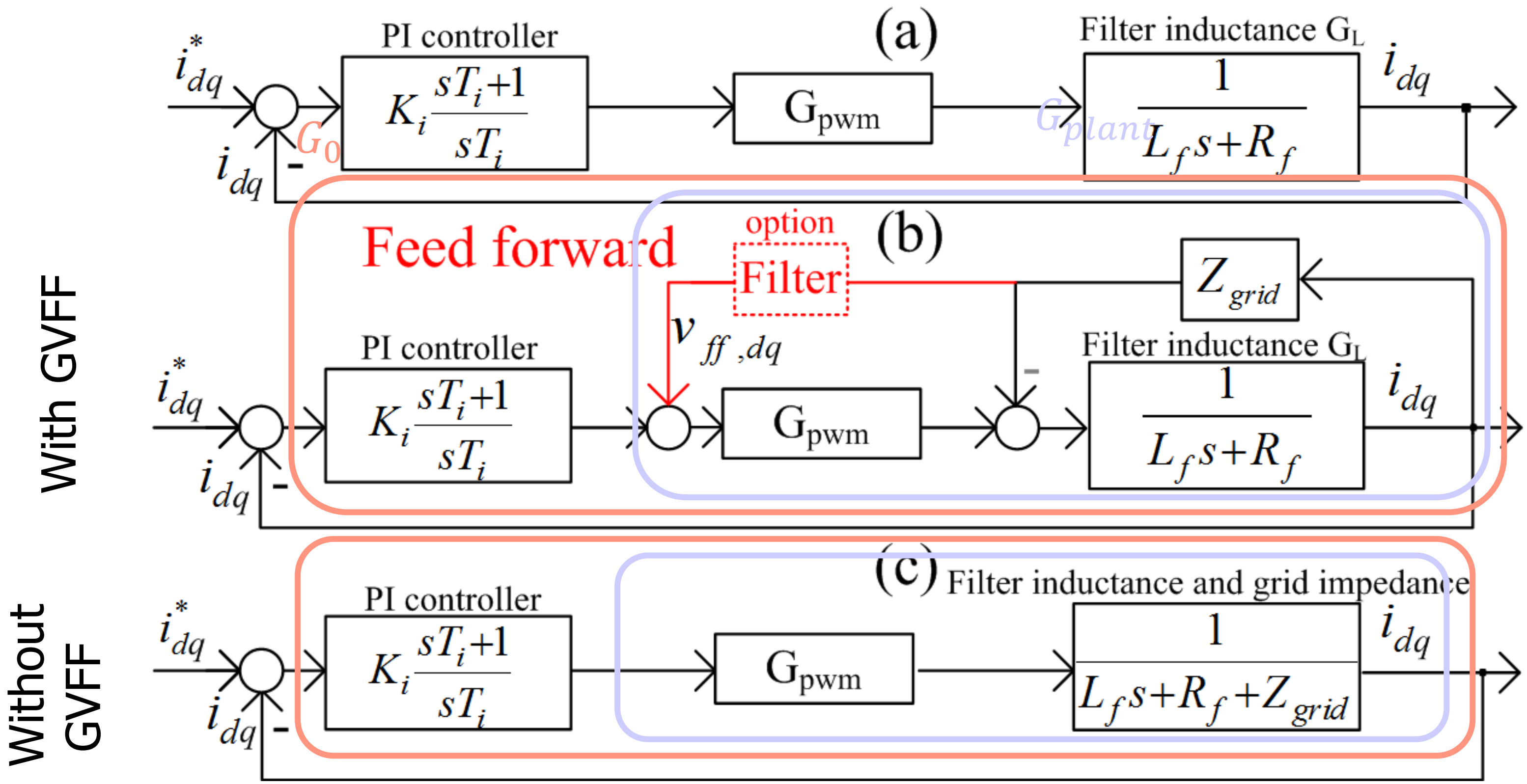
Transfer Function Based Analysis

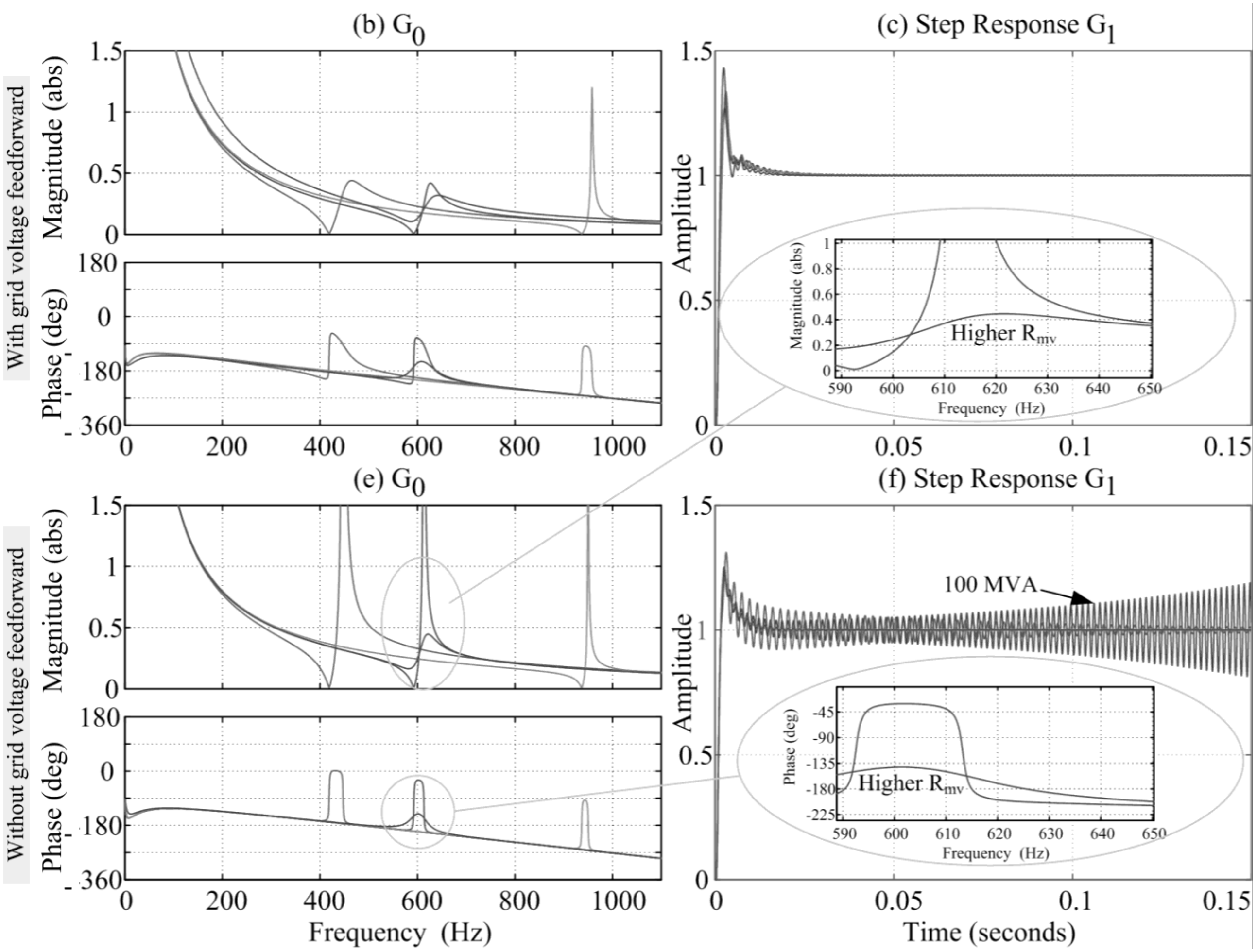
- Standard grid voltage oriented dq current control is analysed
  - With grid voltage feedforward (GVFF) (b) and without GVFF (c)



$$G_{pwm}(s) = e^{-sT_s}\frac{1-e^{-sT_s}}{sT_s}$$

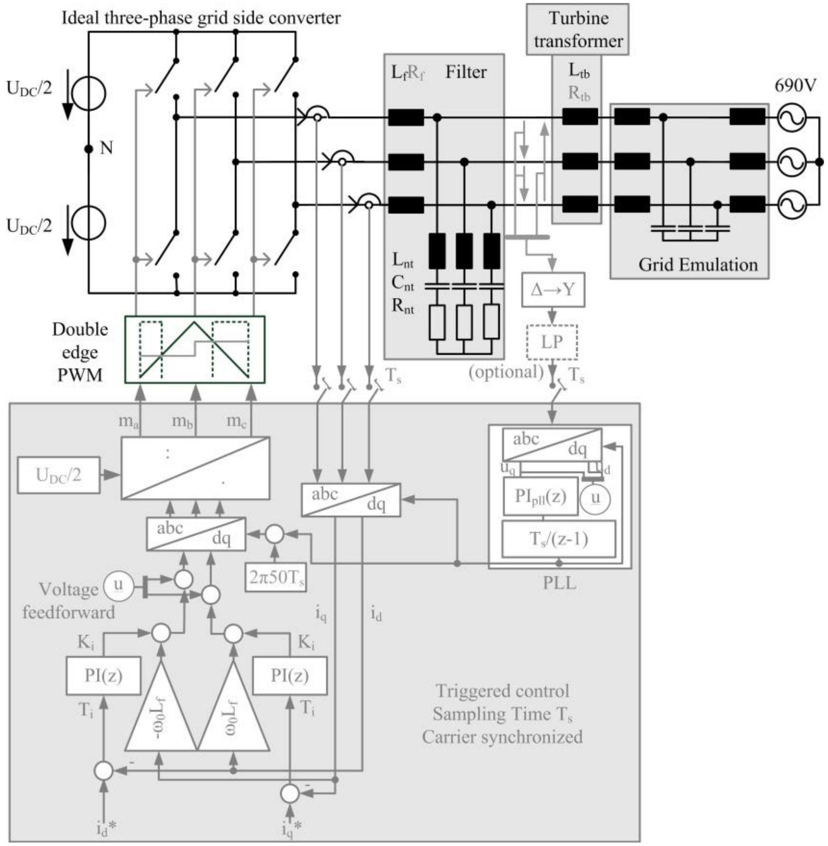
Transfer Function Based Analysis

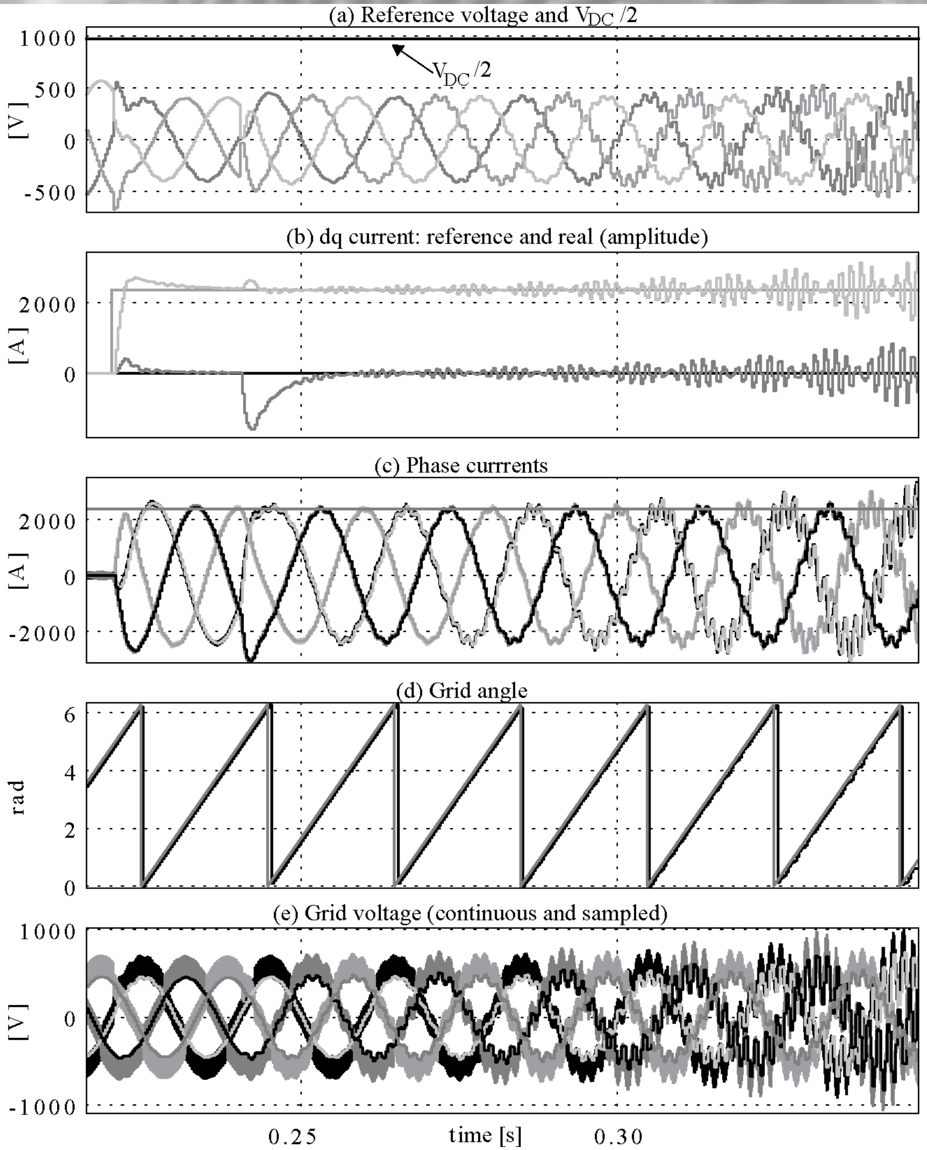
- Results for the proposed grid impedance with resonance



Transfer Function Based Analysis

- Simulation results for critical resonance combination
  - Predicted stability/instability for control with/without GVFF is validated





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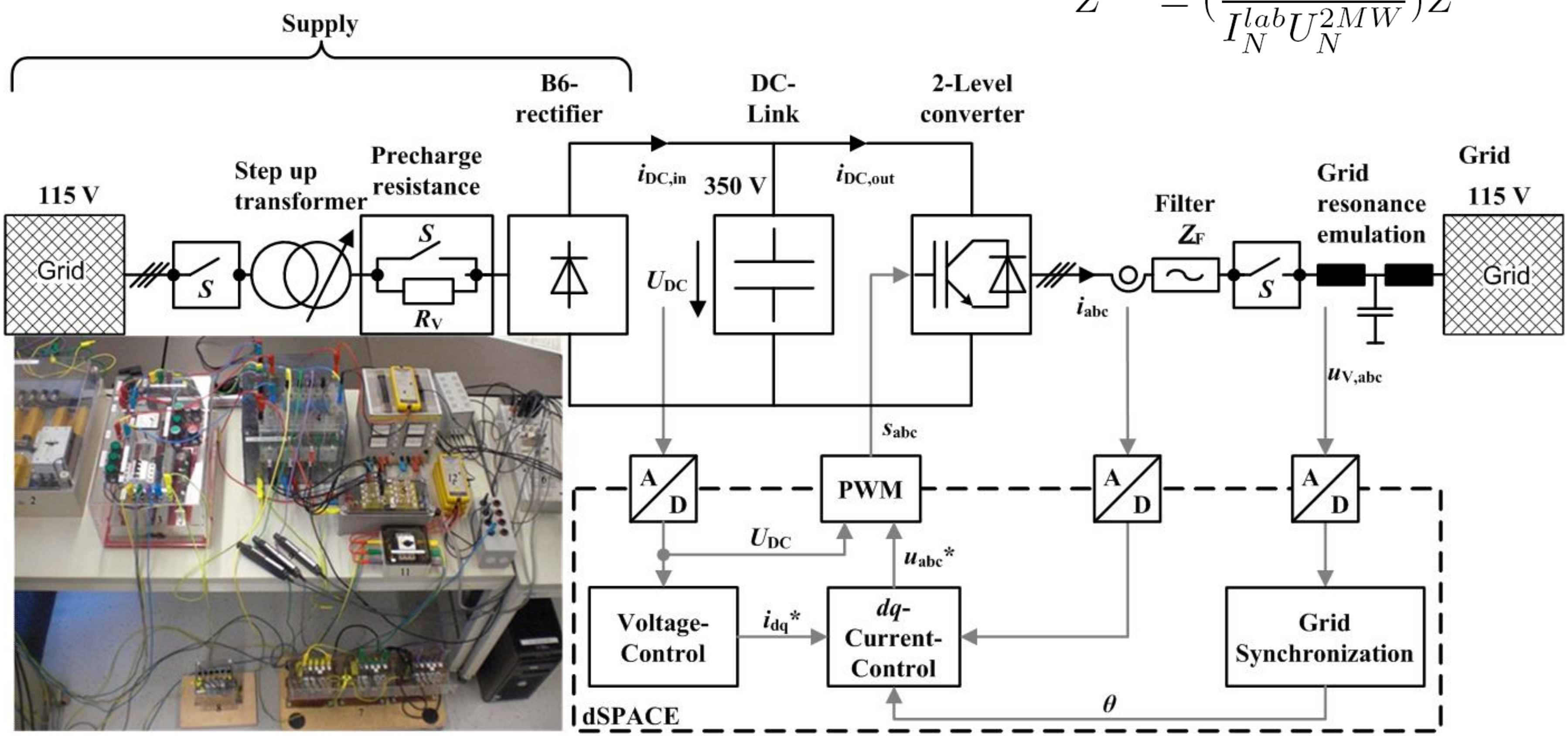
Experimental Validation

- Laboratory Setup (p.u. transformed parameters)

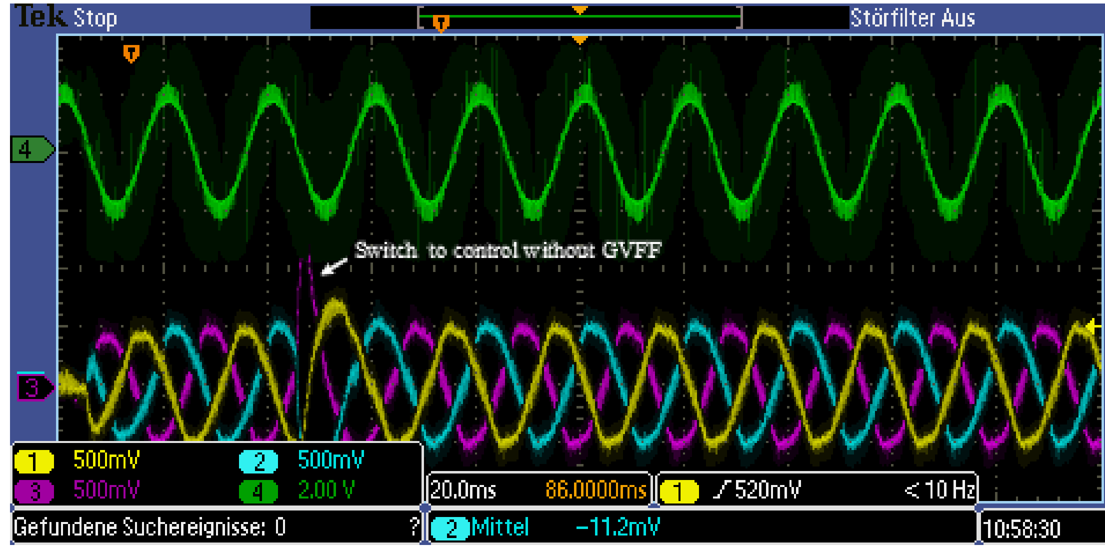
$$Z^{lab} = \left(\frac{I_N^{2MW} U_N^{lab}}{I_N^{lab} U_N^{2MW}}\right) Z^{2MW}$$

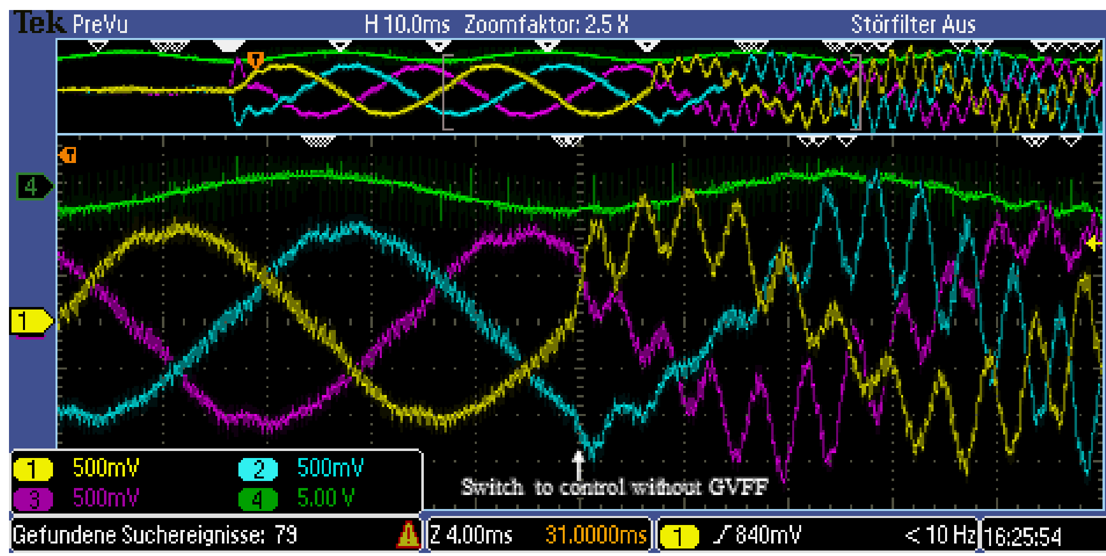


Experimental Validation

- Results
  - Predicted Instability not Observable, due to higher Resistances in laboratory
  - Including higher resistances in predictions, instability with increased controller (285%) gain is predictable

⇨ Control with GVFF allows Higher bandwidth than without GVFF concerning resonance





Conclusion

- Grids with Renewables and Resonances is interdisciplinary research field
- Grid impedance seen by converter depends on several factors
- Here: Approach for grid impedance with series and parallel resonance
- dq Current Control with GVFF allows higher bandwidth than without GVFF

Thank you for your attention!

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Smart Nord

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Symbol	Value 2 MW	Value 2.85 kW	p.u.
L_f/R_f	0.17 mH/1mΩ	3.2 mH/19.4mΩ	0.21/0.004
L_{mv}	15.1 μH/0.16mΩ	0.29 mH/3.1mΩ	0.02/0.0007
S_{mv}	100 MVA	143 kVA	50
$u_{k,trsf}$	0.06	0.06	-
L_{trsf}/R_{trsf}	36.4 μH/1mΩ	0.71 mH/19.4mΩ	0.048/0.004
S_{PFC}	0.75 MVA	1.07 kW	0.36
C_{PFC}/R_{PFC}	5 mF	258μF/0.5mΩ	2.7
r	1/20	1/20	-
V_{DC}	1950 V	325 V	2.82
f_s/f_c	3 kHz/ 3 kHz	3 kHz/ 3 kHz	-
V_N	690 V	115 V	1
I_N	1673 A	14.4 A	1
S_N	2 MW	2.85 kW	1
$R_{nt1}L_{nt1}C_{nt1}$	15mΩ46μH60μF	0.3Ω0.9mH3.1μF	0.06/0.06/0.03
$R_{nt2}L_{nt2}C_{nt2}$	0.1Ω12μH60μF	1.9Ω0.2mH3.1μF	0.4/0.016/0.03