Grid Control 2.0 – Control and Stability in Inverter Dominated Power Systems

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Grid control is mainly based on bulk power plants with synchronous machines.

Share of power electronics is increasing considerably (PV/Wind)

Today, conventional power plants are inevitable to support system stability

Even during very high feed in of renewable power conventional power plants need to run

For some splitting scenarios new inverters control technologies are needed to support system stability

Non-representative day with high inverter participation in Germany

Source: www.energy-charts.de
Project Objectives

- Proving, that interconnected power systems can be operated stably with very high shares of inverters by applying suitable control technology.

- Investigate stability for separated system parts during system split.

- Preparation of the implementation - concretely for the German part of the continental European power system.
Grid Control 2.0: Stakeholders

 Projekt objective:
 Design of stable, robust and efficient inverter dominated power system

*Grid Operators (TSOs, DSOs):*
Power system requirements

*Manufacturers of PV-, Wind-, Storage-, HVDC-systems:*
Abilities of inverters

*Political Stakeholders:*
Regulatory aspects

*Research institutions:*
Innovative solutions
Grid Control 2.0: Consortium
“Momentary reserve and voltage forming in the power system can be sufficiently provided by power units with (grid) voltage forming inverters.”

Provision of momentary reserve by inverter coupled power units can be integrated seamlessly into the existing control structure.

Example: SelfSync
dog) - control with
- \( f(P) \) and \( V(Q) \)-droops
- phase feed-forward control
- here: decoupled control of \( P \) and \( Q \)

Grid Control 2.0 - Workflow

WP 1: Simulation-methodology

WP 2: Scenarios, critical grid states

WP 3: Studies for grid integration and system stability
   - One-Machine/One-Inverter-Modell
   - Simulation
   - Frequency control
   - Models:
     - Grid
     - Electrical loads
     - Conv. generators
   - Inverter models
   - Studies:
     - f/V-stability
     - Angle stability
     - Grid protection
     - Islanding
     - Quality of supply

WP 4: Development of robust inverter control methods
   - Detailed inverter models with
     - grid voltage forming controls and
     - grid following controls

Power System Requirements for inverters

WP 5: Laboratory tests
   - Field tests

WP 6: Transformation path, Preparation for implementation

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One-Machine/One-Inverter-Modell

Frequency control

Simulation

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Frequency Stability

Research Questions

- Which proportions of synchronous generators, grid voltage forming inverters and current feeding inverters can guarantee frequency stability?
  - Which functionalities of inverters are required?
  - How should the inverters be parameterized?

- What is the minimum share of synchronous machines?

- How should voltage forming and current feeding inverters be distributed on the different voltage levels?

- Are RMS-simulations still sufficiently accurate for studying frequency stability with the new types of generators or are EMT-simulations required?

Solved  Work in progress  Not started yet
Test system and grid data

Single-Line-Diagram

- RMS- and EMT-simulations for systems split
- Combinations of generators:
  - SG + PV (current feeding)
  - SG + SelfSync (voltage forming)
  - SG + PV + SelfSync
- Scenarios:
  - Variation of export by changing the load
  - Variation of proportion between inverters and rotating machines by changing SG power

Topology and parameterization supplied by TSOs
EMT Simulation Results
Current Feeding Inverters

Status quo:
- $Q_{\text{const}} = 0$, FRT-Freeze on, reaching $P_{\text{set}}$ in 10s
- Up to 20% within frequency limits

Adapted parameters:
- $V_{\text{const}}$, FRT-Freeze off, reaching $P_{\text{set}}$ in 1 s
- Up to 60% within frequency limits
EMT Simulation Results
Current Feeding vs. Voltage Forming Inverters

Current Feeding Inverters
max. share of inverters between 20% and 60%
(depending on parameterization)

Voltage Forming Inverters
Damped frequency behavior
100% inverters possible
Electrical inertia can be set with parameter
A) Specific\(^*\) electrical inertia of inverters << Specific Inertia of SG
B) Specific electrical inertia of inverters = Specific Inertia of SG
\(^*\) = Inertia / Power

A)

B)
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Power System Requirements for inverters

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Long Term Voltage Stability
Influence of Voltage Supporting Inverters in DN

- Voltage support on the distribution level can be detrimental for the voltage stability on transmission level, because of compensating the self-regulating effect.

- New emergency controller against voltage collapse incorporating inverter based generation into the System Integrity Protection Schemes (SIPSs) proposed

- The “IEEE Test Systems for Voltage Stability Analysis and Security Assessment“ *) is being applied for the studies
  - Full network representation
  - All dynamic models, e.g. AVR, PSS, Speed Governor, OEL, LTC logic

*) http://resourcecenter.ieee-pes.org/pes/product/technical-publications/PESTR19
Test System
Detailed Model of the Grid and IBG

- 1594 buses
- 203 Transformers
- Time between consecutive tap changes is randomized (T1=28-32 s, T2=8-12 s)
- 395 IBGs
- 20% of the load of each DN is supplied by IBG
- 1597 static loads
- 948 Induction Motors (IM)
- 70% static load
- 30% IM
- Quadratic mechanical torque
- Combination of large and small IM. Parameters taken from [4]
- IBG: WECC model and a voltage source boundary model
Results with the proposed emergency control

Moment of alarm

Coordinated control of OLTCs and IBG

After emergency control
Results with the proposed emergency control

Transmission voltages in the affected area

Time since incident

-5.0  336.0  277.0  418.0  559.0  700 s

0.920  0.945  0.970  0.995  1.020  1.045 [p.u.]
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Inverter capabilities

Power System Requirements for inverters
Synchronized Grid Voltage Forming by Synchronous Machines or Voltage Forming Inverters

AC power systems need a minimum share of power units that
A) provide electric inertia. Inverters should produce voltage phasors that act delayed to disturbances in the power system
B) have a self-synchronization effect.
C) Damping is needed e.g. if the voltage phasor is controlled according to the swing equation
Control of Voltage Forming Inverters

SelfSync

- U(Q)- and f(P)-droops
- PT₁ low-pass filter
- Angle feedforward control

\[ \Delta U \rightarrow G_{\Delta UQ}(s) \rightarrow Q \]

\[ \Delta f \rightarrow \frac{2\pi}{s} \rightarrow \Delta \vartheta \rightarrow G_{\Delta \vartheta P}(s) \rightarrow P \]

\[ f = f_0 - k_p \cdot (P - P_0) \]

\[ U = U_0 - k_q \cdot (Q - Q_0) \]
Control of Voltage Forming Inverters

SelfSync +

- For grids with higher R/X relation Selfsync-control was extended
- Voltage and frequency cannot be controlled independently:
  - Influence of voltage on active power: $G_{\Delta U P}(s)$
  - Influence of angle on reactive power: $G_{\Delta \delta P}(s)$
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Power System Requirements for inverters

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Project Transstabil-EE: Experimental Short-Circuit Test of Voltage-forming Inverters

Experimental validation of FRT-behavior using state of the art test equipment.

- Device under test: voltage forming inverter with virtual impedance
- Control is able to comply with connection rules,
- Inherent, instantaneous (first cycle) reaction by applying three-stage current limitation
  - Virtual Impedance
  - Fall-back current control
  - PWM Blocking

Duckwitz, Knobloch et. al.: Experimental Short-Circuit Testing of Grid-Forming Inverters in Microgrid and Interconnected Mode, NEIS Conference, September 20, 2018, Hamburg
FRT- Test Setup at Fraunhofer IEE
Lab-Test: voltage dip to 50%
Grid Voltage Forming Inverter with Three-stage Current Limitation

Virtual impedance
\[ k = 2 \]

\[ \Delta i_B = k \cdot \Delta u = \frac{1}{\Sigma} \Delta u \]

Inherent active current contribution.
Lab-Test: Voltage Dip to 12% - Grid Voltage Forming Inverter with Virtual Impedance and Fallback Current Control
Summary

- The project *Grid Control 2.0* is focusing on the integration of (grid) voltage forming inverters for the interconnected power system.
- Splitting scenarios – in which system parts with very high shares of inverters are separating – are being investigated.
- Long-term voltage stability issues have been identified and solutions are under investigation.
- FRT tests for grid forming inverters have been performed successfully within the project *Transstabil-EE*.
- *Grid Control 2.0* is supporting the knowledge exchange with other projects in the "International Project Cluster on Inverter Dominated Power Systems".
The project underlying this report was funded by the Federal Ministry for Economic Affairs and Energy under grant number 0350023A. The responsibility for the content of this publication lies with the authors and does not necessarily reflect the opinion of the consortium of the project Grid Control 2.0 (Netzregelung 2.0).