Grid-Forming Inverters in Microgrids

Axel Seibel, Peter Unruh
Department: Converters and Drive Technology
Contents

- Introduction
- Improving the control of grid-forming inverters
  - SelfSync
  - Improving SelfSync
  - Robust control
- Practical tests
- Conclusion
Grid-Forming Inverters in Microgrids

Introduction

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

\[ f = f_0 - k_p \cdot (P - P_0) \]
\[ U = U_0 - k_q \cdot (Q - Q_0) \]
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

\[ Z_L = j\omega L_L \]

\[ \vec{U} \]

\[ \vec{E}_0 \]

\[ \delta \]

\[ \Delta\delta \]

\[ \Delta U \]

\[ f \rightarrow P \]

\[ U \rightarrow Q \]

\[ \vec{f} \]

\[ \vec{U} \]

\[ \vec{E}_0 \]
Grid-Forming Inverters in Microgrids
Control – SelfSync™

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

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
Grid-Forming Inverters in Microgrids

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
- ……

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

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

Provide a small contribution!
Grid-Forming Inverters in Microgrids

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
Grid-Forming Inverters in Microgrids

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
Grid-Forming Inverters in Microgrids
Control – Improving SelfSync

Feedback matrix $F$
- $k_p$, $k_q$ reflect the droops
- angle feedforward: improve stability and transient behavior ($k_p'$, $k_q'$)

\[ k_p = \frac{\Delta f}{P_{\text{max}}} \quad k_q = \frac{\Delta U}{Q_{\text{max}}} \]
With a higher resistive grid impedance the parameter $k_q'$ gets more relevance (here $L_k = 1\text{ mH}$, $R_k = 0.4\ \Omega$).
Grid-Forming Inverters in Microgrids
Comparing grid parameters to choose $k_p'$, $k_q'$

Different $L_k = xx \text{ mH}$ ($R_k = 0.4 \text{ } \Omega$)
Grid-Forming Inverters in Microgrids
Comparing grid parameters to choose $k_p'$, $k_q'$

Different $L_k = xx \text{ mH} (R_k = 0.4 \Omega)$
Grid-Forming Inverters in Microgrids
Comparing grid parameters to choose $k_p'$, $k_q'$

Different $L_k = \text{xx mH} (R_k = 0.4 \ \Omega)$
Grid-Forming Inverters in Microgrids

Experimental results – voltage step

- Voltage step from 230 V\textsubscript{eff} to 245 V\textsubscript{eff} and back
- Grid impedance (0.345 Ω, filter)
- Smooth settling with double angle feedforward
Grid-Forming Inverters in Microgrids

Experimental results – frequency step

- Frequency step from 50Hz to 49.5Hz and back
- Smooth settling
- Instantaneous reaction
Grid-Forming Inverters in Microgrids

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!
Contact

Axel Seibel
Königstor 59
D-34119 Kassel
axel.seibel@iwes.fraunhofer.de