Grid-forming inverters in power grids

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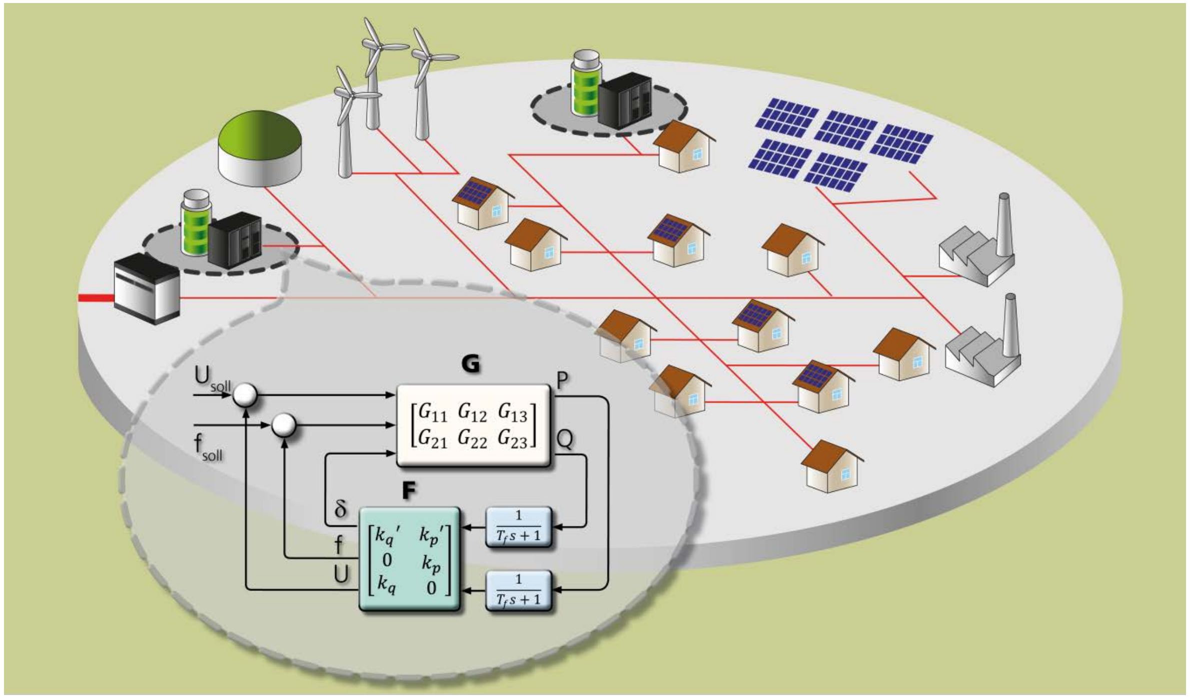

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Agenda

- Introduction
- Control of grid-forming inverters
- Grid impedance estimation
- Practical tests
- Conclusion

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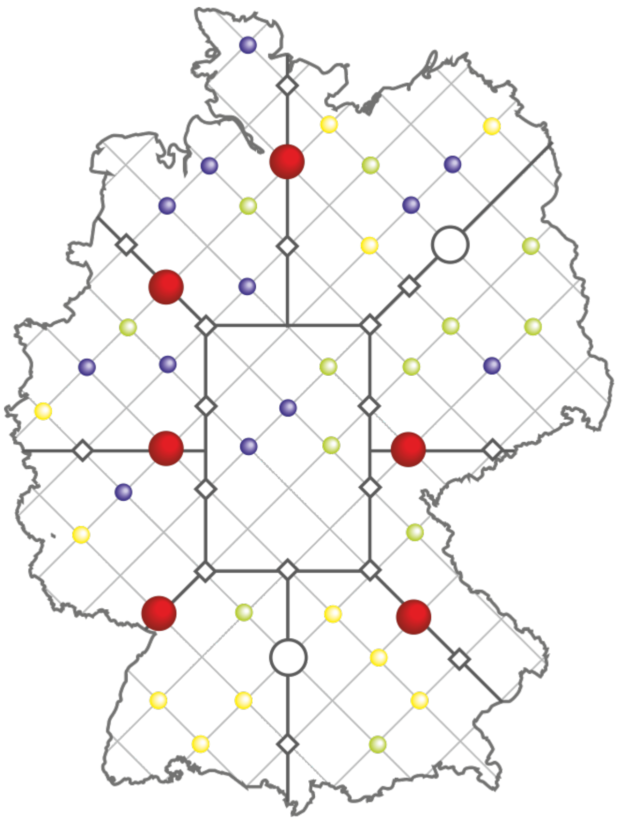
Grid-forming inverters in power grids

Introduction



- **„Grid-forming“** means that an operating device participates actively on forming the grid voltage.
- Grid-forming inverters act as **voltage sources.**

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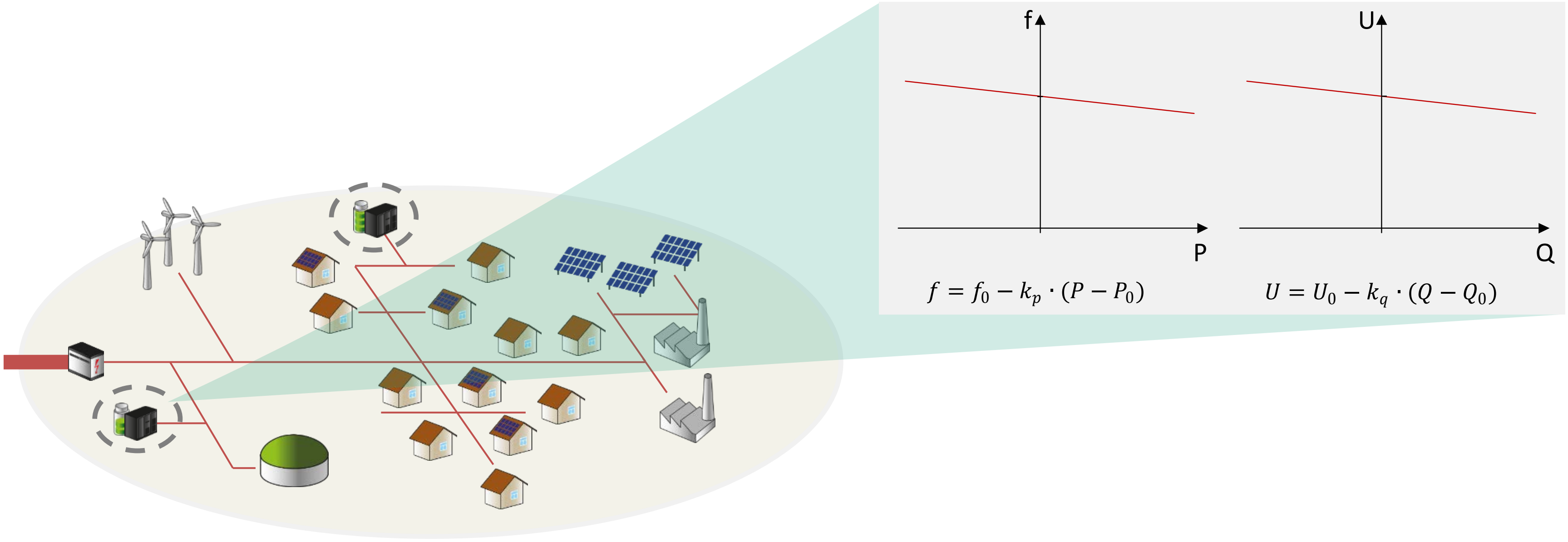
Introduction

- A high penetration of grid-forming inverters is inherently system stabilizing.



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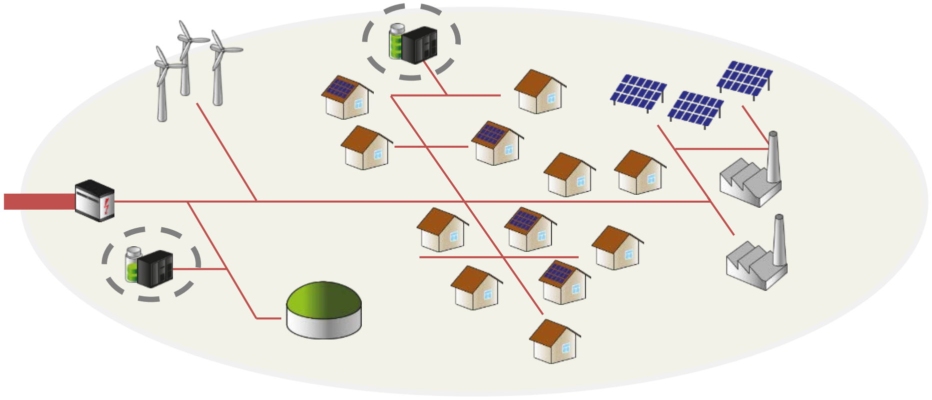
Introduction

- A high penetration of grid-forming inverters is inherently system stabilizing.



This approach can cover:

- Virtual inertia
- Uninterruptable power supply
- Black start capability…

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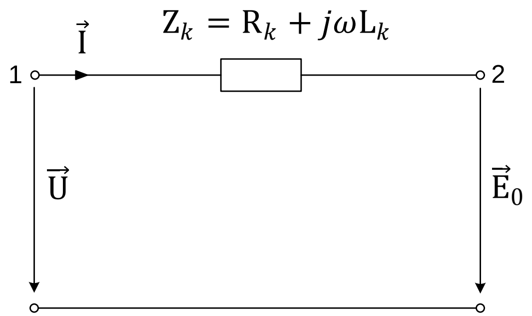
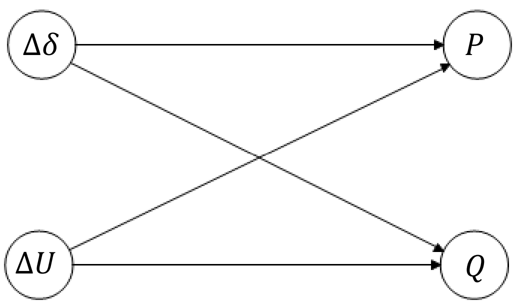
Control - challenge



$$P = \frac{L_k s + R_k}{(L_k s + R_k)^2 + (\omega L_k)^2}(U^2 - U E_0 \cos\delta) - \frac{\omega L_k}{(L_k s + R_k)^2 + (\omega L_k)^2} U E_0 \sin\delta$$

$$Q = \frac{\omega L_k}{(L_k s + R_k)^2 + (\omega L_k)^2}(U^2 - U E_0 \cos\delta) + \frac{L_k s + R_k}{(L_k s + R_k)^2 + (\omega L_k)^2} U E_0 \sin\delta$$



Difficulty: distribution grid

- angle/frequency deviation results in reactive power flow.
- Arbitrary spatial distribution

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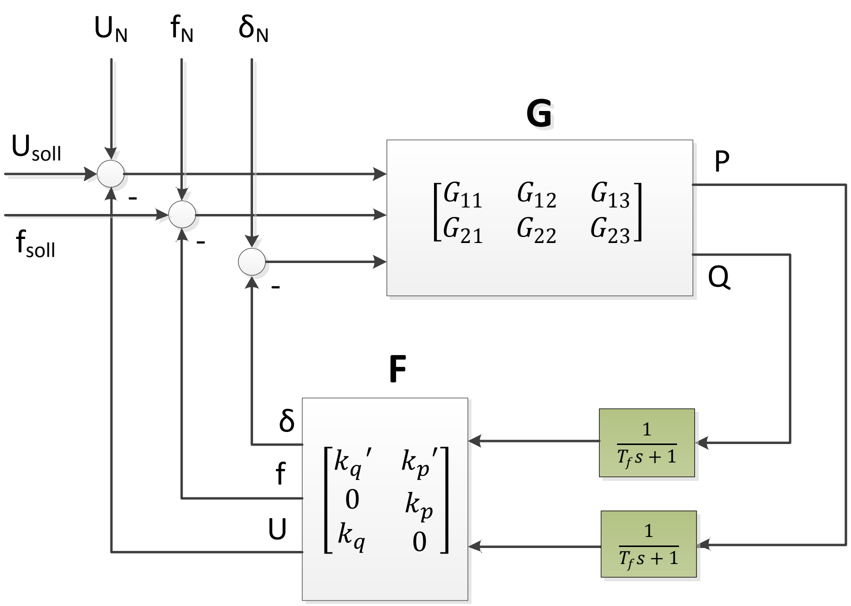
Control - proposed algorithm



Feedback matrix **F**

- k_p, k_q reflect the droops
- angle feedforward: improve stability and transient behavior (k_p‘, k_q‘)

$k_p = \Delta f / P_{max}$ $k_q = \Delta U / Q_{max}$

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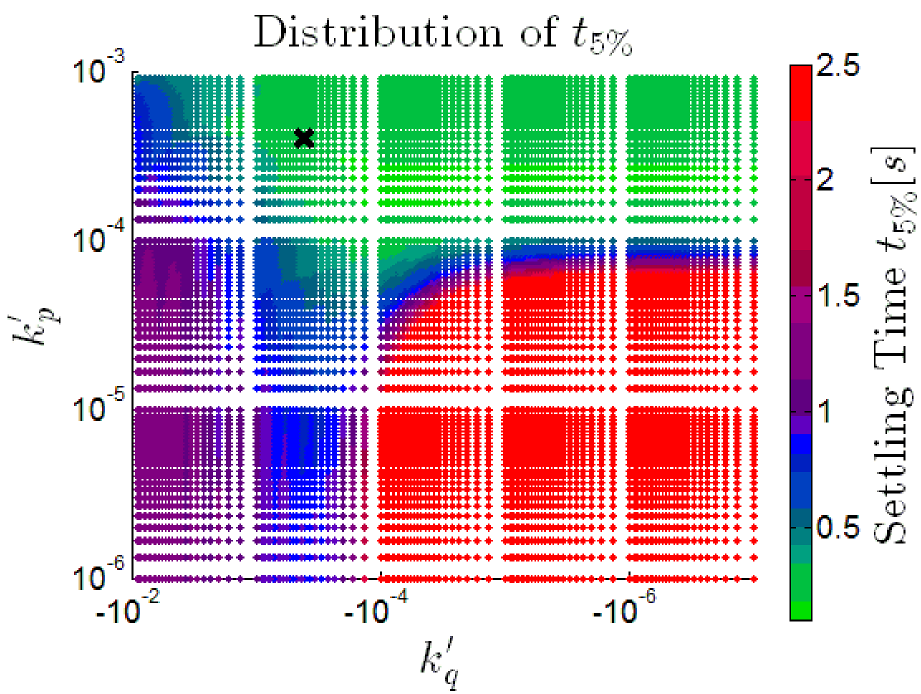
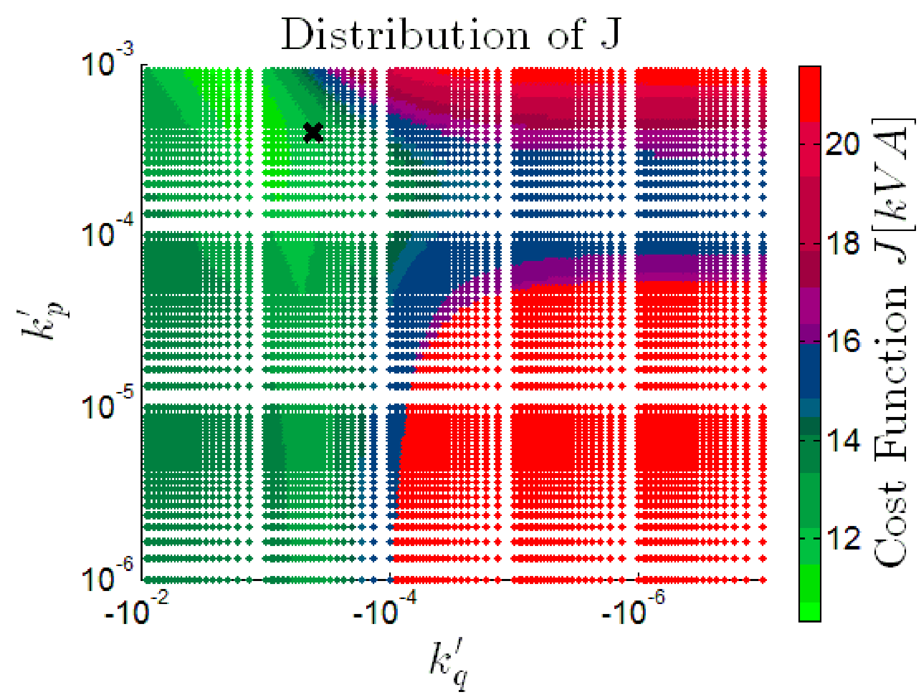
Control - choice of the parameters k_p', k_q'

With a higher resistive grid impedance the parameter k_q‘ gets more relevance (here L_k = 1 mH, R_k = 0.4 Ω).





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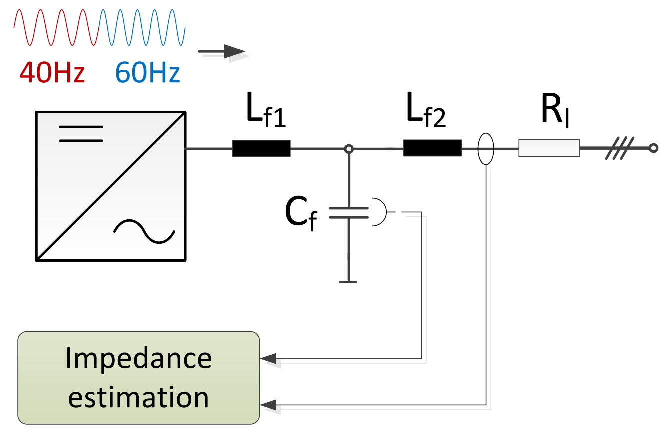
Impedance estimation

- Active method with interharmonic injection (40 Hz, 60 Hz)
- Referenced resistance change to 174.2 mΩ
- Estimated value amounts 176 mΩ
- Accuracy around 1%



before change		*after change*	
resistive [mΩ]	inductive [mH]	resistive [mΩ]	Inductive [mH]
505.7	1.357	328.1	1.334
506.1	1.352	326.4	1.344
501.4	1.353	330.6	1.341

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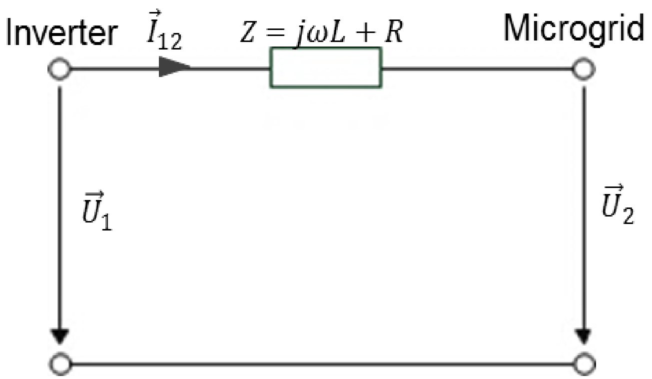
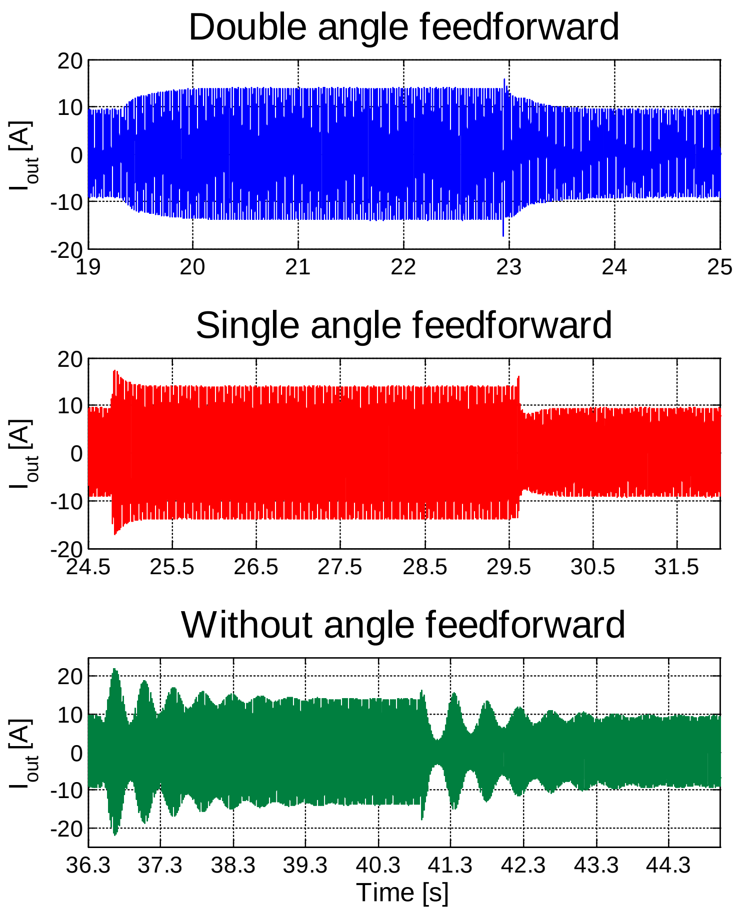
Experimental results – voltage step



- Voltage step from 230 V_{eff} to 245 V_{eff} and back
- Grid impedance (0.345 Ω, filter)
- Smooth settling with double angle feedforward



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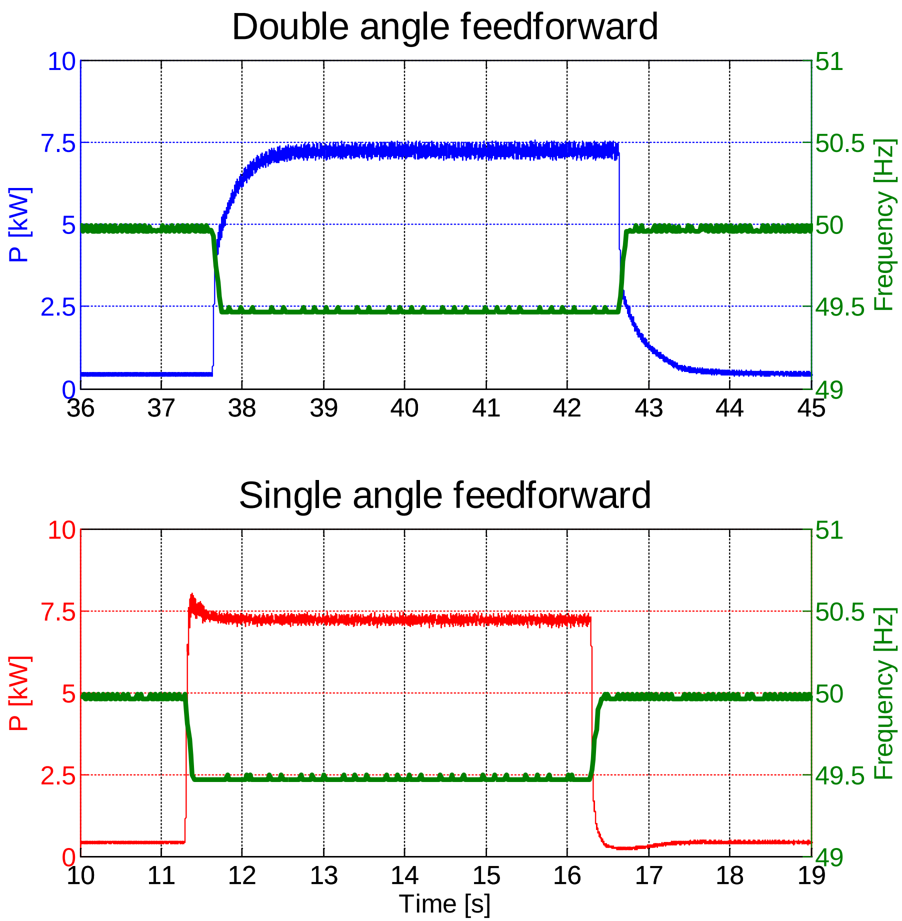
Experimental results – frequency step

- Frequency step from 50 Hz to 49.5 Hz and back
- Smooth settling
- Instantaneous reaction



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Conclusion

- **Grid-forming** inverters are inherently **system stabilizing** with regard to the power grid control.
- **Improved** control behavior due to the **angle feedforward**
- For an optimal controller design an **impedance estimation tool** was applied.