Grid-Forming Controllers in the Distribution Network Landscape

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Outline

	Thema	Key Points
1	Introduction	• Distribution networks • Grid-following • Grid-forming
2	Grid-Forming Control	• GFM control system • GFM model stability
3	Distribution network	• Selection of the network • Test cases & validation
4	Conclusions	

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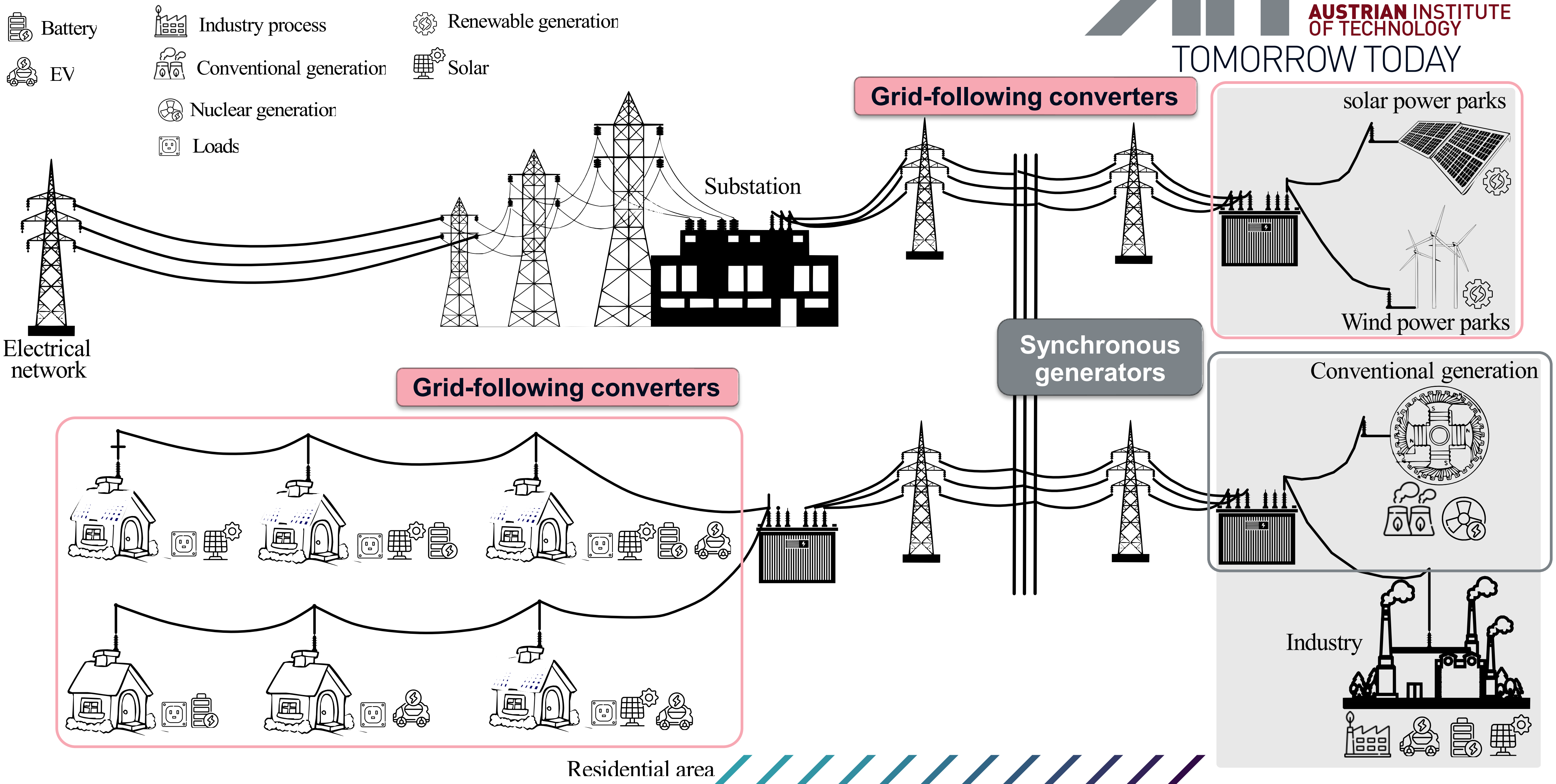
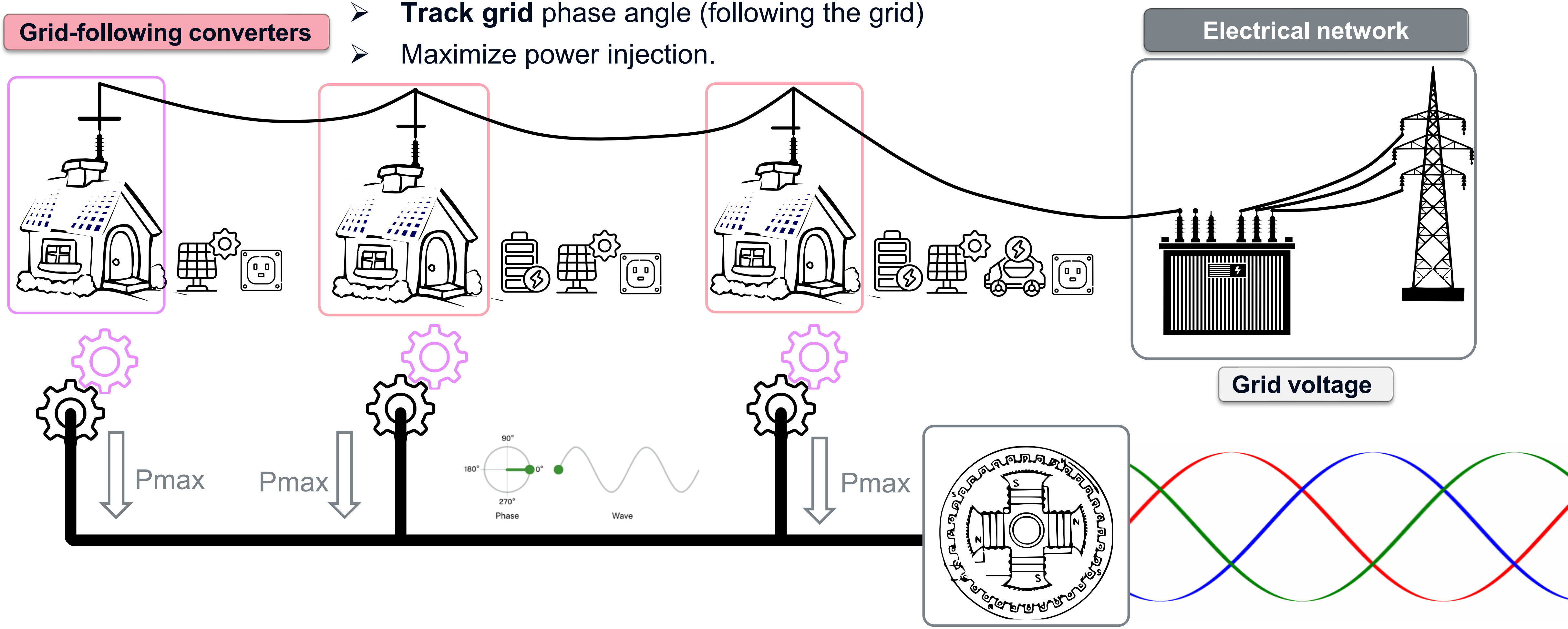
1. Introduction – Grid following on distribution networks



1. Introduction – Grid following systems

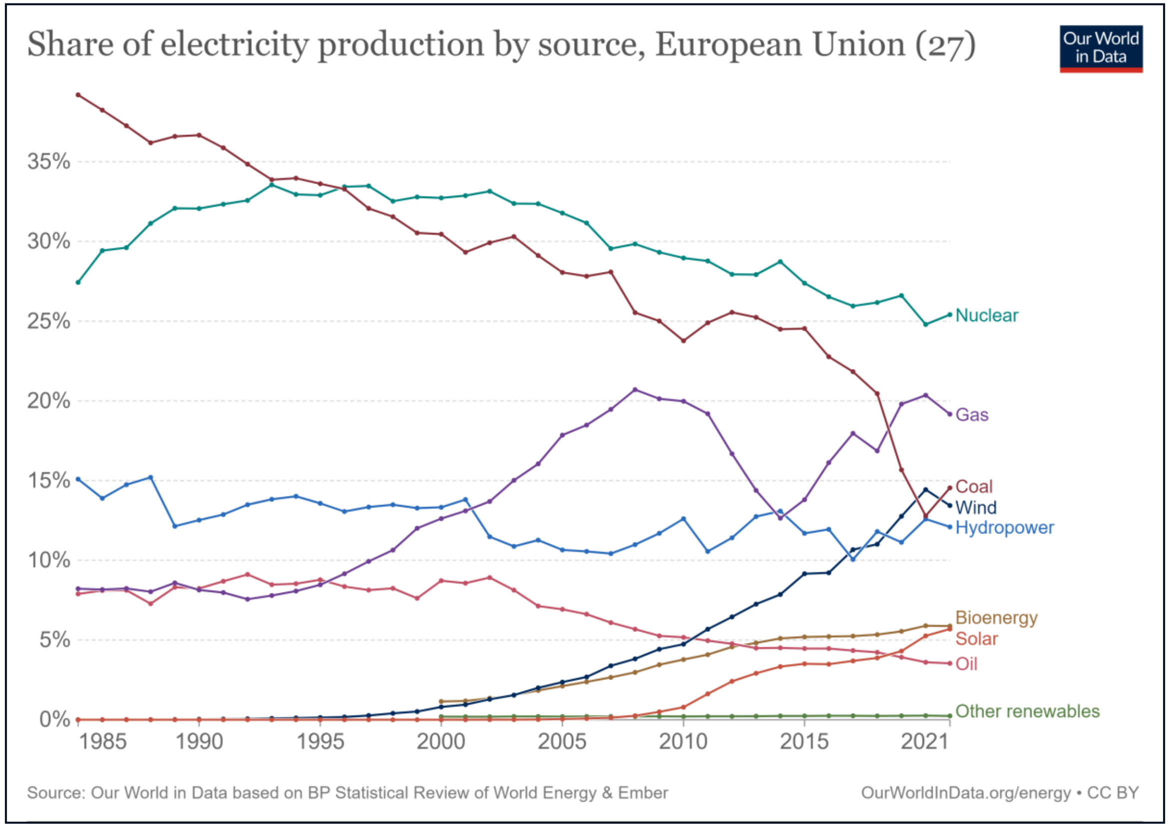
Grid-following converters

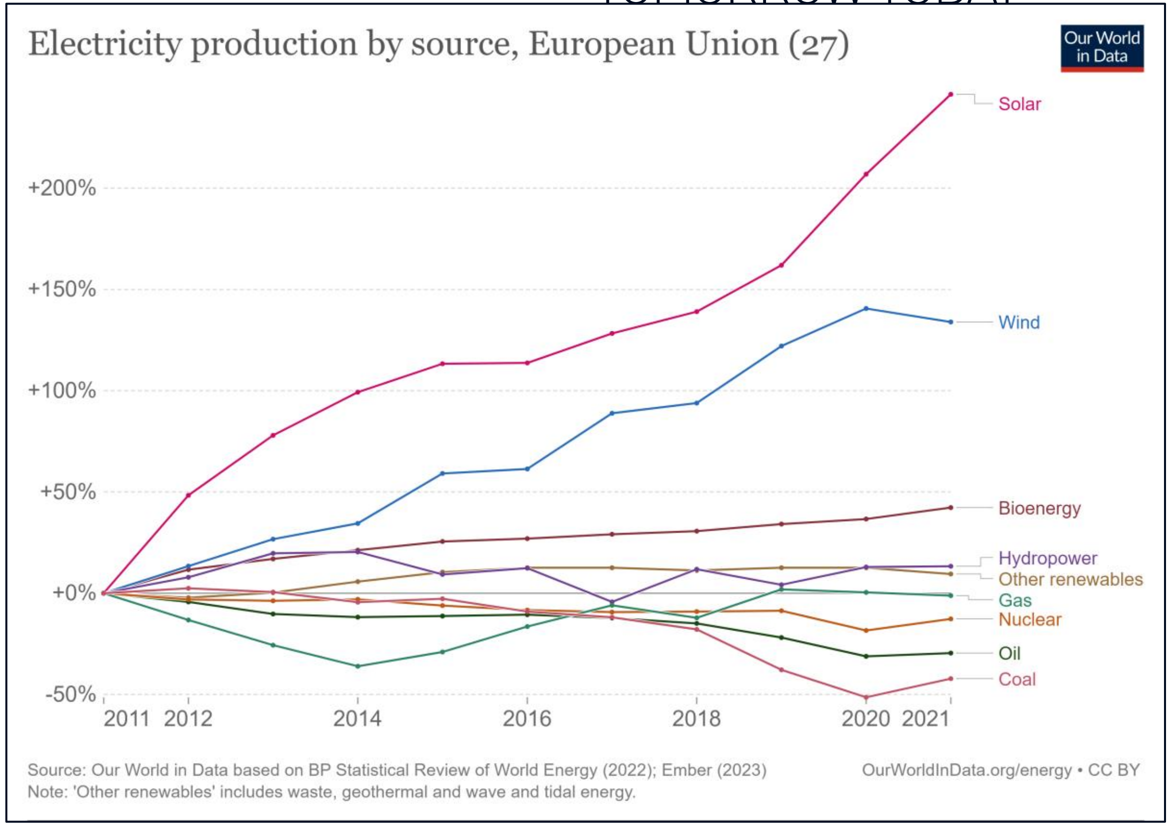
- **Track grid** phase angle (following the grid)
- Maximize power injection.



1. Introduction – Renewable energy in europe

Electricity production mix transformation





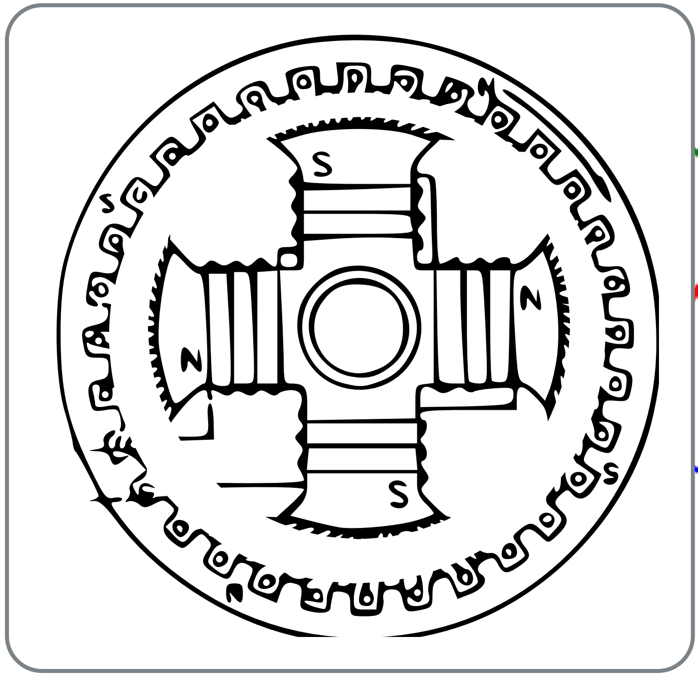
What is an impact on increase of the low carbon electricity production on the power system stability?

Overall inertia decrease ↓

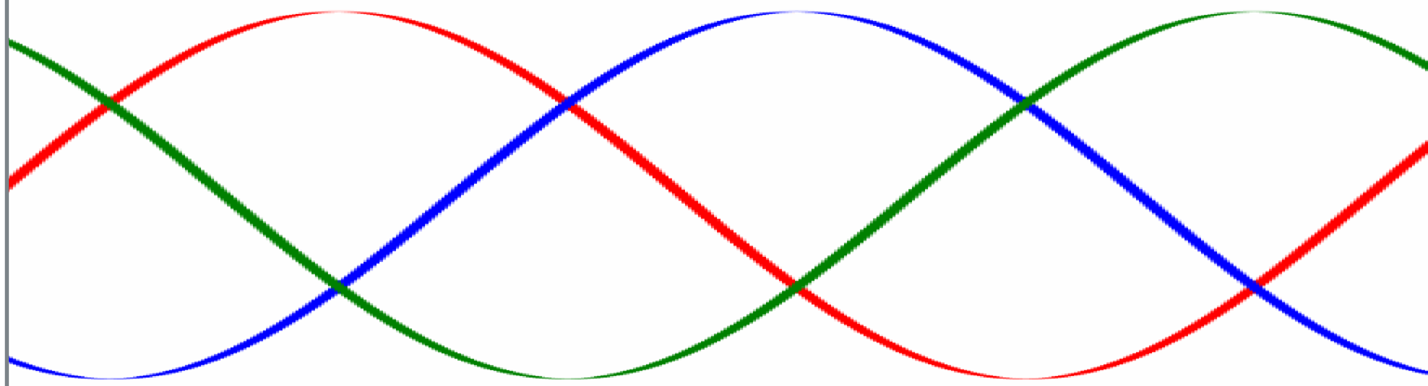
1. Introduction – Grid forming control

Emulation of the synchronous generator:

- **Stator (Fixed part):** Electromagnetic loop
- **Rotor (Rotating part):** Electromechanical loop

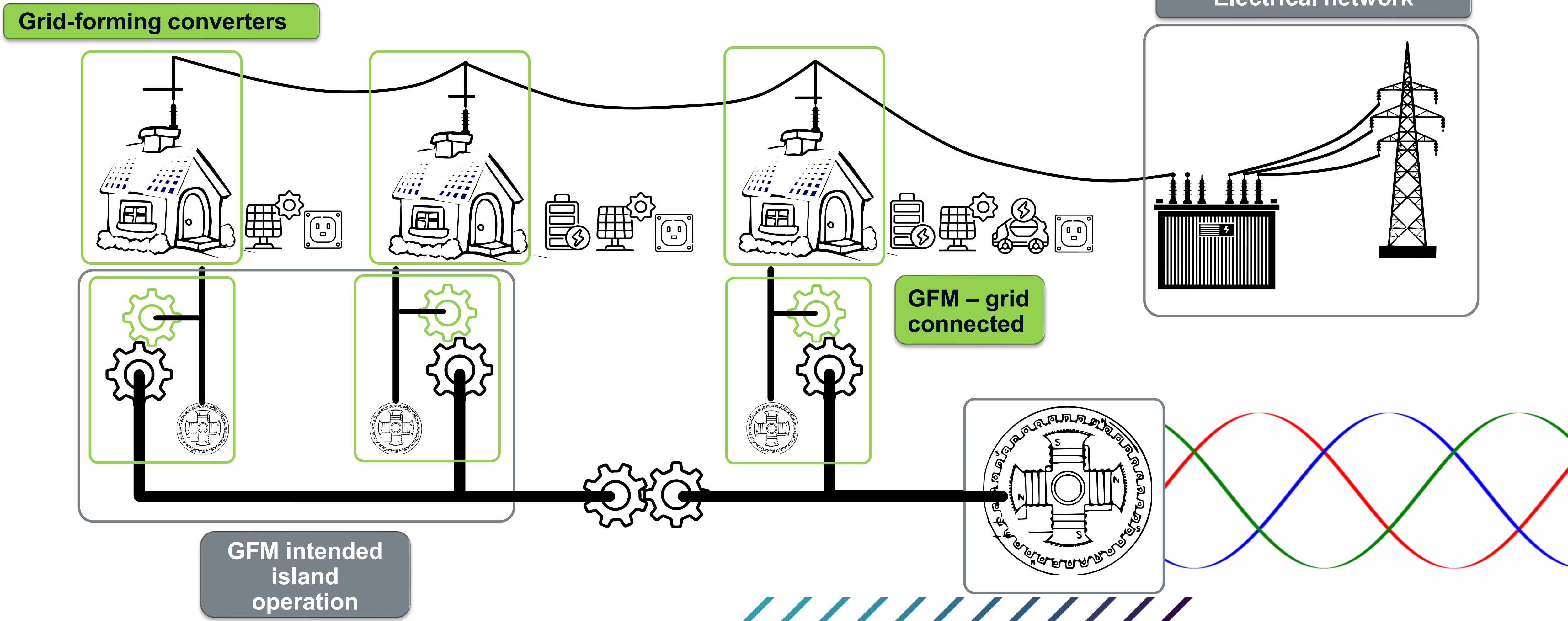


Synchronous generator



1. Introduction – Grid forming control

- It creates its **own voltage and frequency**
- Natural interaction with the grid
- **Increases grid stability** with inertia and damping



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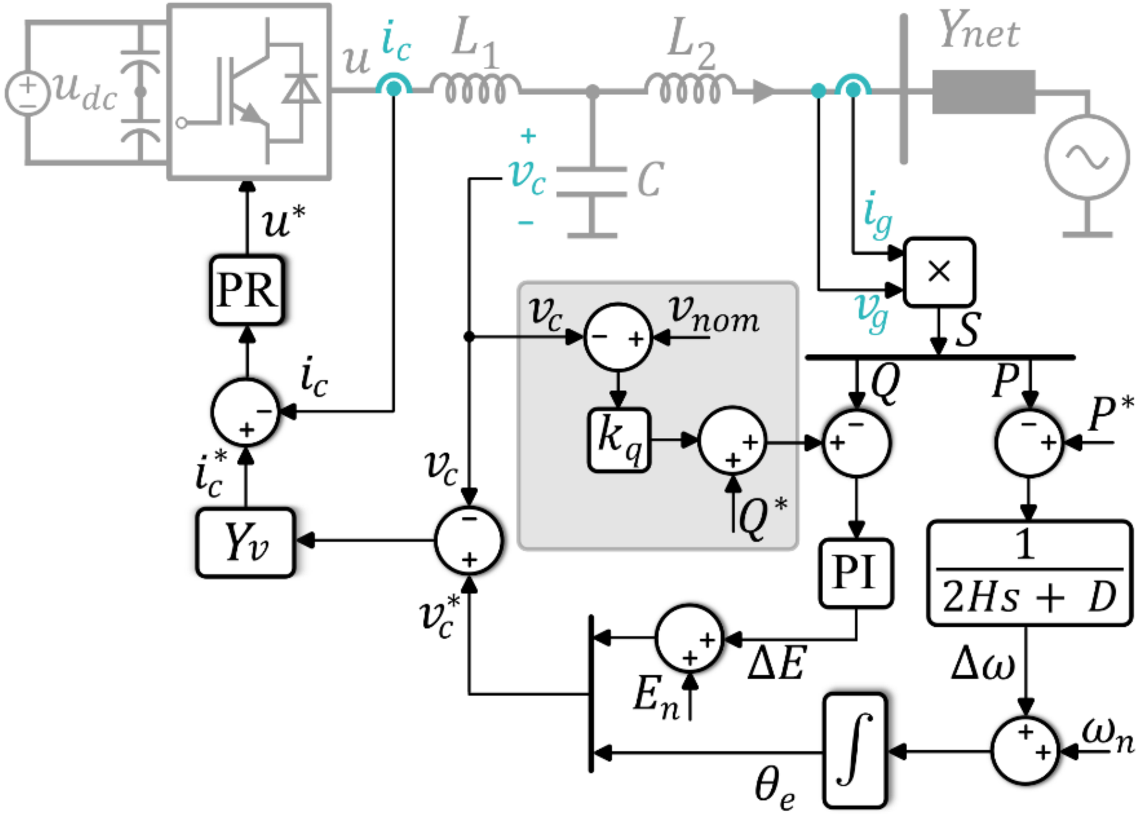
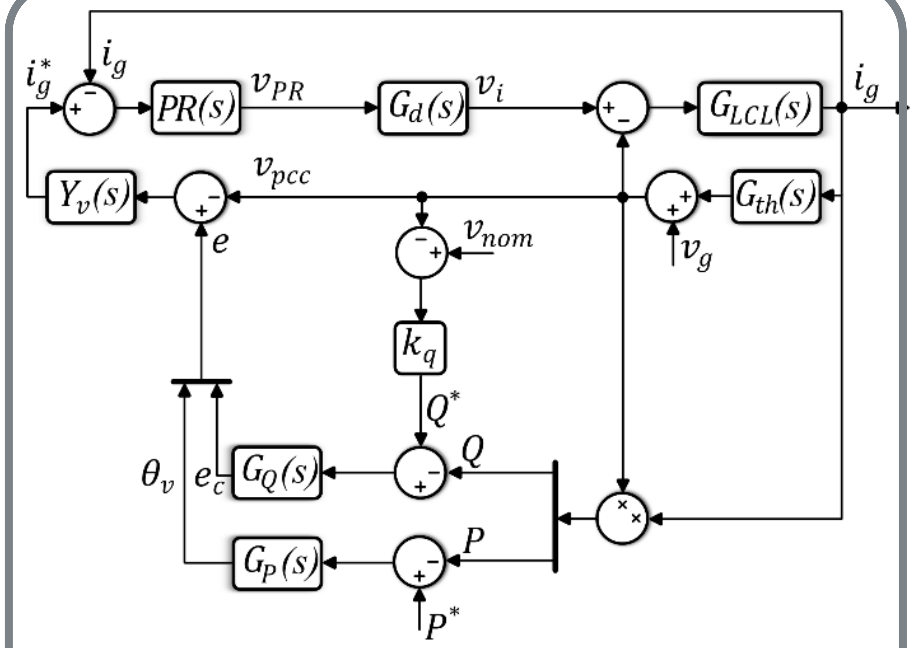
2. Grid-forming control system



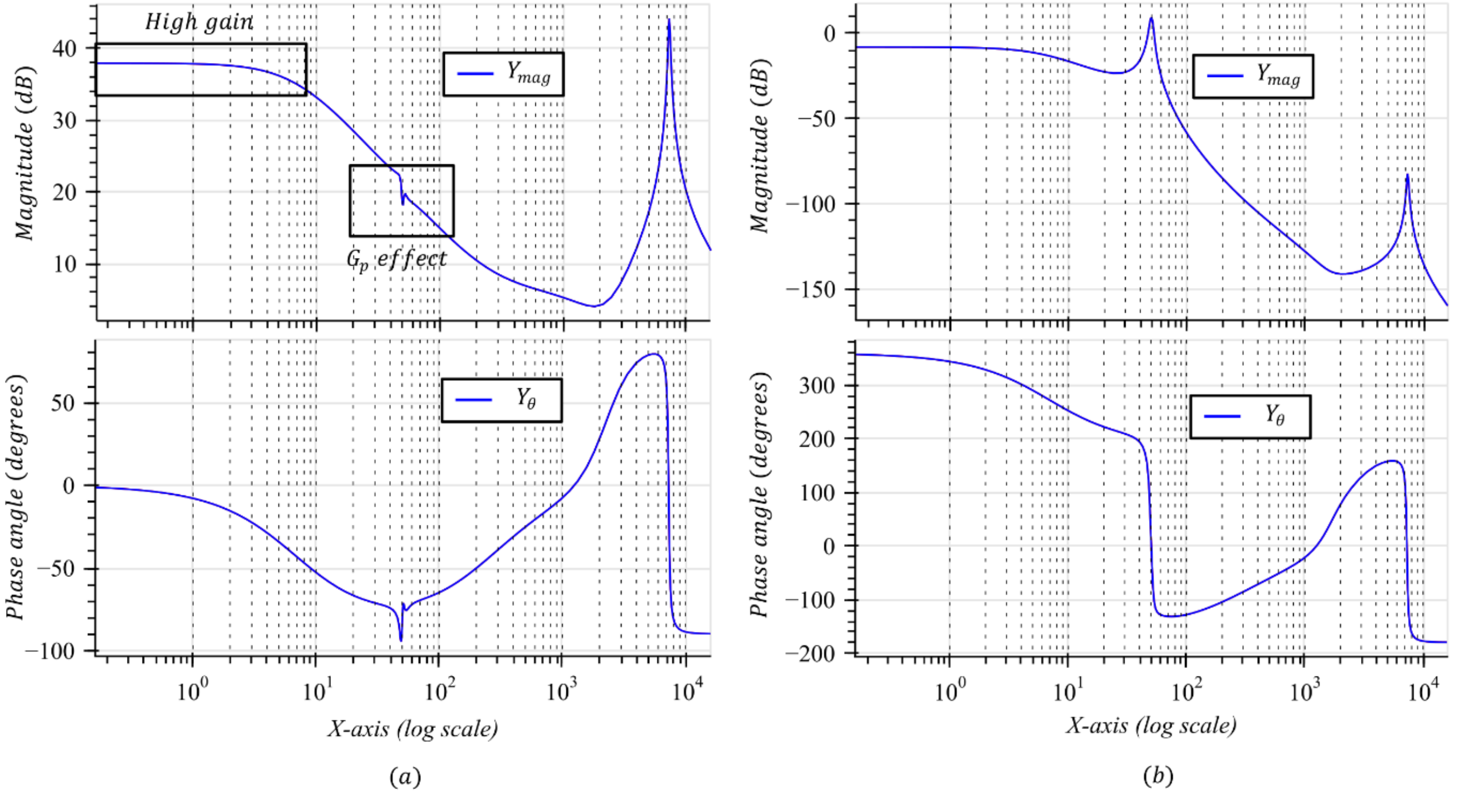
- Current controller $PR(s) = k_p + \frac{2k_i}{s^2 + \omega_n^2}$
- Virtual admittance $Y_v(s) = \frac{1}{L_v s + R_v}$
- Power controller $G_P(s) = \frac{1}{2Hs + D}$
- Reactive controller $G_Q(s) = \frac{k_p s + k_i}{s}$
- Droop control $\Delta Q = (v_{nom} - v_c) \cdot k_q$
- PWM Delay $G_d(s) = \frac{12 - 6T_d s + T_d^2 s^2}{12 + 6T_d s + T_d^2 s^2}$

2. Grid-forming model

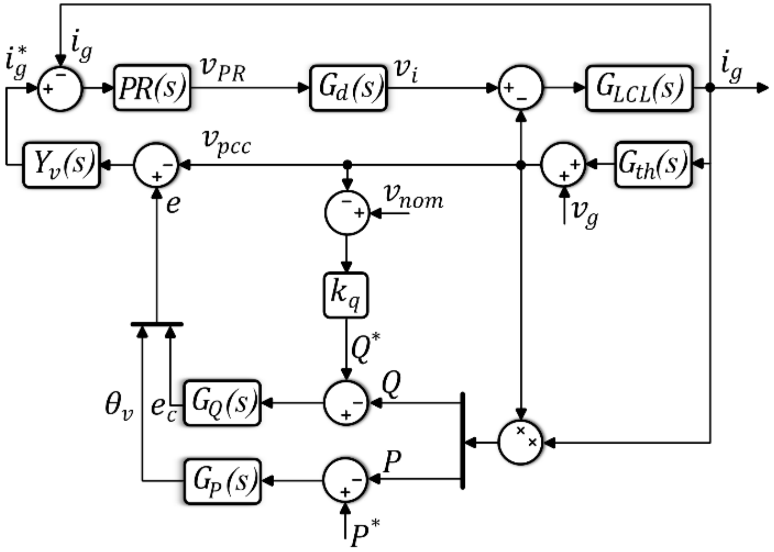
Linearization – point of operation

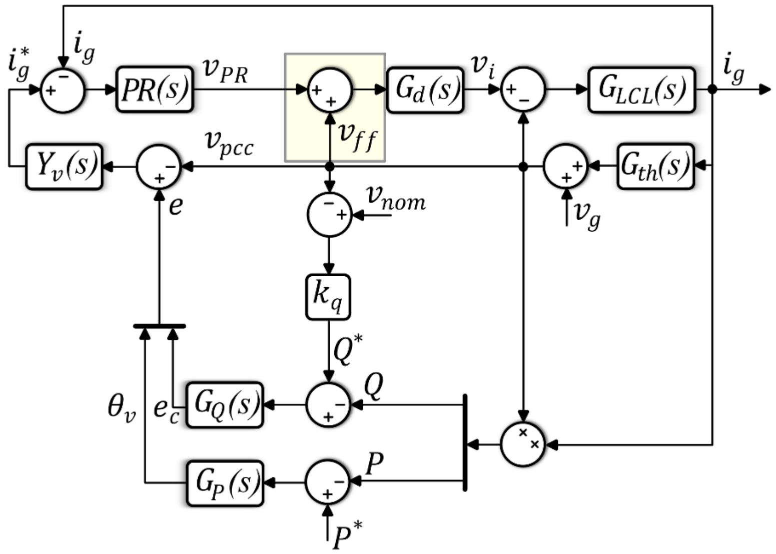


Transfer function representation



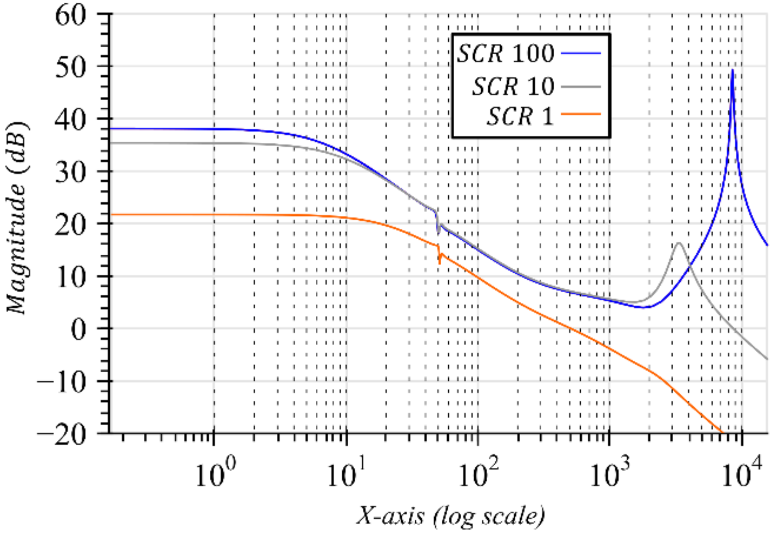
2. Grid-forming model – feedforward & SCR

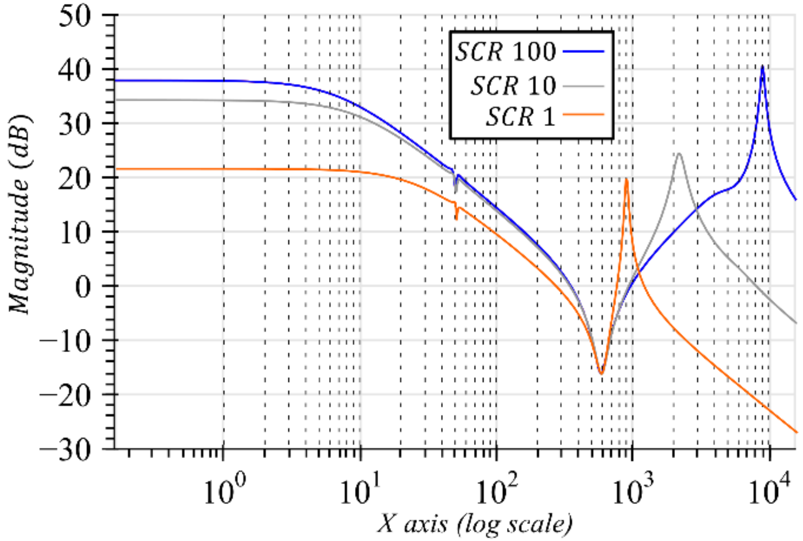




- Use of feedforward allows the system to **respond quickly.**
- **Increase resonances** in weak grids.
- LCL resonance reduces with SCR

SCR change from 100 to 1





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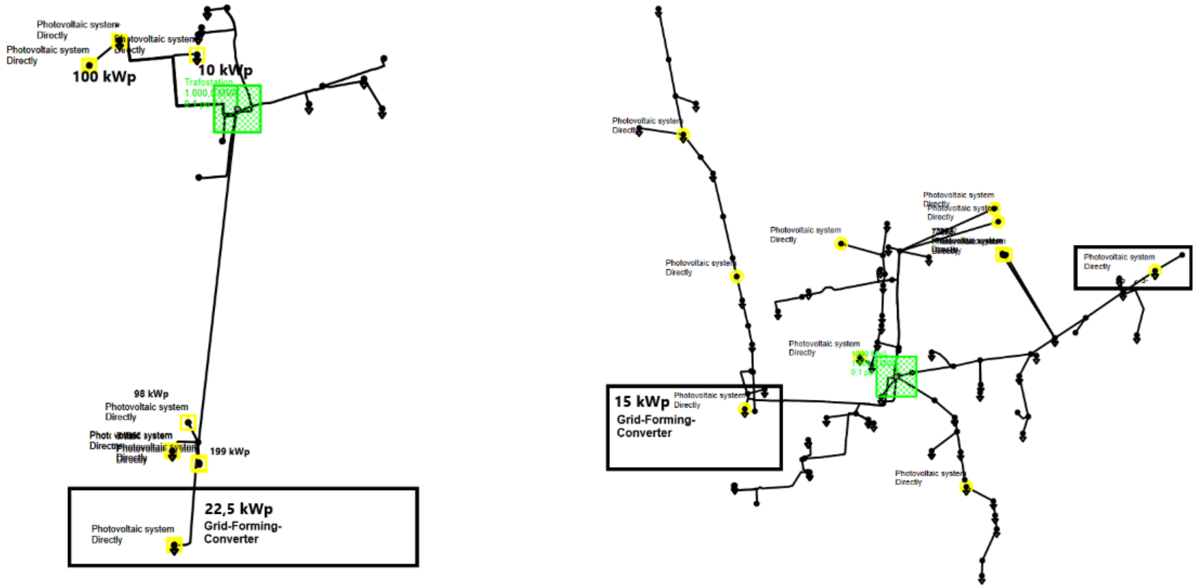
3. Selected network topology

- Location of **5 grid-connected** units at the yellow dots.
- System was analyzed in **two forms**:
  - 4 GFL / 1 GFM
  - 5 GFM
- All power converter **remained connected and stable** during the multiple grid events:
  - Phase jumps
  - Voltage drops
  - Rate of change of frequency (RoCoF)

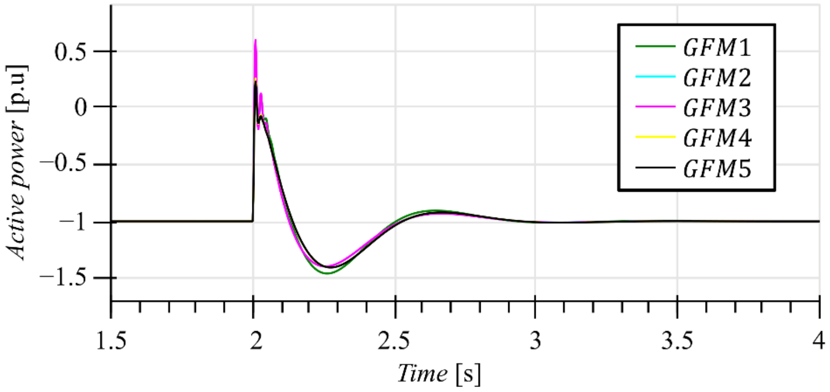


Test num	Description	Grid SCR	Grid R/X	Operating point
1	Nominal powers	1000	0.33	P=1, Q=0.0382, V=1.0595,
2	Negative setpoint on conv.	1000	0.33	P=-1, Q=0, V=1.0475
3	Load set to zero	1000	0.33	P=1, Q=0.3558, V=1.1389
4	Prod PV to zero	1000	0.33	P=0, Q=-0.2479, V=0.8880
5	Nominal powers	100	0.33	P=1, Q=0.1040, V=1.076
6	Reduced powers	10	0.33	P=1, Q=0.0, V=1.0059
7	Reduced powers	1	0.33	P=1, Q=0.0, V=0.9869
8	Nominal powers	100	1	P=1, Q=0.2599, V=1.1150
9	Nominal powers	100	3	P=1, Q=0.3666, V=1.1416
10	**All grid forming**	**100**	**1**	**P=1, Q=0.0, V=1.0059**

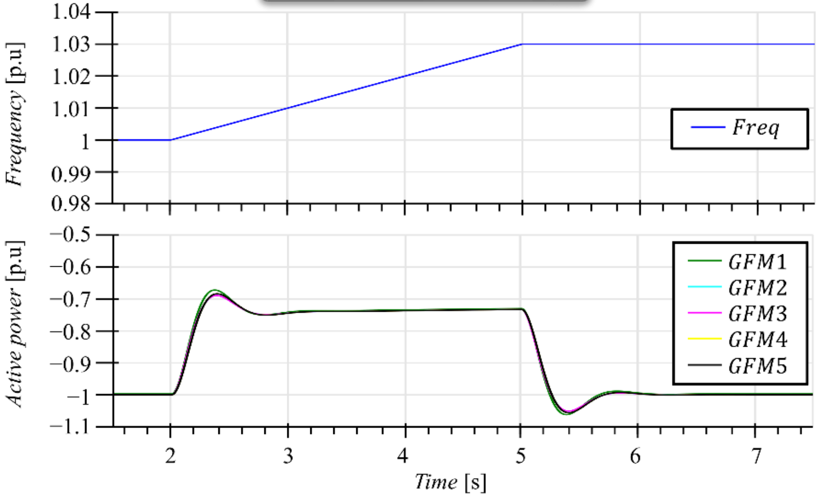
3. Validation cases

- **Phase jump of 10-degree** creates an initial current spike dependant on the virtual impedance, **Xv**, and recovers actual power due to power synchronization parameters **H** and **D**.
- Considering a **RoCoF of 0.5Hz/s** on the distribution network the GFM power converter provide a power based on the inertia constant, **H**, and the virtual impedance, **Xv**.
- With a drop of **2% of the voltage** at the grid, the power converter should provide an equivalent reactive power based on **kq** (droop factor) and the virtual impedance, **Xv**.

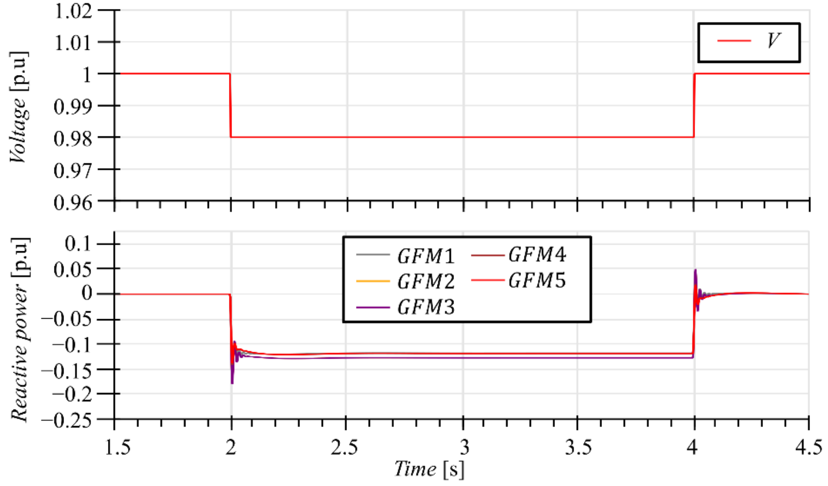
10-degree phase jump



RoCoF of 0.5Hz/s



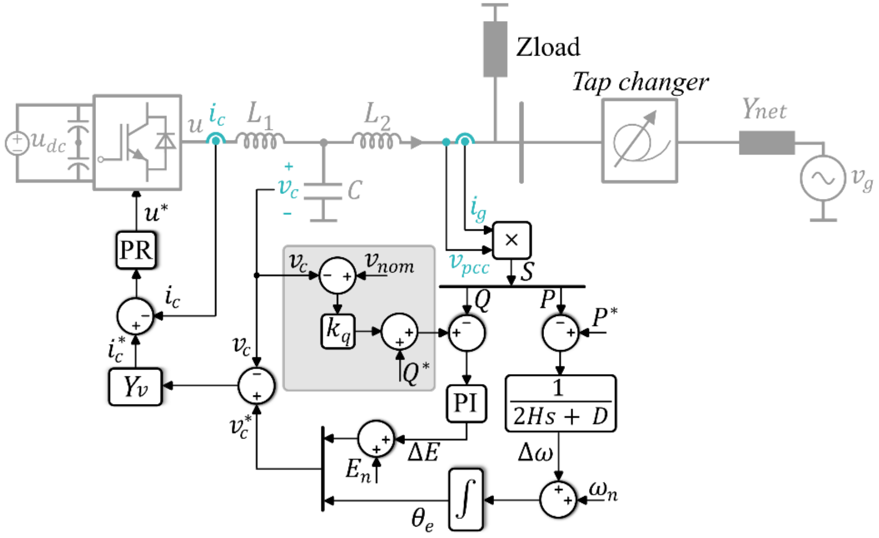
RoCoF of 0.5Hz/s



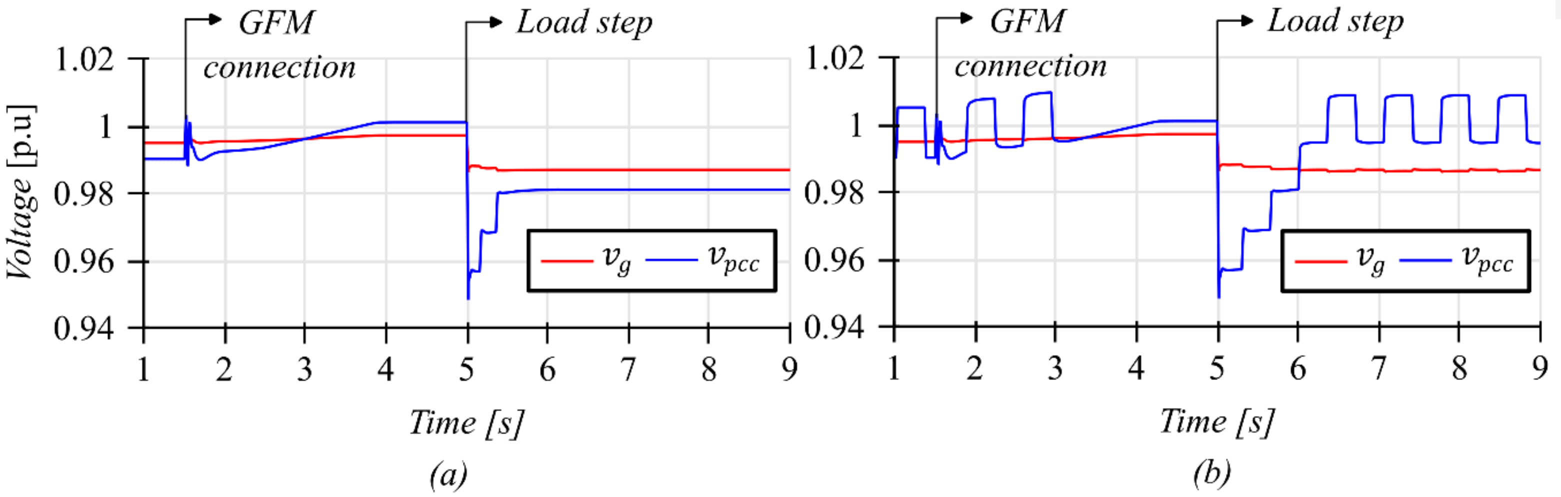
3. Validation cases – Tap changer

➢ Validation of the GFM structure in front of two different settings of a tap changer system.

- Stable case → The GFM unit **did not have a negative effect** on the tap changer.
- Unstable case → The tap changer already had oscillations prior to the GFM connection. Even standard GFL units were having bad performance.



Stable Case	Unstable case
delay_tapChanger = 0.15 s	delay_tapChanger = 0.3 s
deadband_tapChanger = 0.05 s	deadband_tapChanger = 0.01 s



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4. Conclusions

- ✓ Step-by-step examination of GFM control within the distribution network environment.
  - Small signal model, impedance behavior and analysis over feedforward strategies.
- ✓ Comprehensive assessment of the grid-forming behavior in a real industrial environment.
  - Multiple SCR
  - Multiple X/R rations
  - Active/reactive power setpoints.
- ✓ Evaluation of interoperability between GFM units and tap changers on the distribution network.

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