Grid-Forming Inverters in Microgrids

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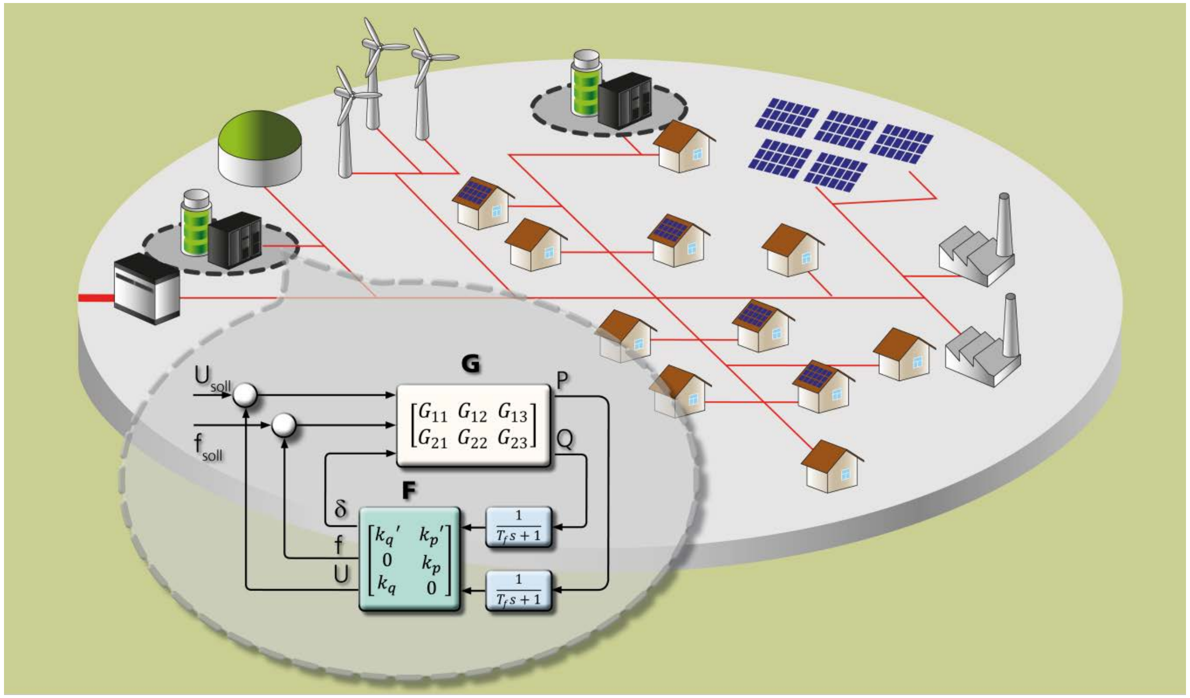

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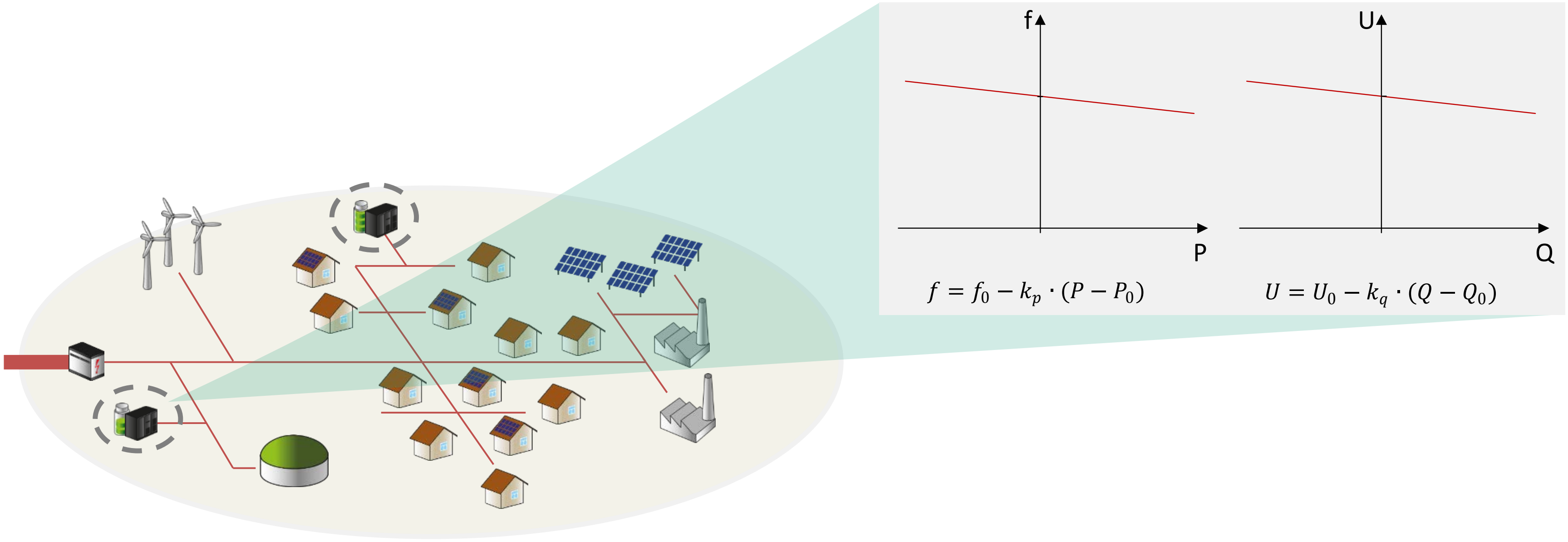
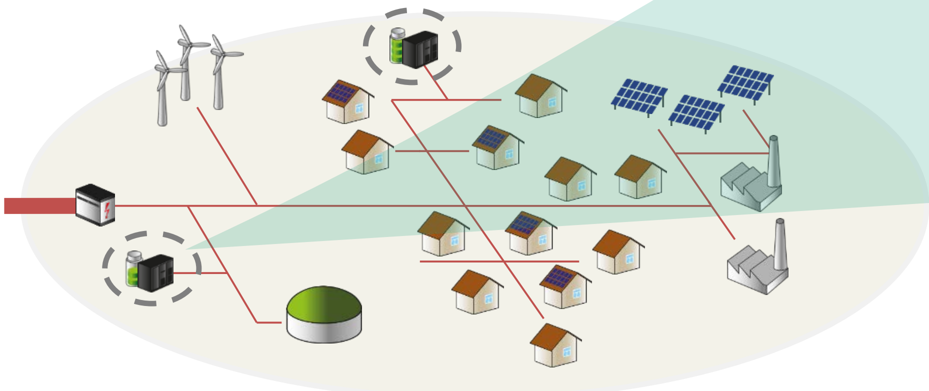
Introduction

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



Grid-Forming Inverters in Microgrids
Introduction

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



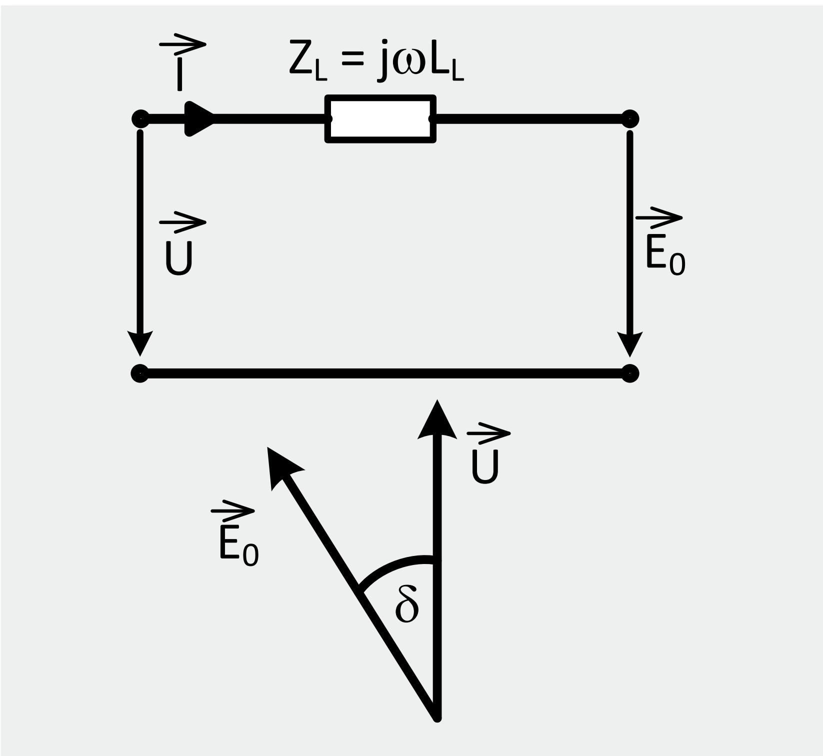
This approach can cover:

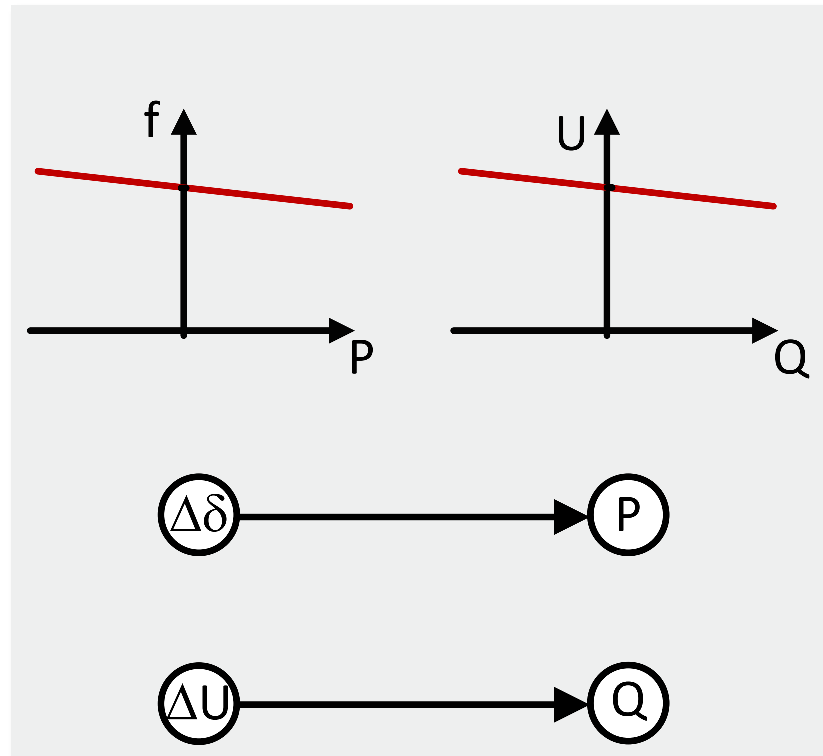
- Virtual inertia
- Uninterruptable power supply
- Black start capability…

Grid-Forming Inverters in Microgrids

Basic Idea for grid forming inverters

- Transfer droops of power plant behaviour with synchronous generators to inverters





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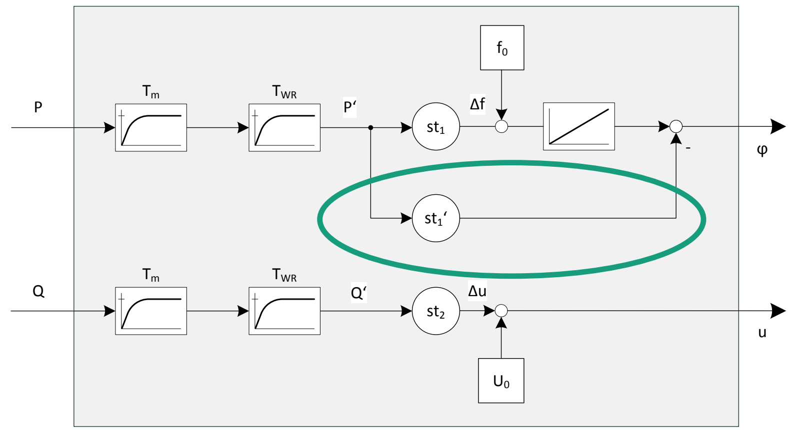
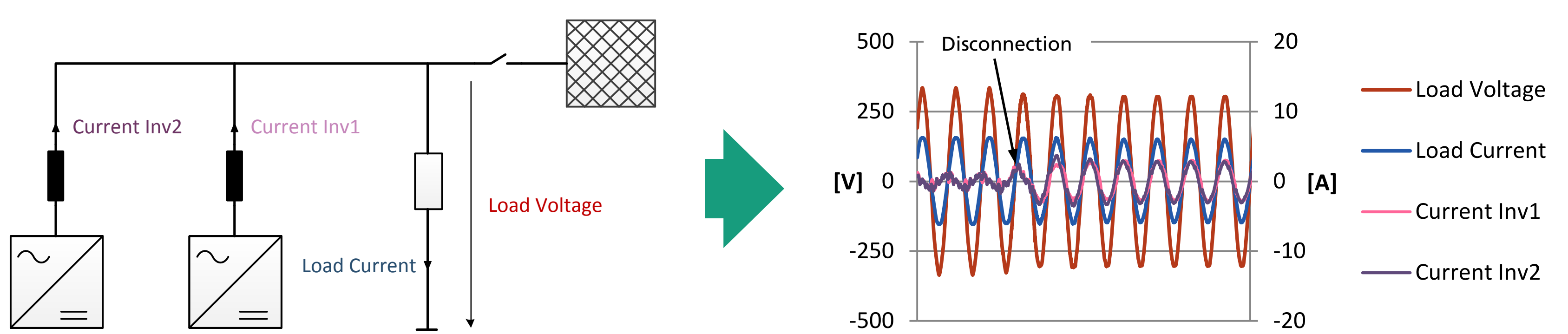
Control – SelfSync™

- **SelfSync™** is a technique that based on conventionel droops (f(P)- respectively U(Q)-characteristic)
- An additional **angle feedforward** improves stability and the dynamic behavior



SelfSync™



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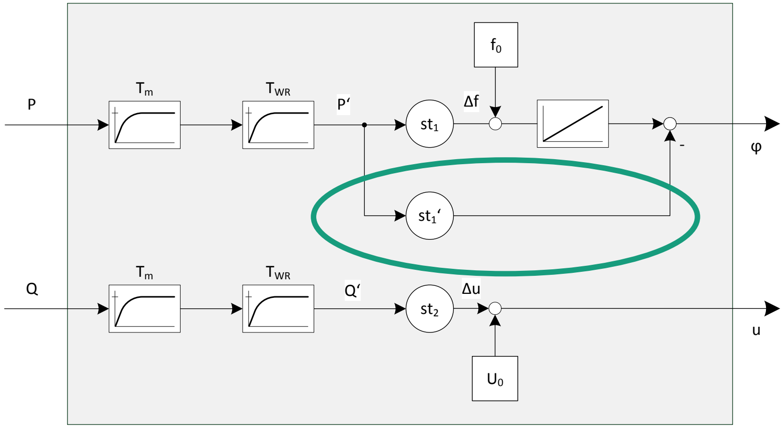
Control – SelfSync™

- Transfer droops of power plants with synchronous generators to inverters
- Represent the "Best of" behaviour of a synchronous generator in the control structure

\+ working well and stable in well planned microgrids (industrial application)

\- Line resistance is ignored: Quality criteria (performance) of control deteriorates



SelfSync™

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Control – challenge 20xx

Wishes for the future of energy production (20xx):

- 100% renewables in all voltage levels
- Arbitrary spatial distribution of grid-forming inverters
- Stable control in all voltage levels
- ……

Provide a small contribution!

Handicaps for the future of energy production (20xx):

- Storage of energy
- Stability of the electrical energy system
- Market (investments, politics, industrial interests, ……..)

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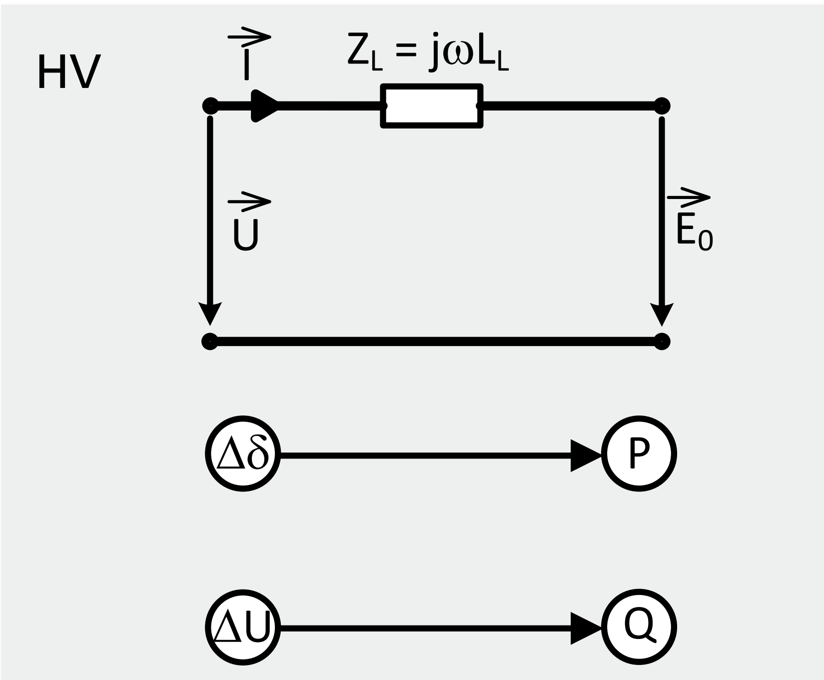
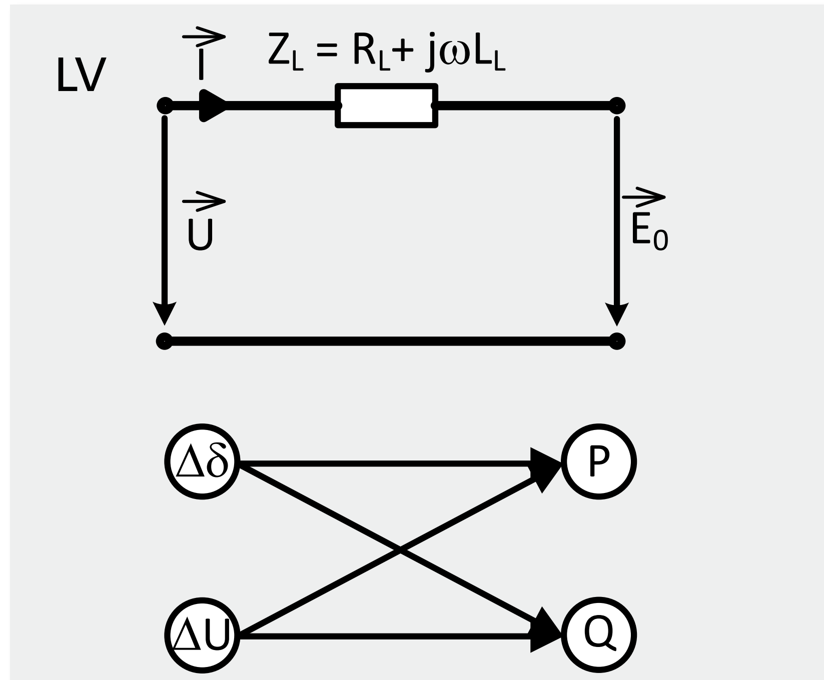
What happen at low voltage level?

- High voltage (HV) cable has X_L/R_L ratio of appr. 7 (mainly inductive)
- Low voltage (LV) cable has a X_L/R_L ratio of appr. 2





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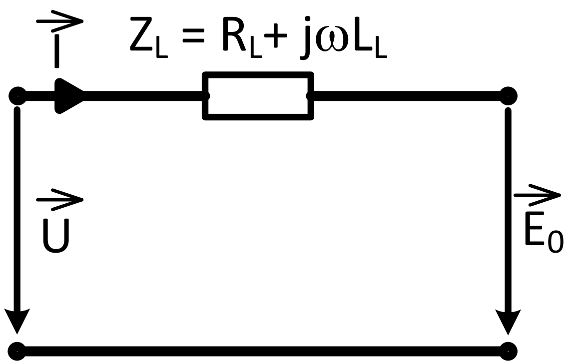
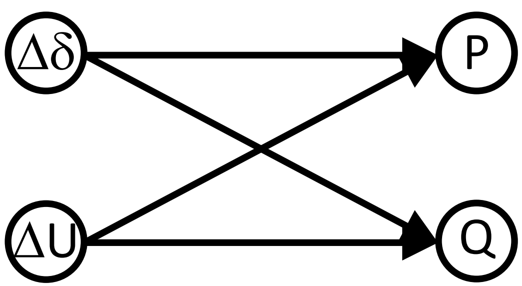
Control – challenge



$$P = \frac{L_k s + R_k}{(L_k s + R_k)^2 + (\omega L_k)^2}(U^2 - UE_0 \cos\delta) - \frac{\omega L_k}{(L_k s + R_k)^2 + (\omega L_k)^2} UE_0 \sin\delta$$

$$Q = \frac{\omega L_k}{(L_k s + R_k)^2 + (\omega L_k)^2}(U^2 - UE_0 \cos\delta) + \frac{L_k s + R_k}{(L_k s + R_k)^2 + (\omega L_k)^2} UE_0 \sin\delta$$



Difficulty: distribution grid

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

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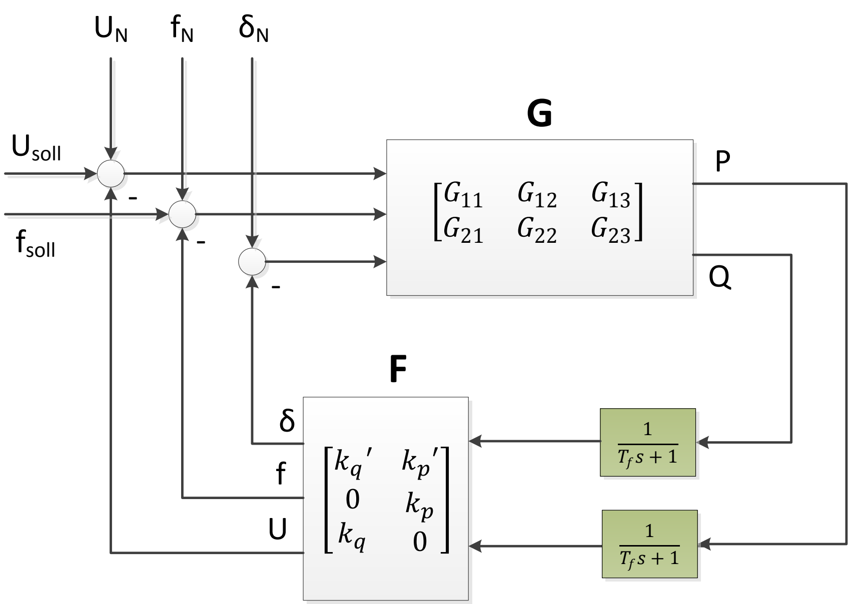
Control – Improving SelfSync



Feedback matrix **F**

- k_p, k_q reflect the droops
- angle feedforward: improve stability and transient behavior ($k_p{}'$, $k_q{}'$)

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

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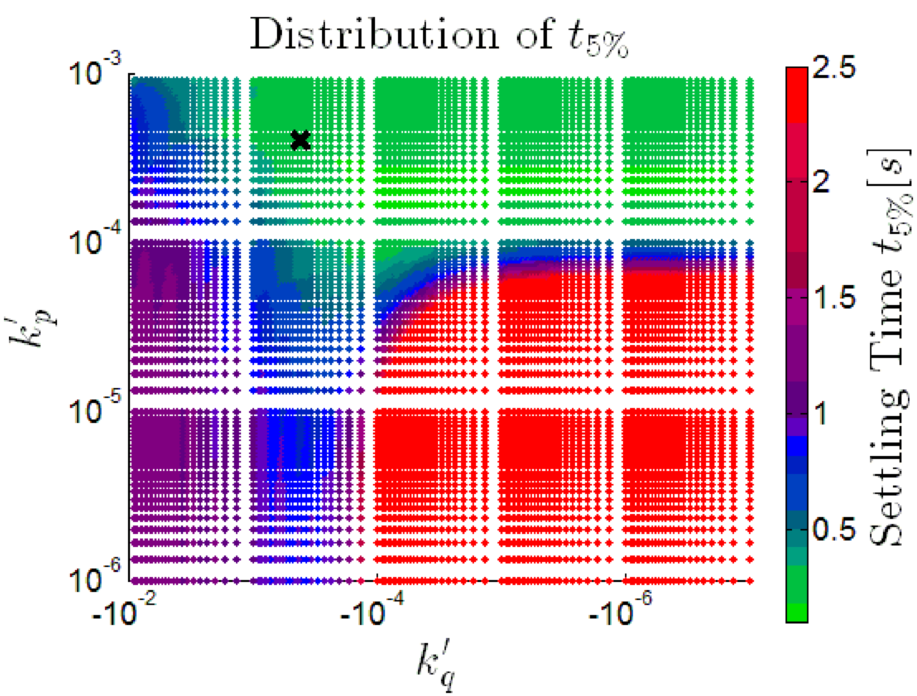
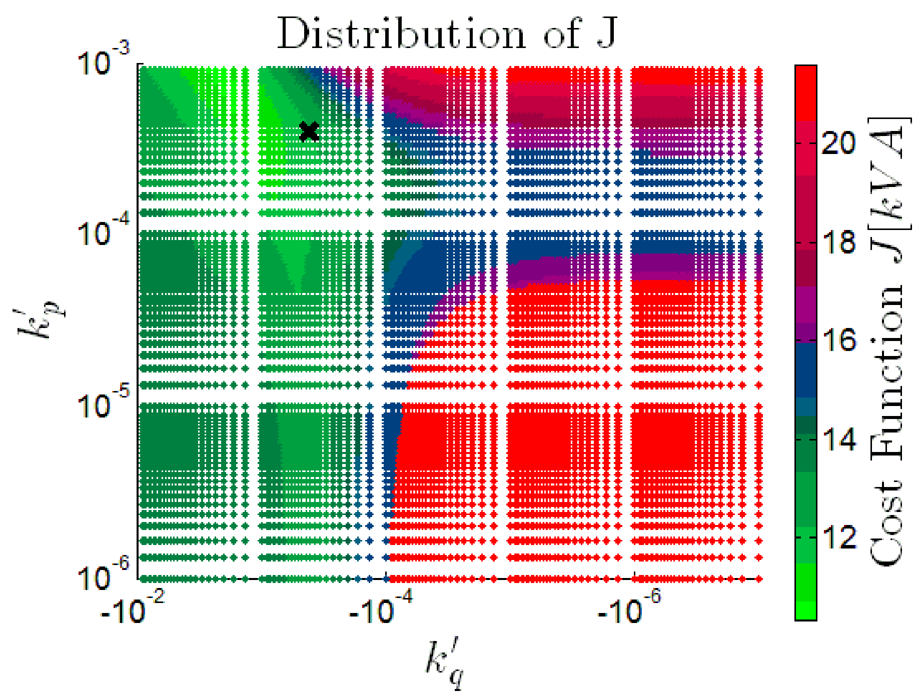
Improving SelfSync - choice of the parameters k_p', k_q'

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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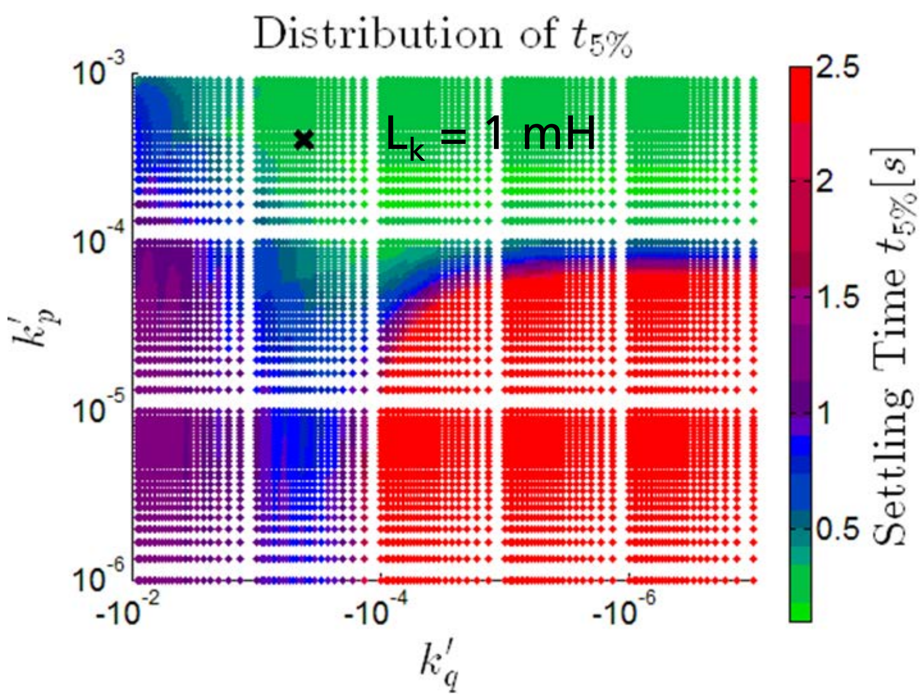
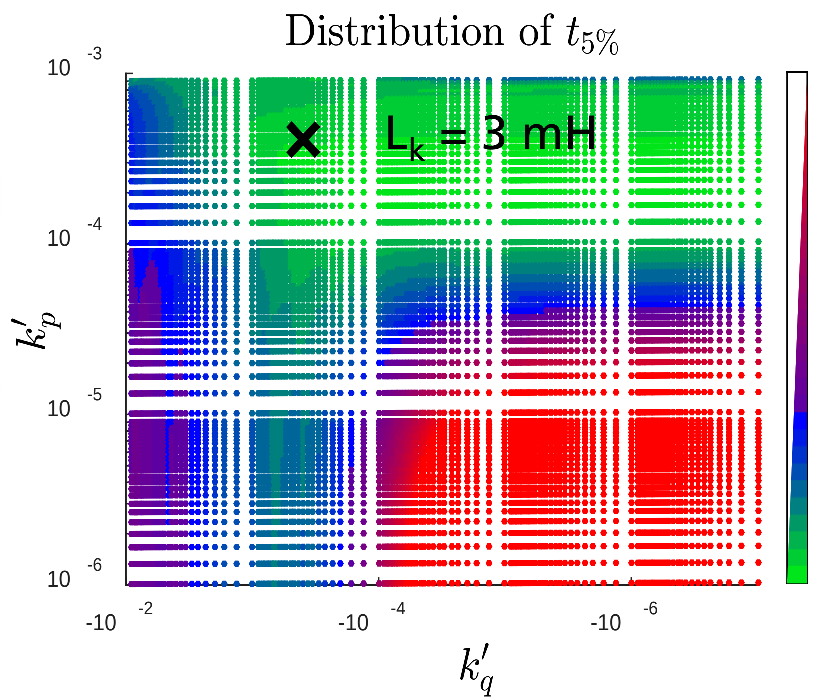
Comparing grid parameters to choose k_p', k_q'

Different L_k = xx mH (R_k = 0.4 Ω)





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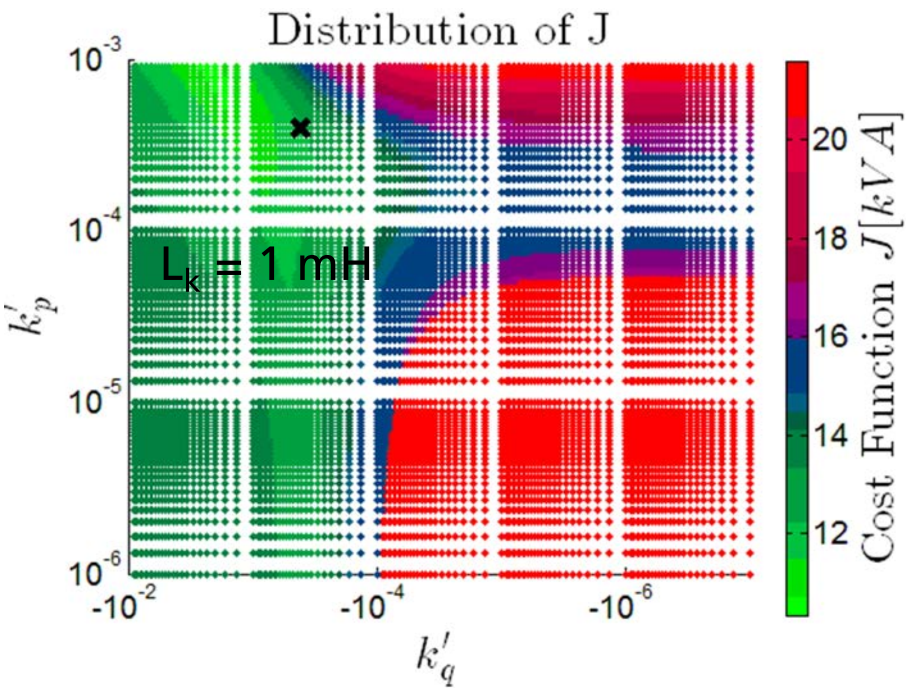
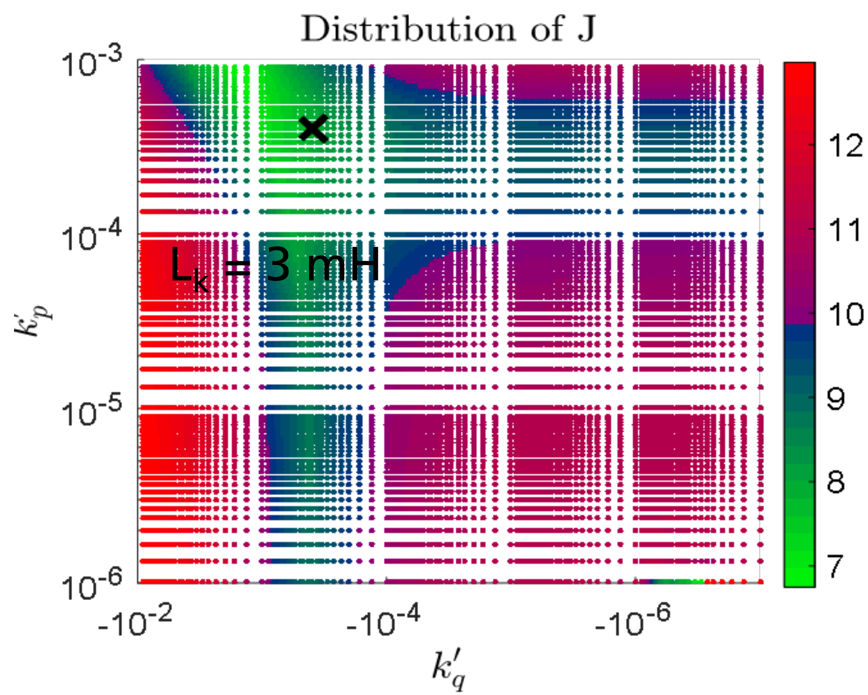
Comparing grid parameters to choose k_p', k_q'

Different L_k = xx mH (R_k = 0.4 Ω)





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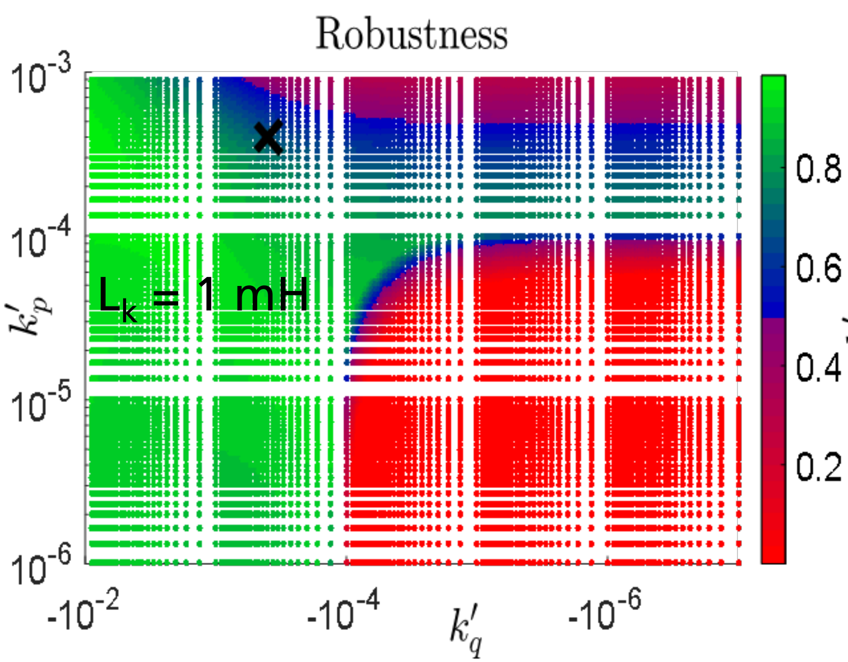
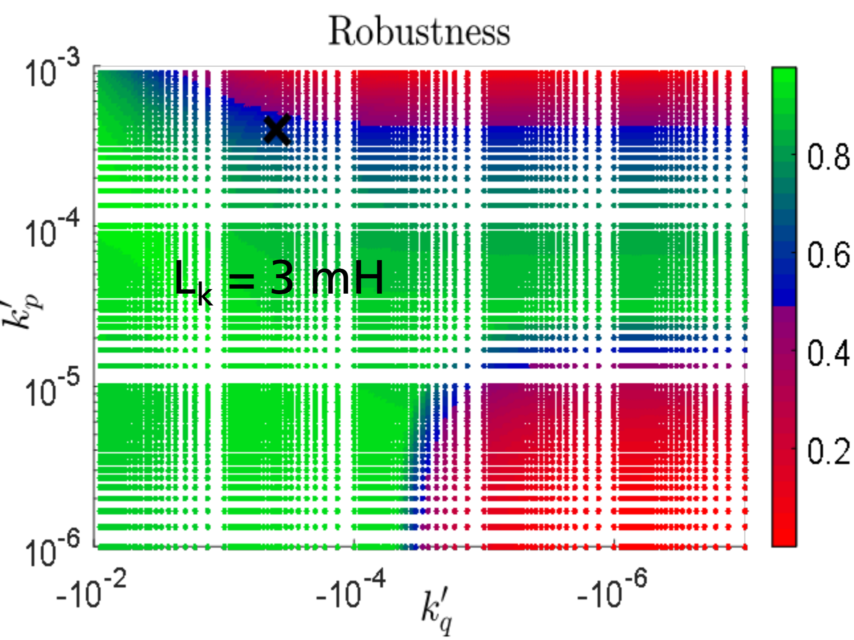
Comparing grid parameters to choose k_p', k_q'

Different L_k = xx mH (R_k = 0.4 Ω)





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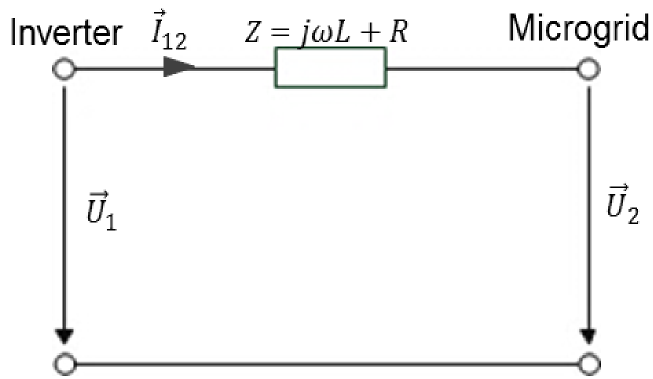
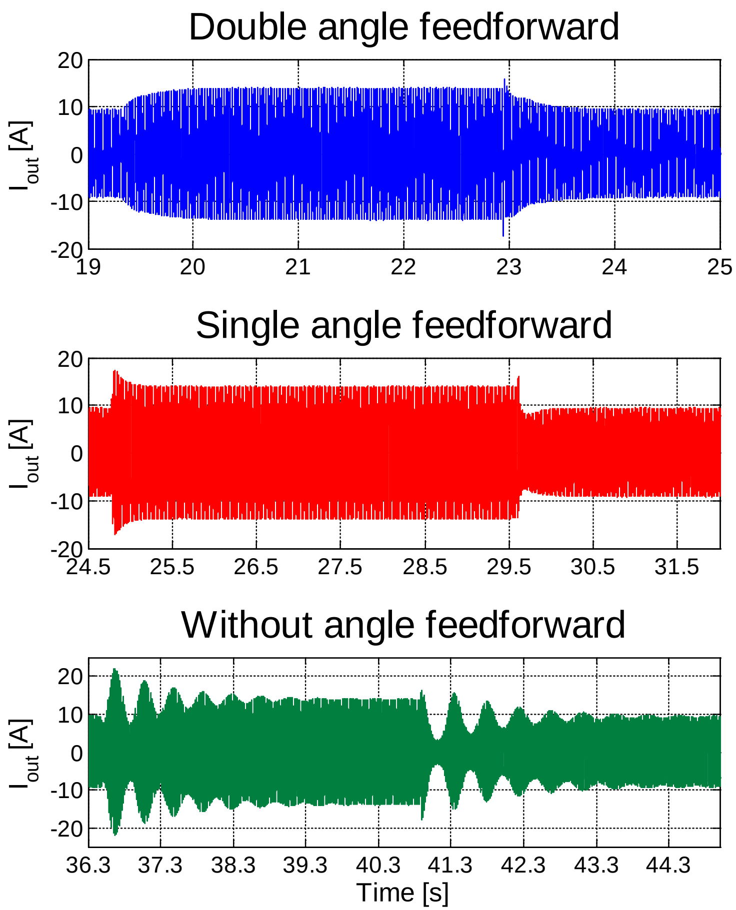
Experimental results – voltage step



- 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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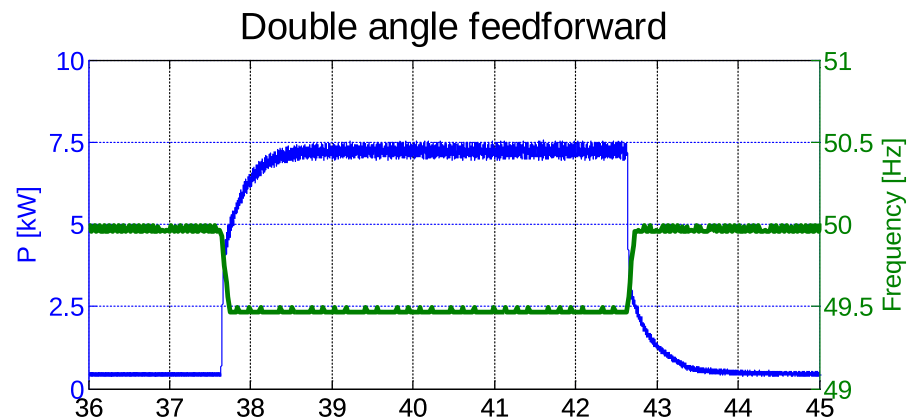
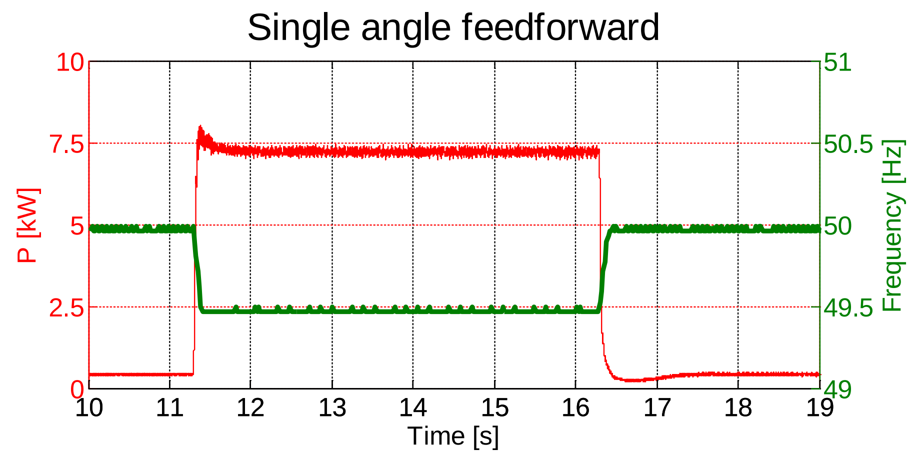
Grid-Forming Inverters in Microgrids

Experimental results – frequency step

- Frequency step from 50Hz to 49.5Hz 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
- Outlook:
  Actual we are designing a robust control for grid forming inverters
  This will be the next story!

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