Testing an IEC61850 compliant voltage control algorithm, using a real-time simulation

Sicherheit und Zuverlässigkeit von Verteilungsnetzen
auf dem Weg zu einem Energieversorgungssystem von morgen

Supported by:
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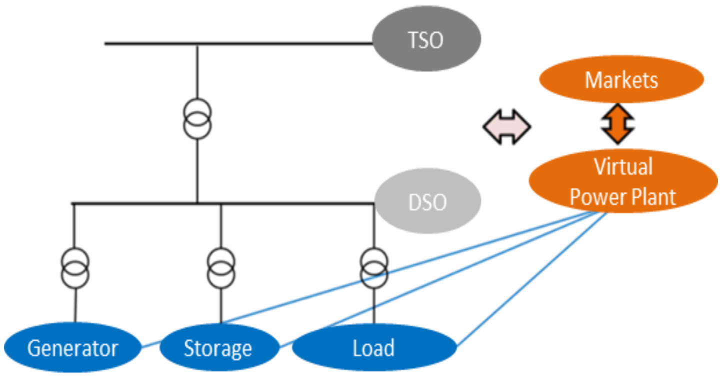
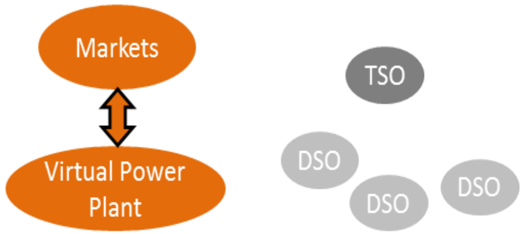
Introduction (1/3) - OpSim

Motivation
In reality, many parallel actors (TSOs, DSOs, VPPs, …) control generators, storages, loads and compensator equipment in power grids

Common practice in many studies on this topic (often due to simulation tool inflexibility):

- just one grid voltage level is considered for grid optimization/simulation
- just one grid topology, weather data set or plant type is applied per investigation
- VPP control strategies neglect the grid topology altogether





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Introduction (2/3) - OpSim

The OpSim–project:

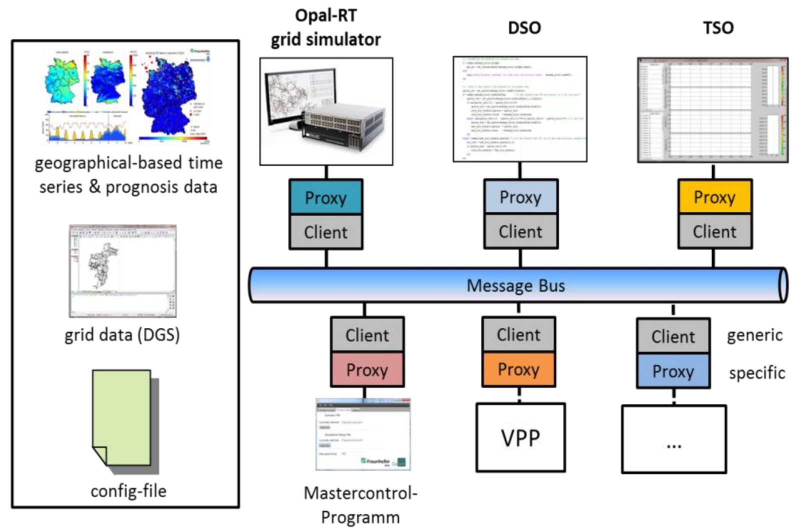
- Fraunhofer IWES and the University of Kassel
- Industry consortium: 11 known companies, from grid operation to energy management
- Governmental funding (BMWI), 2013-2017

Result:

A real-time testing platform for smart grid control strategies

- **Simulator** for large-scale power networks
- A flexible architecture to connect **multiple** controllers
- Scenario-data from weather databases & forecast tools

www.opsim.net



[1]Opal RT image source: http://www.opal-rt.com
[2]Python image source: https://pypi.python.org/pypi/PYPOWER

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Introduction (3/3) - SecVer

Goals of the project:

- Implement methods to estimate the distribution grid state from PMUs
- Design of a distribution area monitoring system (DAMS)
- Design of a control method for safe operation of distribution grids (DACS)
- Design of a monitoring and control system for distribution grids (DAMCS)
- Validate DAMCS through **simulations and field tests**

www.secver.de

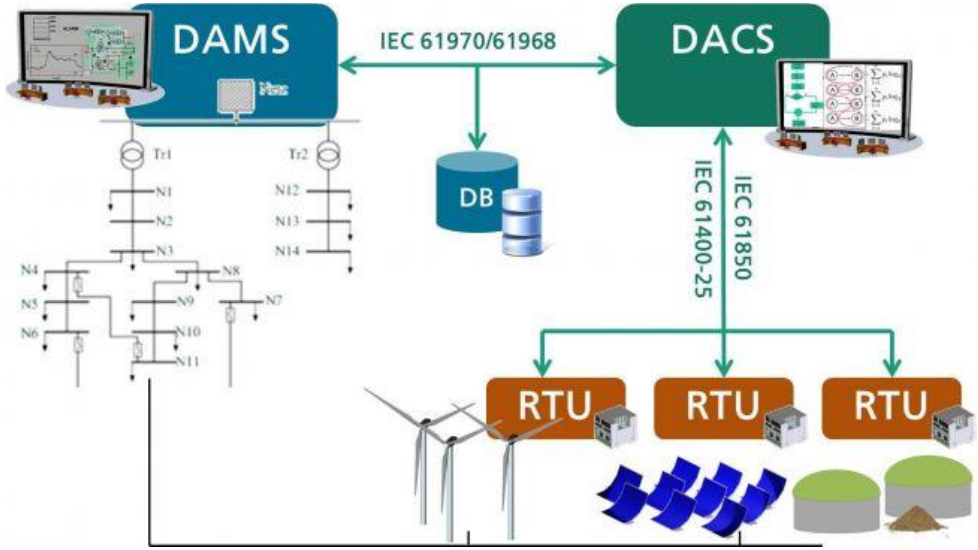

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Image source (top panel): www.secver.de

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SecVer control algorithm (1/3)

The grid-control algorithm:

- Uses (re)active power from distributed power sources (e.g. diesel, battery) to:
  - minimize grid losses
  - solve bottlenecks
  - meet reactive power demand at PCC
  - perform local voltage control
- Optimization routine based on SLSQP, implemented in Python
- Communicates with lab-equipment via PMUs, RTUs and standardized interfaces
- Real-time operation every 10 seconds

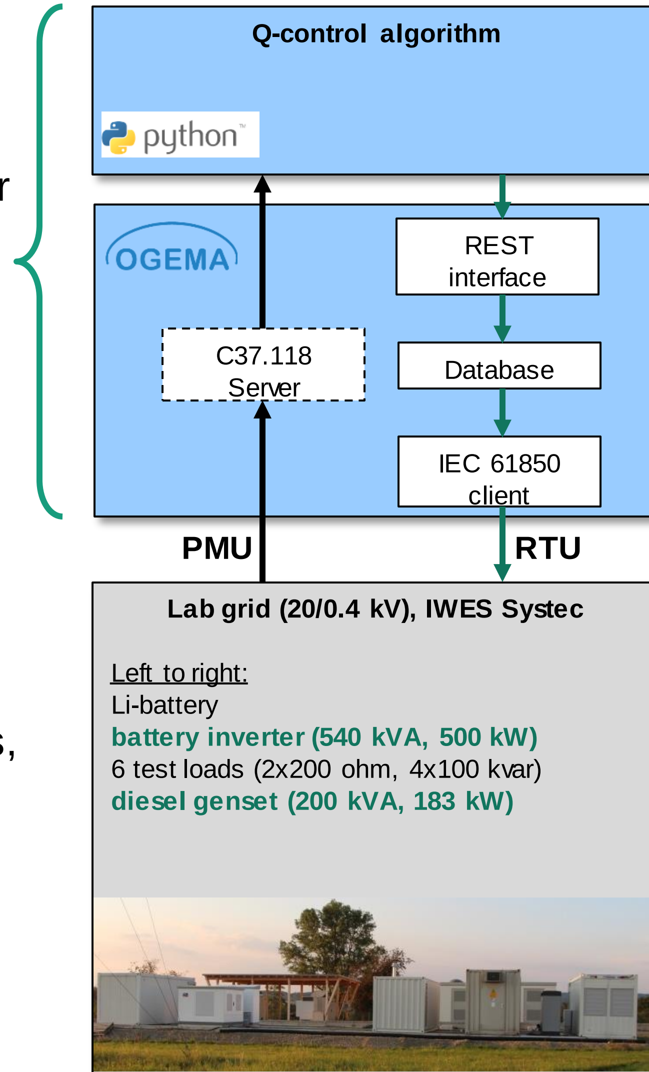

Image source: *Fraunhofer IWES*
Python logo source: *www.python.org*
Ogema logo source: *ogema-source.net*

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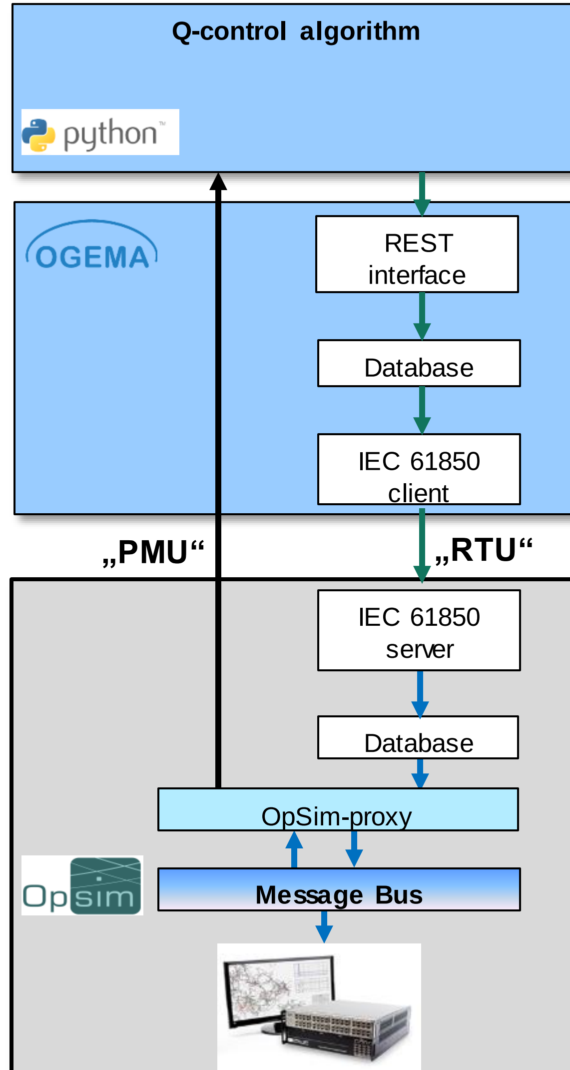
SecVer control algorithm (2/3)

Before connecting it to the lab…

- Perform „offline tests“ with **real-time grid simulation (OpSim)**
- Use „almost“ the same interfaces as the lab test
- Use a simulation scenario (controllable DGs) similar to lab test

-> Identification of possible bugs in the algorithm, or optimization of control-parameters!



Python logo source: *www.python.org*
Ogema logo source: *ogema-source.net*
Opal-RT Hardware Picture: *www.opal-rt.com*

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SecVer control algorithm (3/3)

Why use a real-time simulation to test the control algorithm?

Static simulation (load flows)

- Only “snapshots” of the grid are analyzed
- Set points of voltage controller are sent to snapshot -> perfect result, but not realistic
- Generators in the grid immediately adjust themselves to set point
- Calculation time of controller is not important

Real-time simulation

- Grid simulation progresses, controller thus works with “old” measurements (realistic!)
- Voltage controller set points are sent to evolved grid state (realistic!)
- Generators in grid do not immediately adjust themselves to set points (lag)
- Calculation time of controller is very important

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Scenario (1/4)

- Generic distribution grid (110 kV)
  - 16 buses, 21 branches
  - 6 loads, 3 generators (2 wind parks, 1 photovoltaic park)
- Time series based on weather data and standard load profiles
- The 3 generators can receive Q-setpoints
- ePHASORsim is used as grid simulation engine, Ts = 0.1s

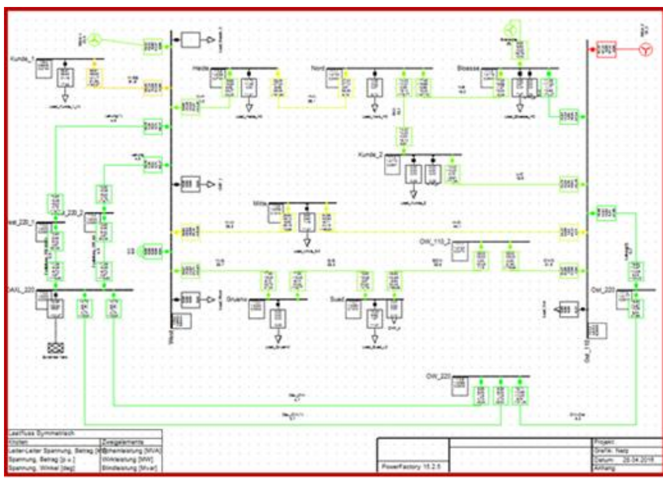
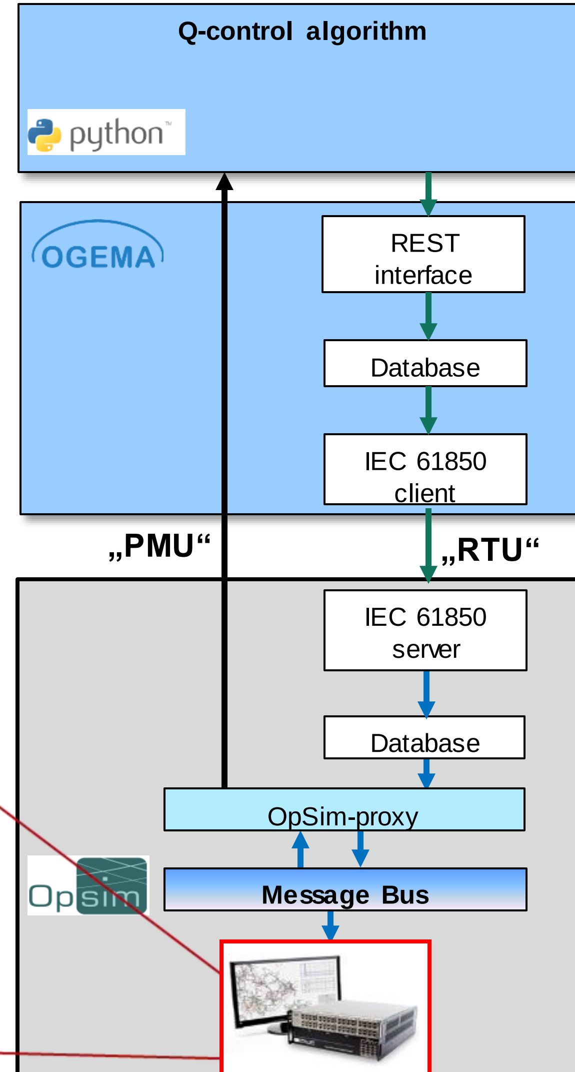


Image source: Grid Layout in PowerFactory, later converted to ePHASORsim



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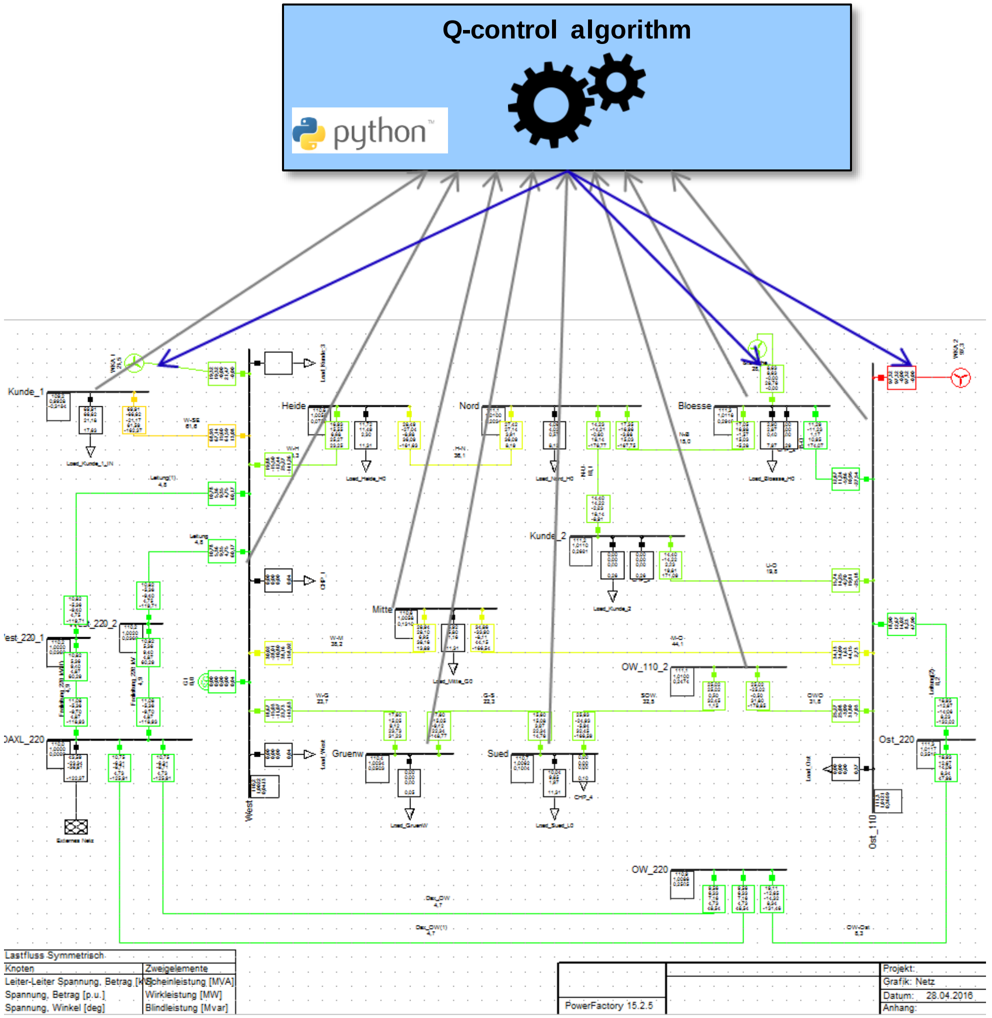
Scenario (2/4)

Voltage controller operates every 10 seconds…

- The voltage controller receives real-time measurements of the RMS-voltages of all network buses
  (only a few sketched in picture)

- Using a gradient-based optimization (from SLSQP), the controller decides reactive power setpoints for the 3 generators in the grid

- Generator Setpoints are sent back to the real-time simulation via the IEC61850 interface



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Scenario (3/4)

Generator profiles

Feed-in time series of a wind park near Dardesheim

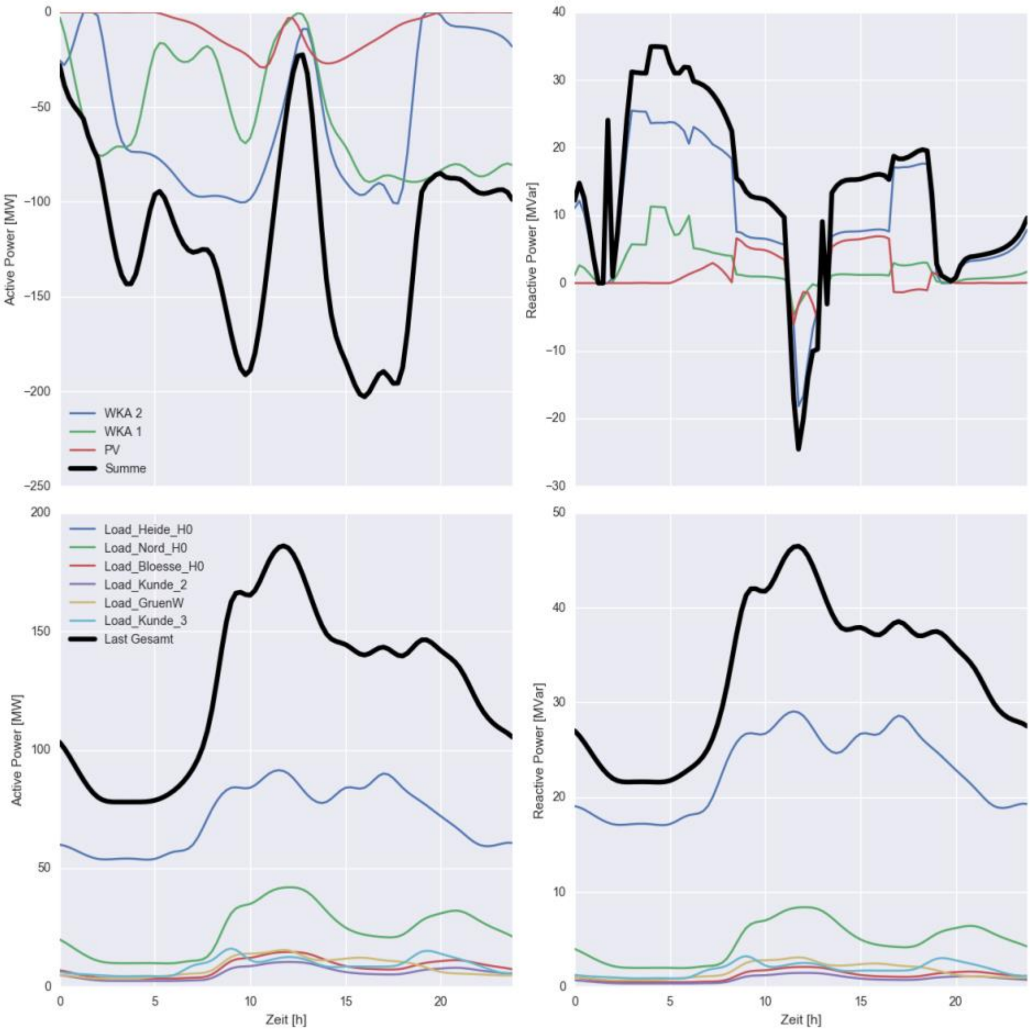
Reference PV profile

Load profiles

Household H0

Industry G0

Agricultural L0



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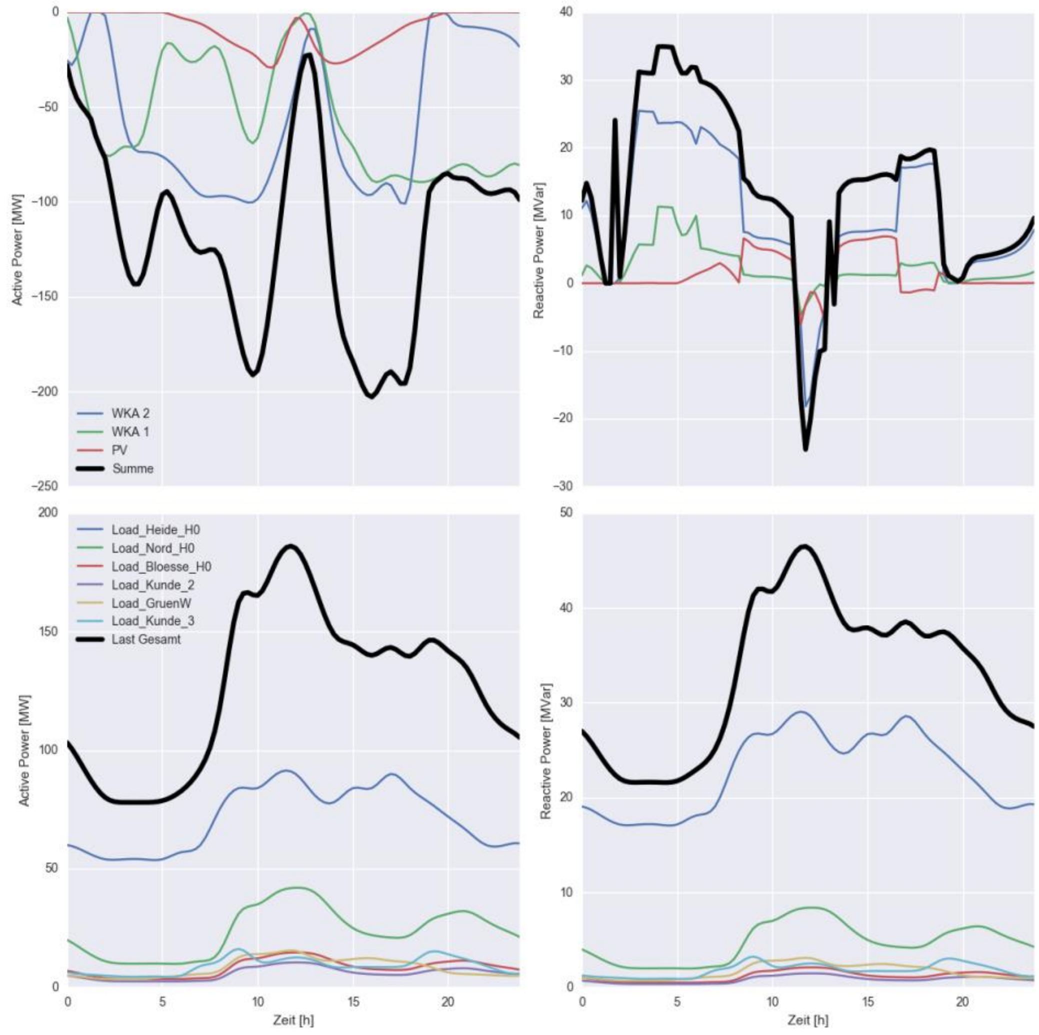
Scenario (4/4)

Scenarios
High/Low grid load
Voltage violations
Reactive power control
Component overloading
Component failure
Loss minimization
Adaption of power outputs (after a curtailment order is issued by TSO)



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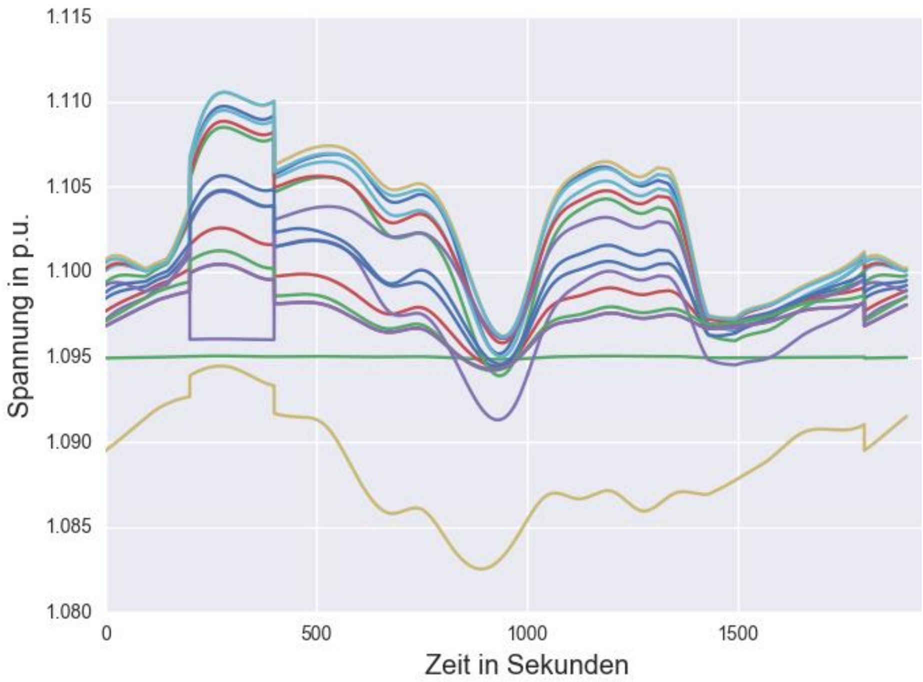
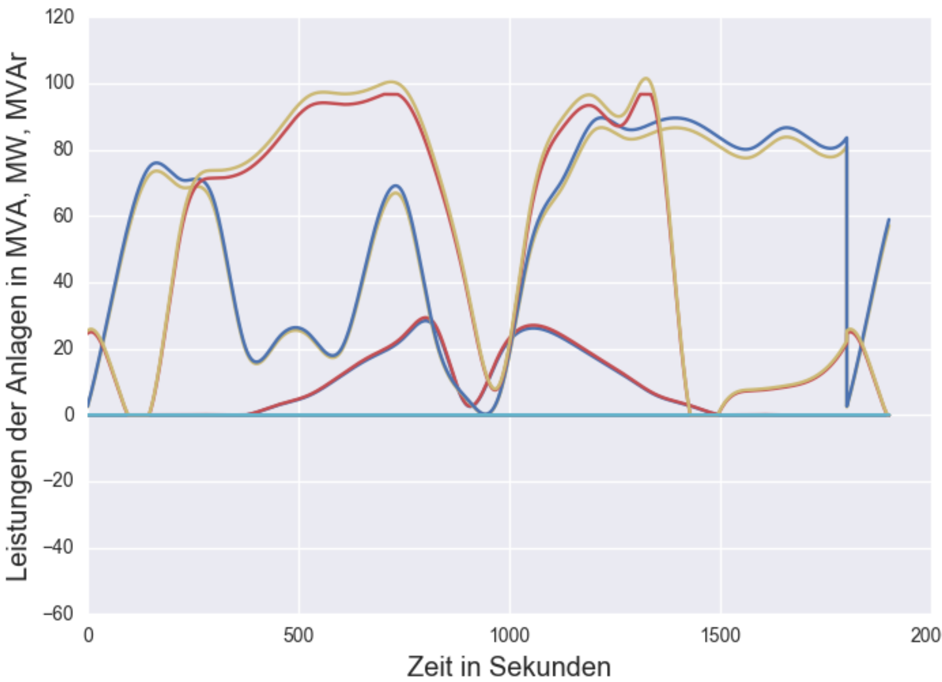
Results (1/4)

Grid voltages **without** controller





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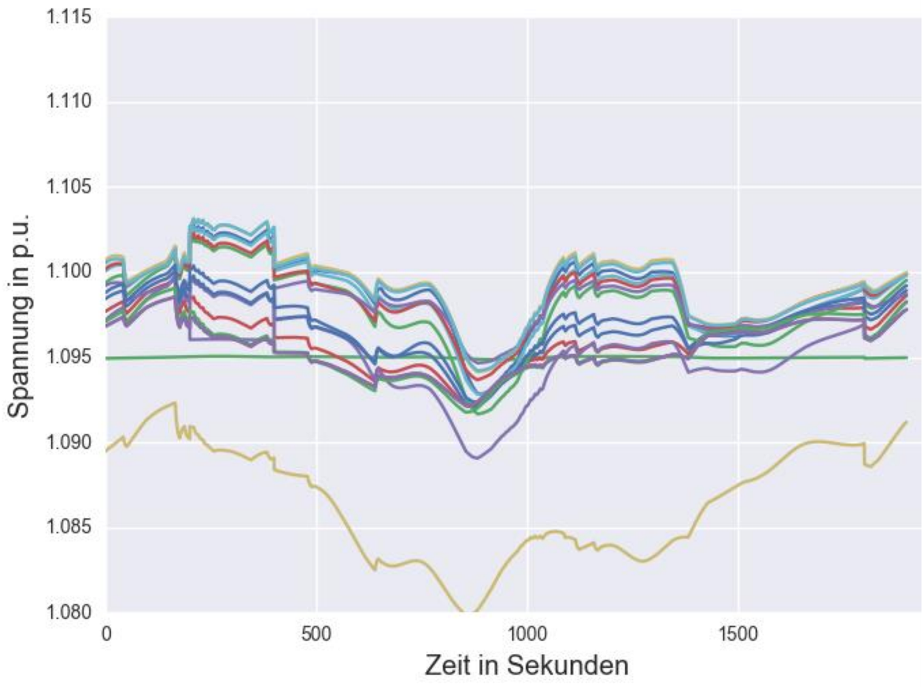
Results (2/4)

Grid voltages **with** controller



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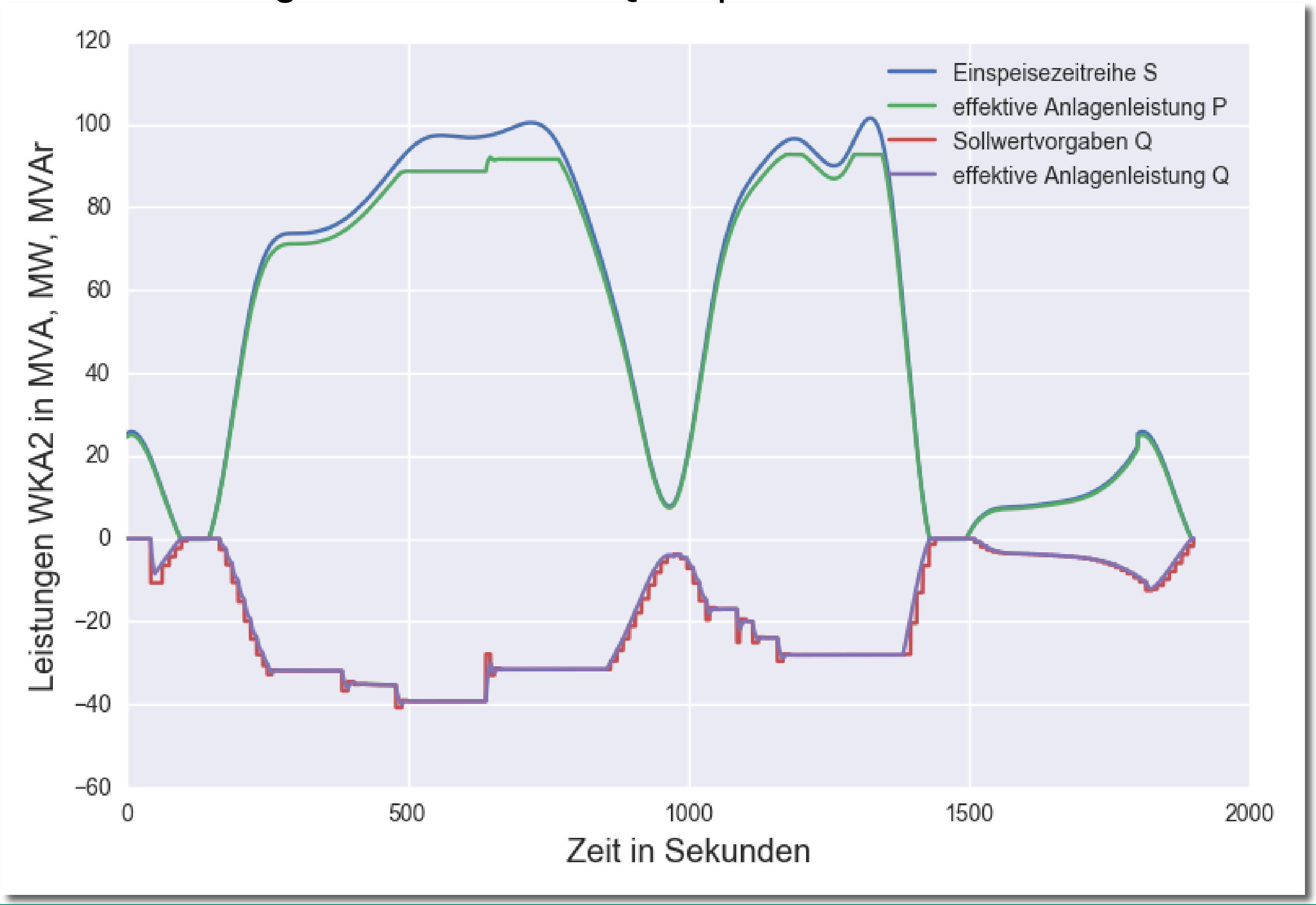
Results (3/4)

Generators, following the controller's Q-setpoints



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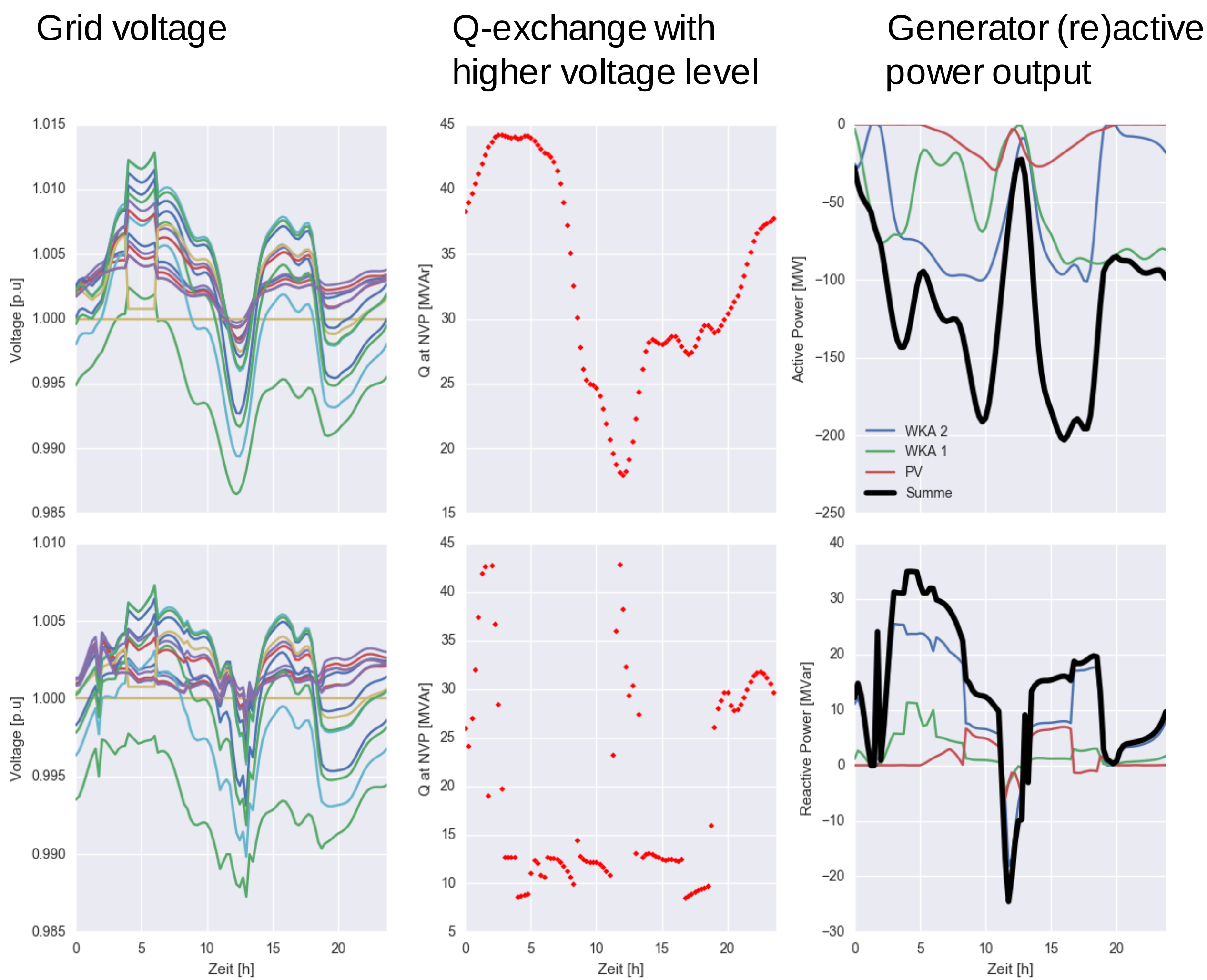
Results (4/4)



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Conclusion & discussion

- We have presented a lab environment to test a python-based grid controller (HIL-testing)
- Prior to HIL-testing, the controller is tested “offline”, using the OpSim real-time simulation environment (Controller-in-the-Loop)
- In this “offline-test”, the controller was able to reduce the grid voltage, using reactive power capabilities from wind parks and a large photovoltaic installation

Thank you very much for your attention!

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Fraunhofer IWES, OpSim, SecVer:

- www.iwes.fraunhofer.de
- www.opsim.net
- www.secver.de

Fraunhofer IWES - Department Distribution System Operation

Research groups:

- Operation and Planning / Hybrid Grids
- Multi-Utility Storage Systems
- Aggregated System Operation

Research focus:

- Energy and ancillary services provided by DER (focus on PV systems, storage systems and E-mobility)
- Techno-economic approaches for planning and operation of active distribution systems
- Energy management in decentralized supply structures

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