RESULTS FOR A MV-HYBRID-MICROGRID TEST CAMPAIGN IN THE MW-RANGE

Roland Singer, Moritz Bader, Christoph Siedle

Fraunhofer Institute for Solar Energy Systems ISE

3rd International Hybrid Power Systems Workshop

Tenerife, 09.05.2018

www.ise.fraunhofer.de

AGENDA

- Project „Zukunftskraftwerk PV“
- Categories of Inverter Control
- Grid-Sustaining Control
  - Implementation
- Laboratory Microgrid Setup
- Measurement Results
  - Single Inverter: On-Grid Behavior
  - Micro-Grid with 2 Inverters and Diesel Genset
- Summary and Outlook

Project Presentation
Zukunftskraftwerk PV

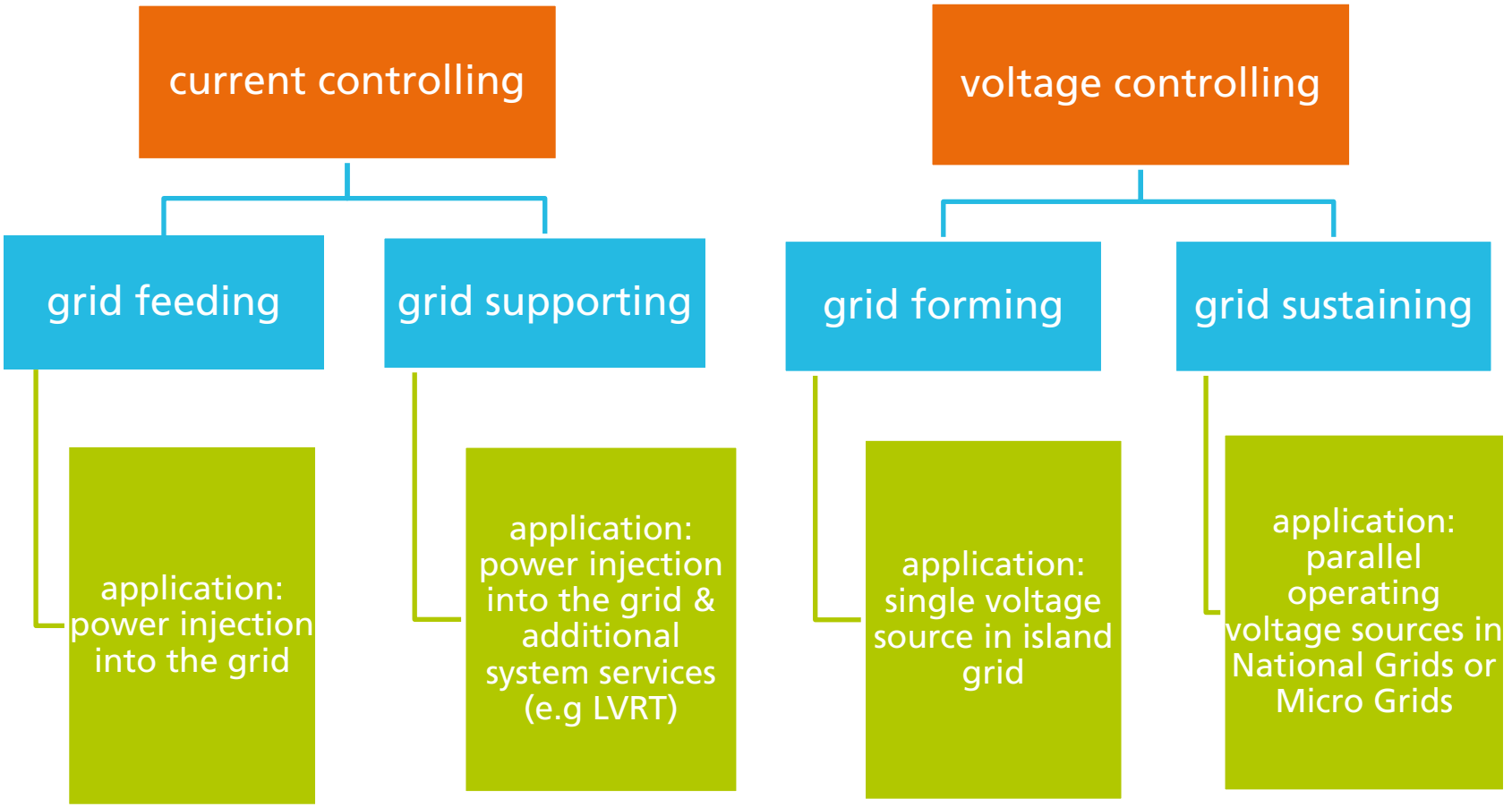
- Partners:
  - BELECTRIC Solarkraftwerke GmbH
  - GE Energy Power Conversion GmbH
  - MTU Friedrichshafen GmbH
- Nov. 2014 to Dez. 2018
- Funded by the Federal Ministry of Economic Affairs and Energy of Germany (BMBF)

Gefördert durch:
Bundesministerium für Wirtschaft und Energie
aufgrund eines Beschlusses des Deutschen Bundestages

Diesel-PV-Hybrid Power Station including storage system (©Belectric)

Categories of Inverter Control

Control Strategies for Grid-Connected Inverters



Fraunhofer ISE

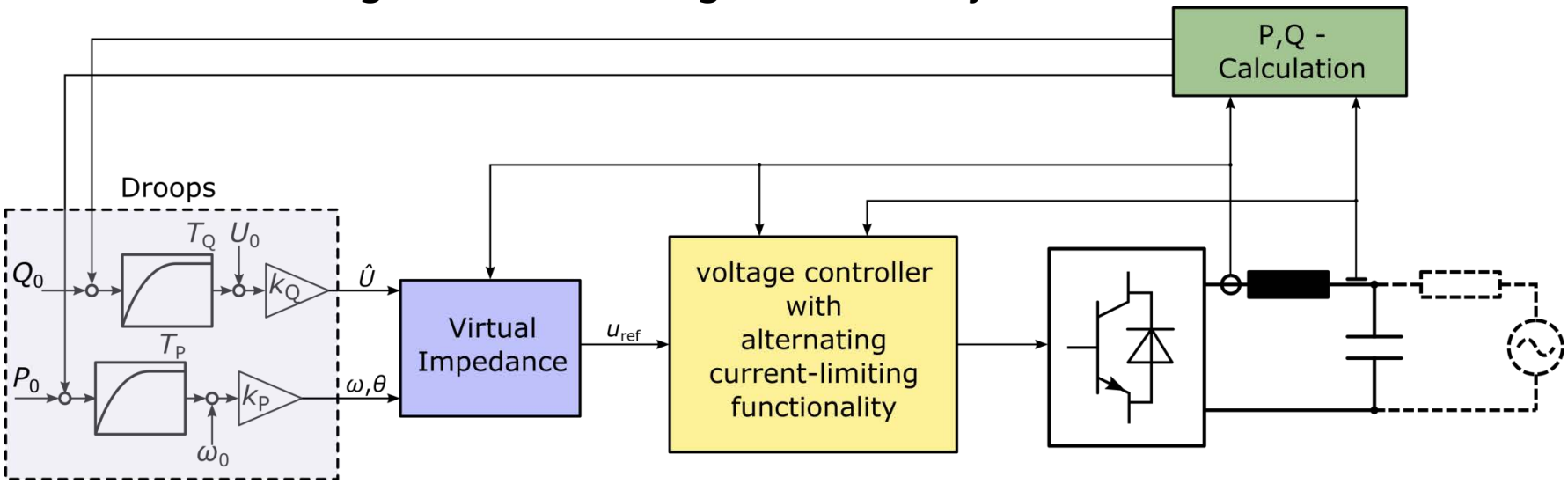
Categories of Inverter Control

Control Strategies for Grid-Connected Inverters

	Grid-Feeding	Grid-Supporting	Grid-Forming	Grid-Sustaining
Behavior	Ideal Current Source	Ideal Current Source	Ideal Voltage Source	Real Voltage Source
Control	PQ - Controller	PQ – Controller + System Services (LVRT, Q(U), …)	const. Frequency/ Voltage (isochronous)	Droop-Control (Static Control)
Source Impedance	$Z = \infty$	$Z = \infty$	$Z = 0$	finite, $\neq 0$
Output Frequency	Synchronous to the Grid Freq.	Synchronous to the Grid Freq.	Fixed Frequency	Defined by Droop
Scope of Application	On-Grid	On-Grid	Off-Grid	On-Grid and Off-Grid
Inertia	No	No	Infinite	finite, $\neq 0$

Grid-Sustaining Control
Implementation of Droop-Control

- Droop Control
- Highly Dynamic Voltage Controller
- Current Limiting required
  - Alternating Current-Limiting Functionality



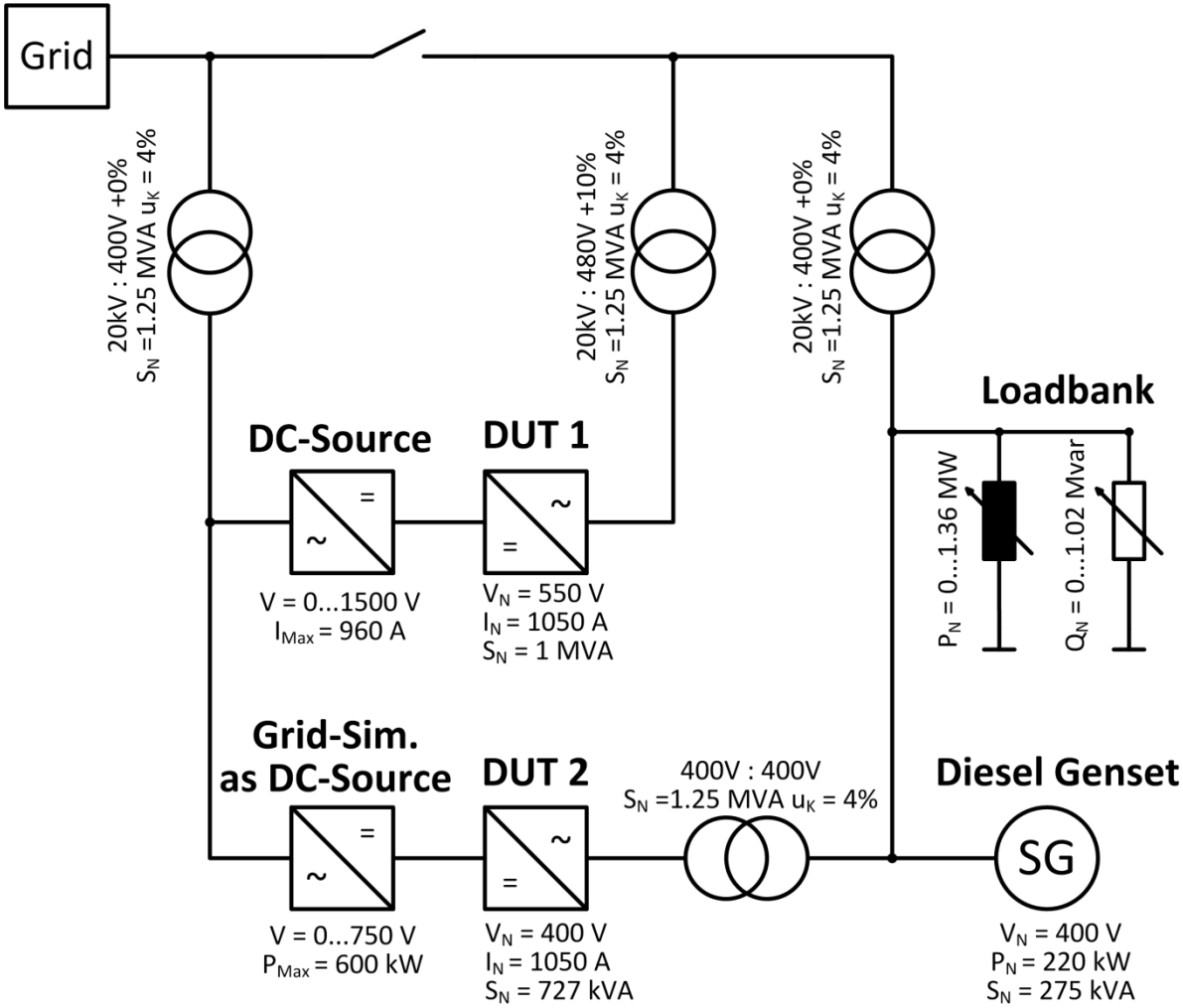
Fraunhofer ISE

Laboratory Microgrid Setup
Equipment

- Sources
  - 2 Inverters with changeable Control (Grid-Supporting or Grid-Sustaining)
    - 1000 kVA and 725 kVA
  - 1 Diesel Genset
    - 275 kVA, 220 kW
- Load
  - Ohmic-Inductiv Load Bank
    - 2280 kVA, ohmic 1820 kW, inductiv 1370 kVar
- Measurement Devices
  - On Medium Voltage and Low Voltage side (46 channels in total)
  - Highly Dynamic, Sampling Rate up to 50 kHz

Laboratory Microgrid Setup

Single-Line Diagram

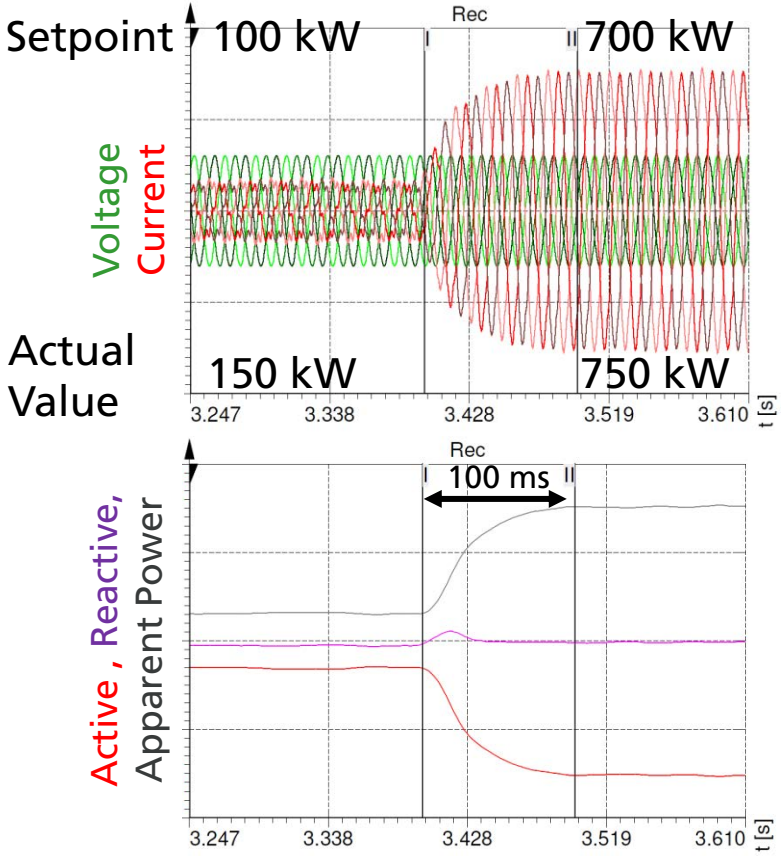


Fraunhofer ISE

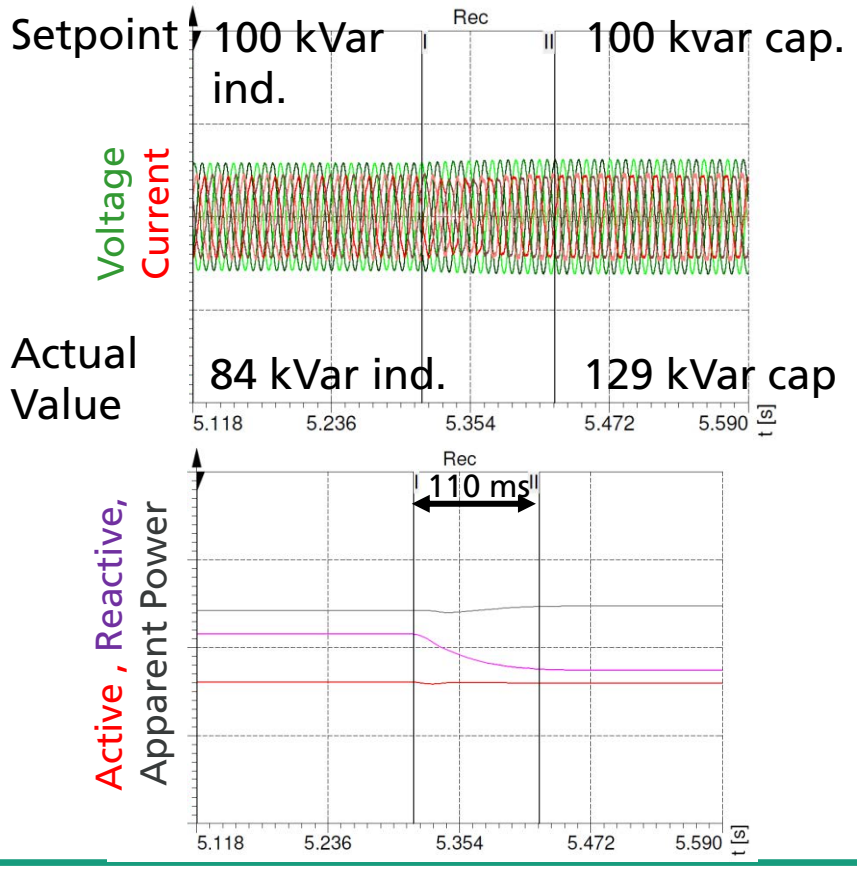
Measurement Results

Single Inverter: On-Grid Behavior

- Setpoint Change Active Power



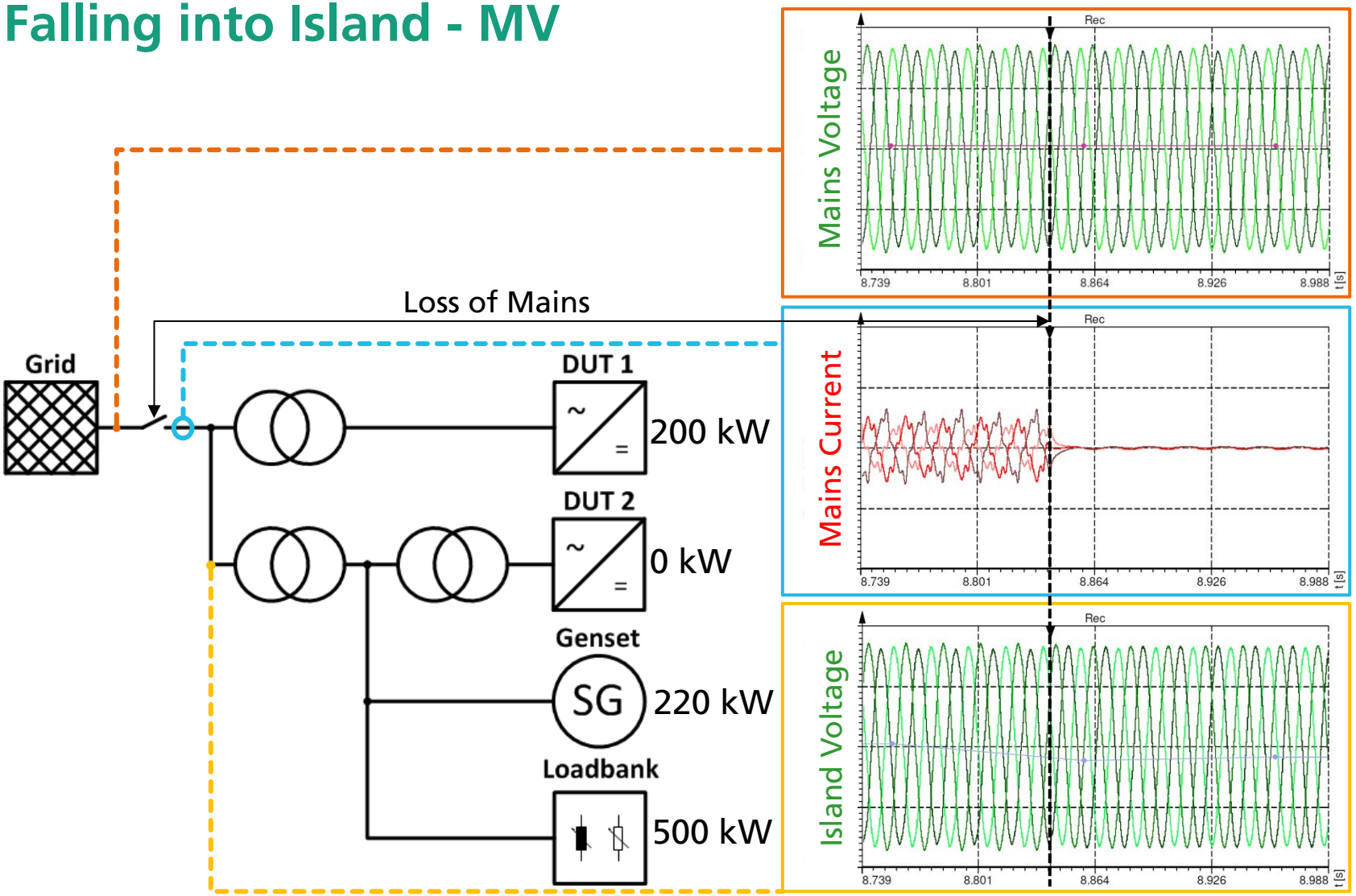
- Setpoint Change Reactive Power



Fraunhofer ISE

Measurement Results

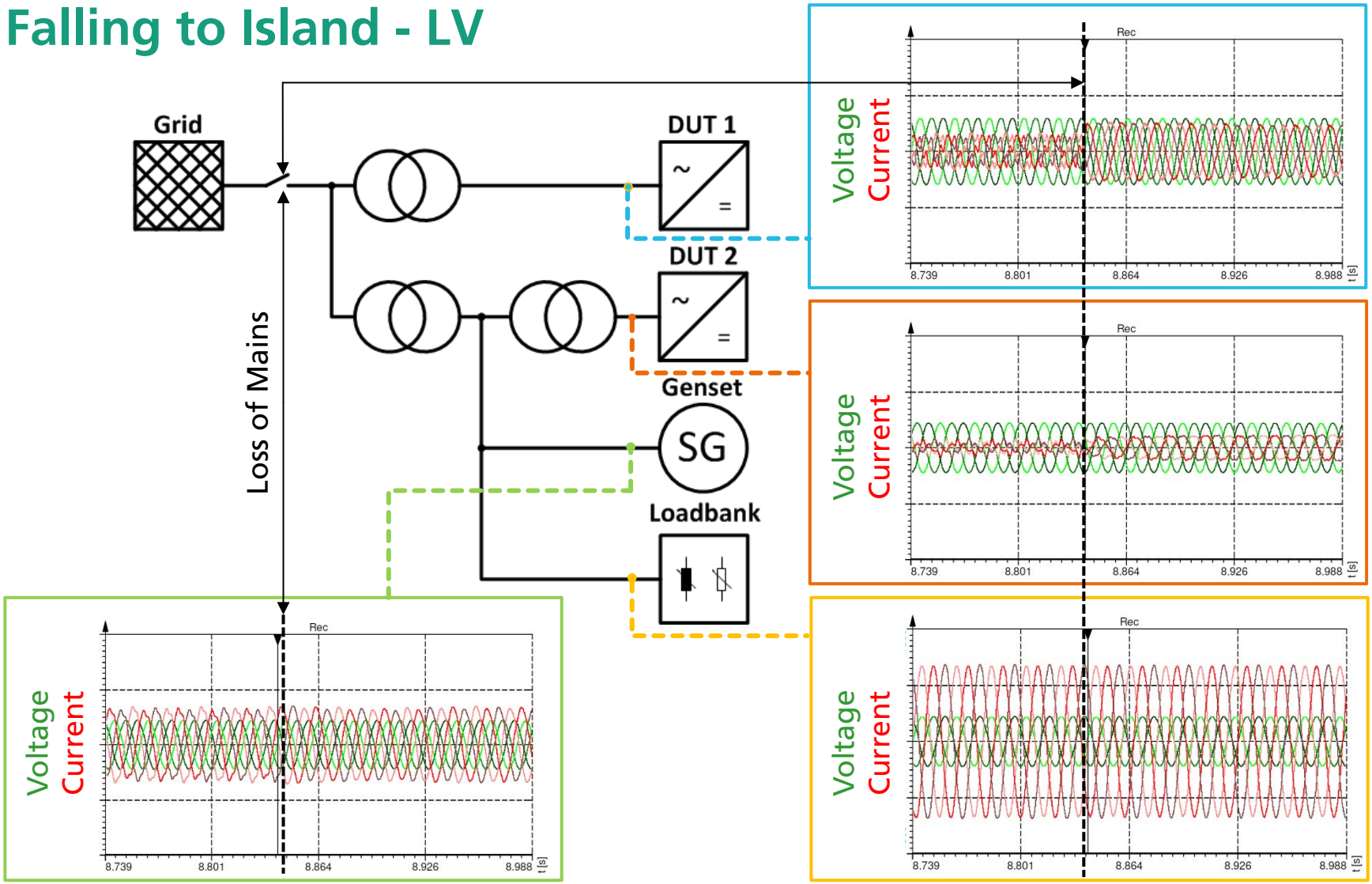
Falling into Island - MV



Fraunhofer ISE

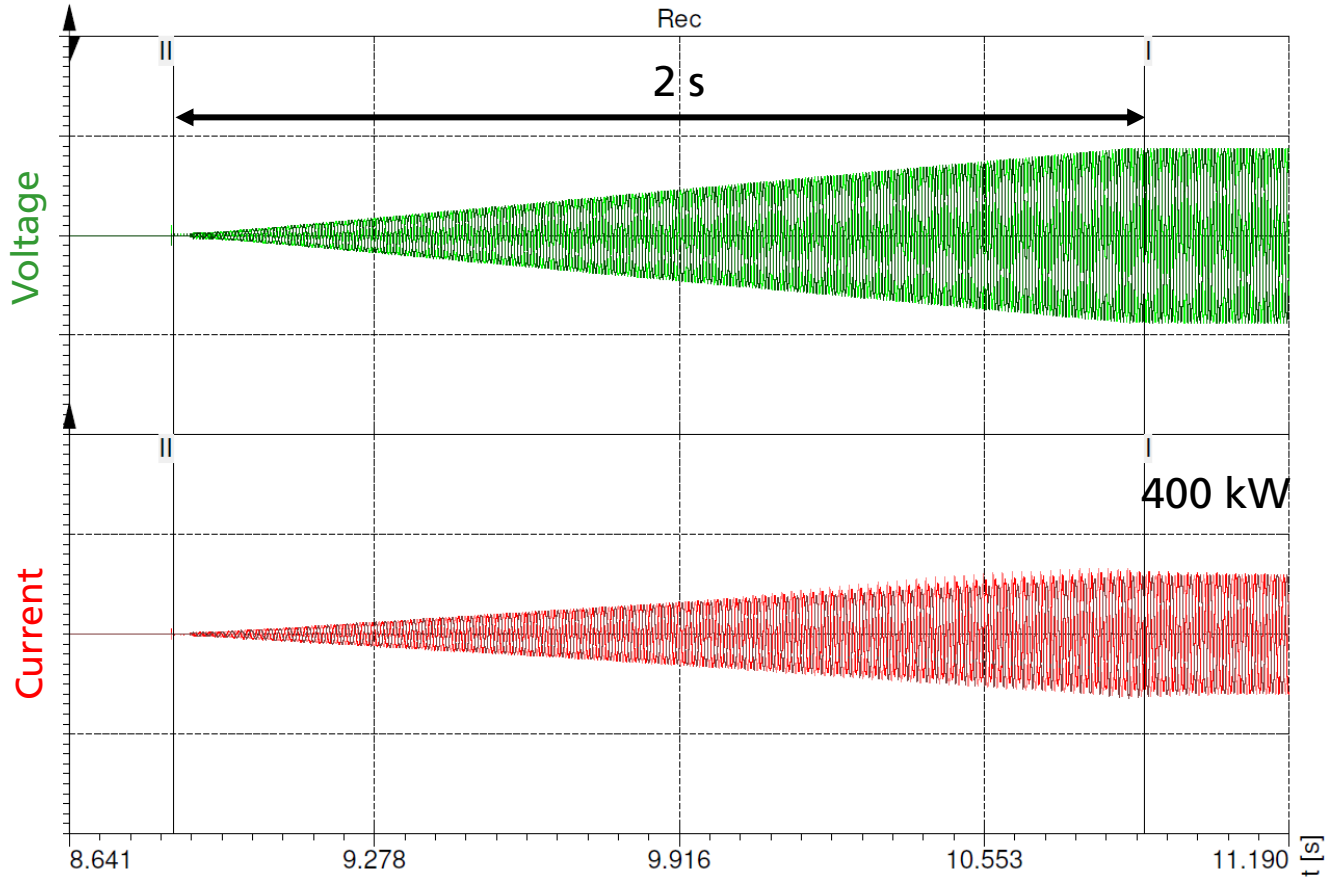
Measurement Results

Falling to Island - LV



Fraunhofer ISE

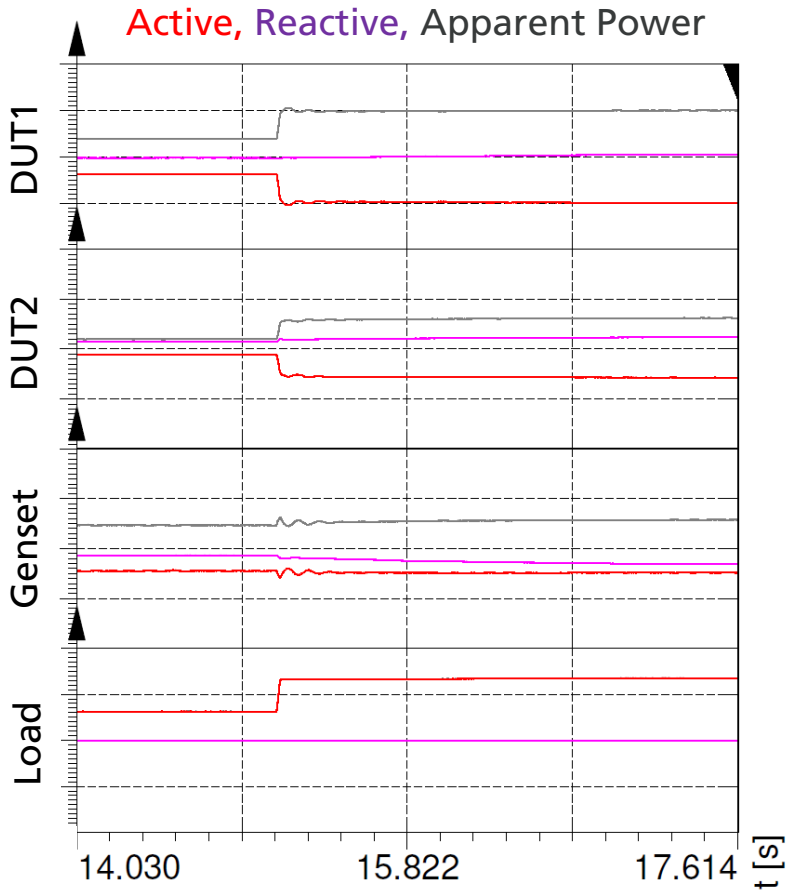
Measurement Results
Black Start



Fraunhofer ISE

Measurement Results
Island Situation – Load Step

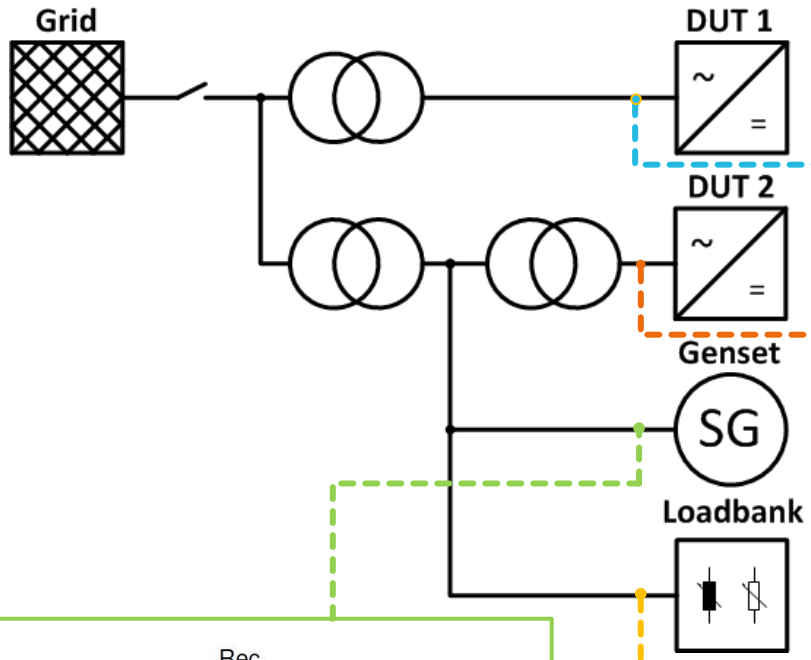
- DUT 1 and DUT 2
  - Grid-Sustaining
- Diesel Genset
  - Power set point of 220 kW (fixed Active Power)
- Load
  - 500 kW → 1000 kW
- Grid Control solely by Inverters

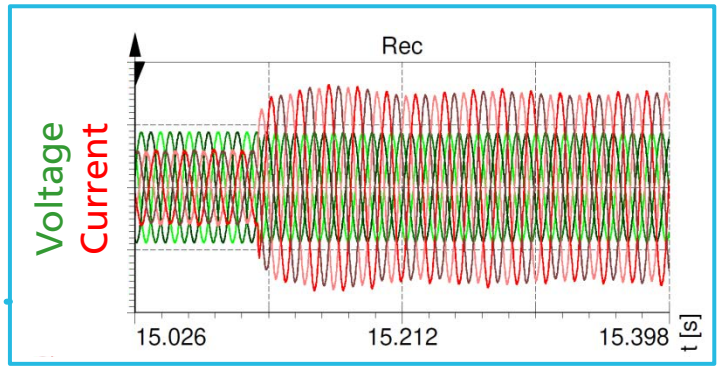


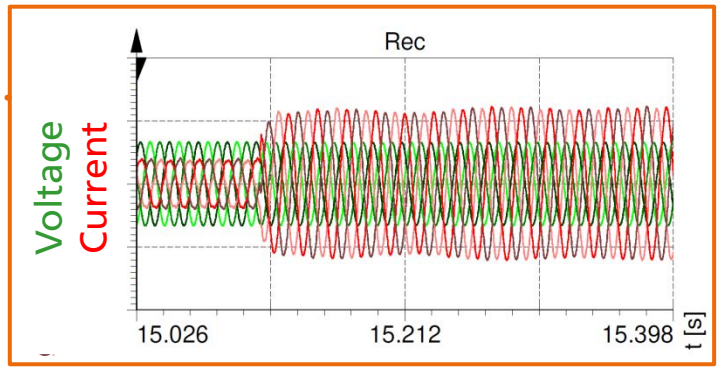
Fraunhofer ISE

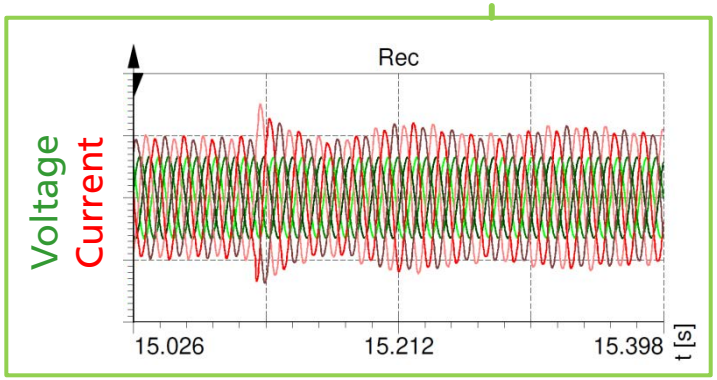
Measurement Results

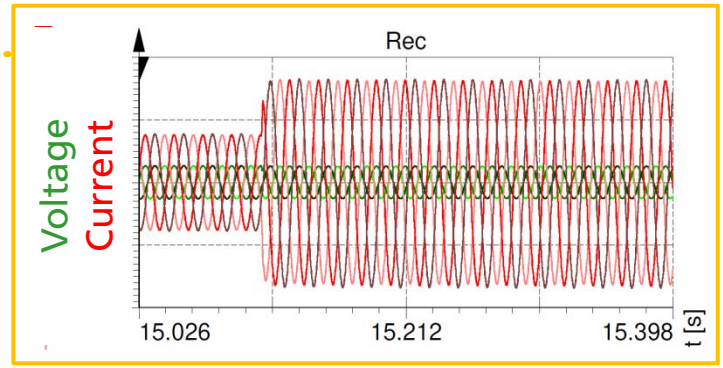
Island Situation – Load Step









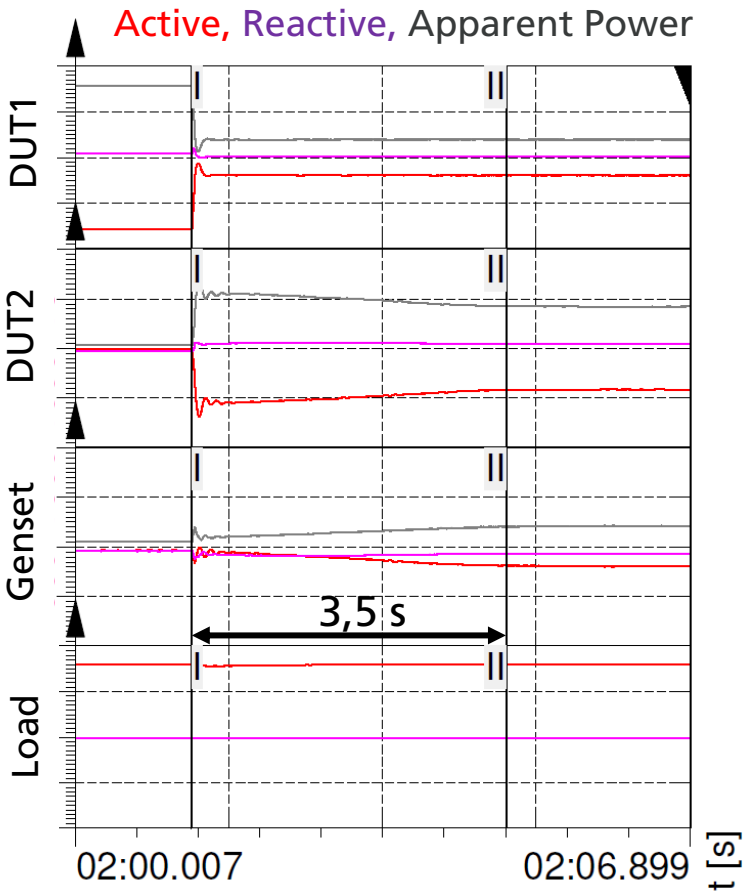


Fraunhofer ISE

Measurement Results
Island Situation – Load Step

- DUT 1
  - Grid-feeding (PV)
    Power Reduction 800 → 200 kW
- DUT 2
  - Grid-Sustaining (Droop)
- Diesel Genset
  - Frequency Control with Droop
- Load
  - 800 kW

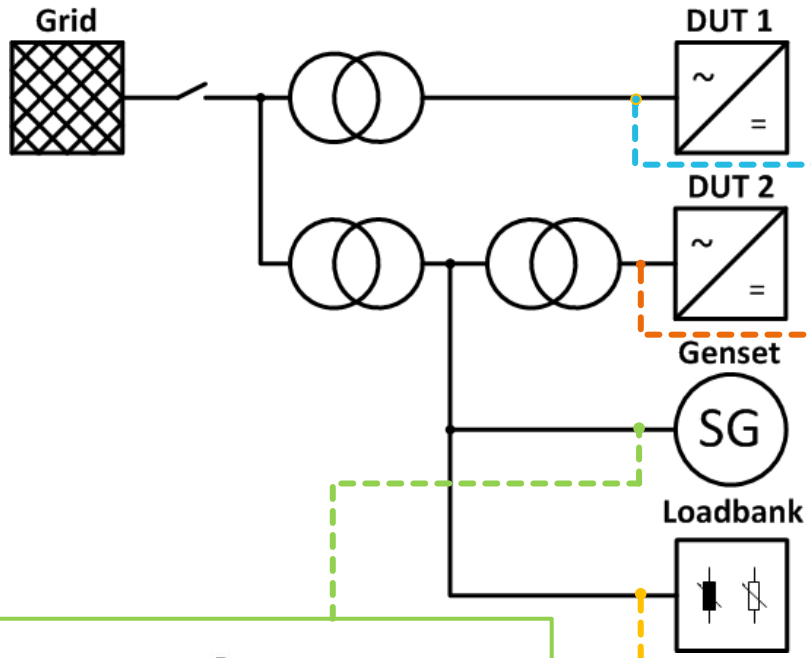
- Grid Control by DUT 2 and the Genset

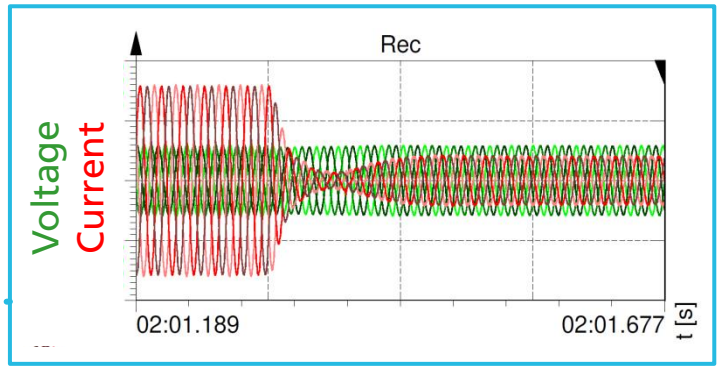


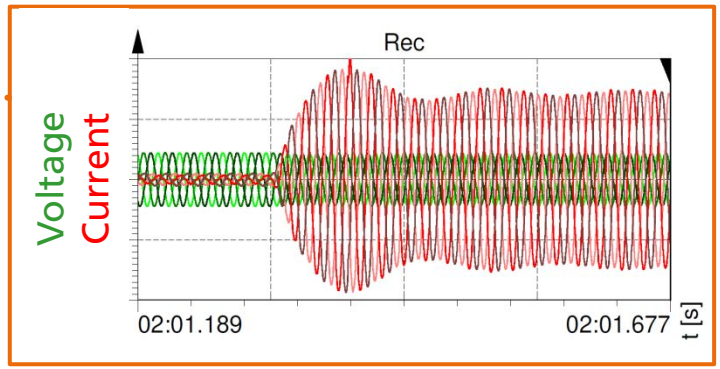
Fraunhofer ISE

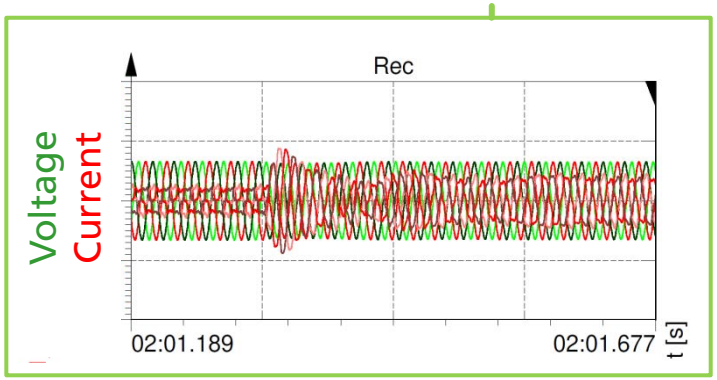
Measurement Results

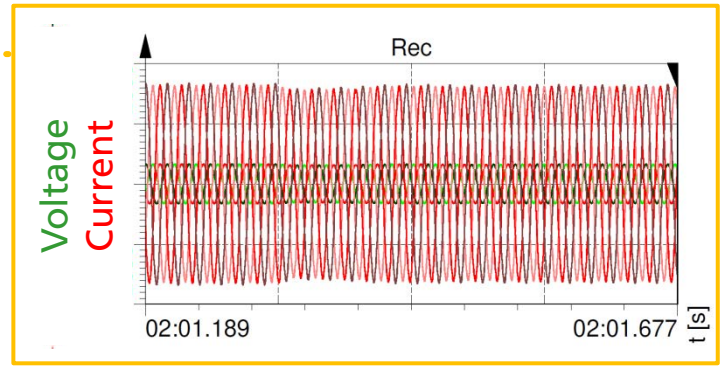
Island Situation – Load Step







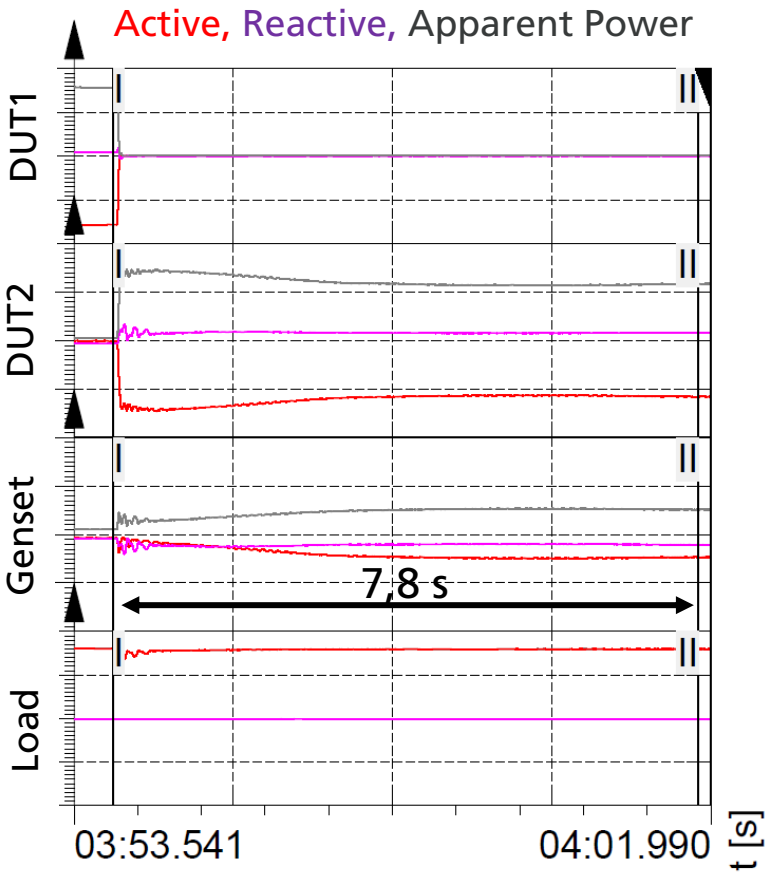




Fraunhofer ISE

Measurement Results
Island Situation – Current Limiting

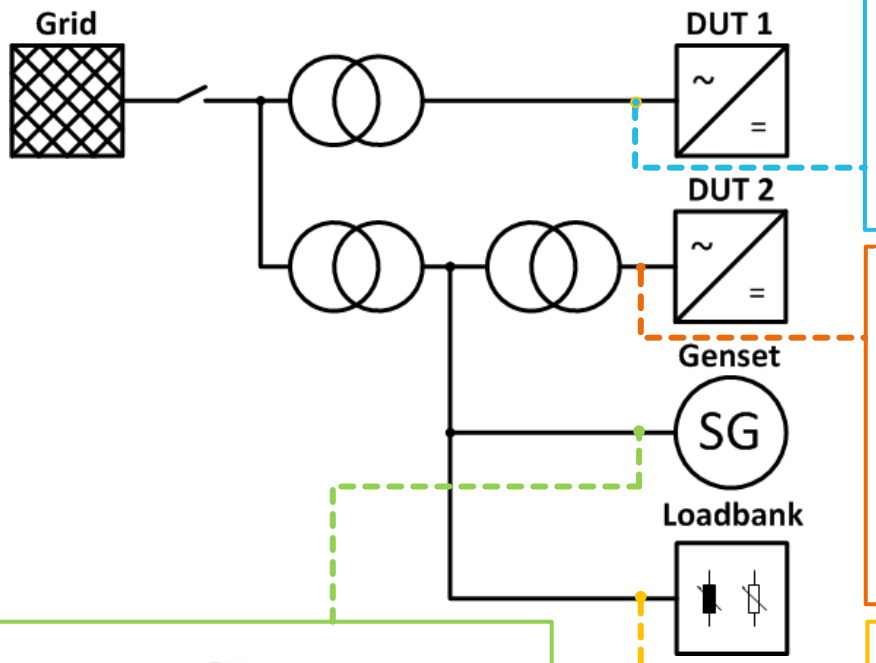
- DUT 1
  - Grid-Feeding (PV)
  - 785 kW → 0 kW (shut down)
- DUT 2
  - Grid-Sustaining (Droop)
- Diesel Genset
  - Frequency Control with Droop
- Load
  - 800 kW
- Slow reaction of Genset → DUT 2 sees an overload during the first cycles and needs to limit the current

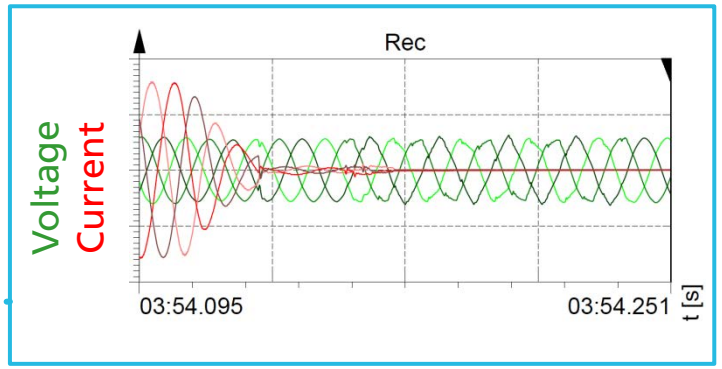


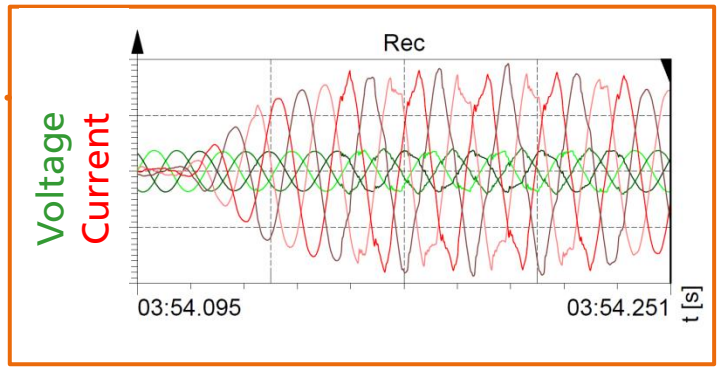
Fraunhofer ISE

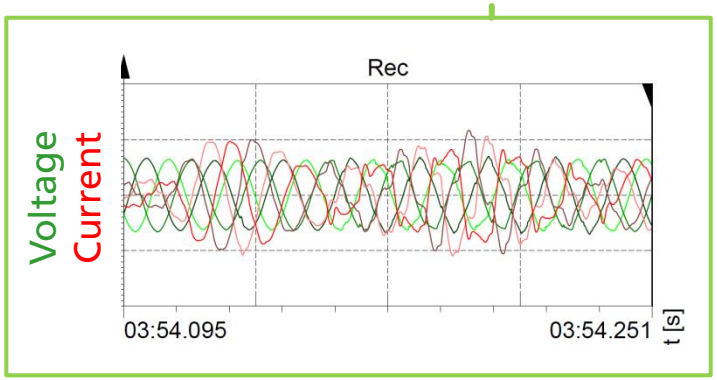
Measurement Results

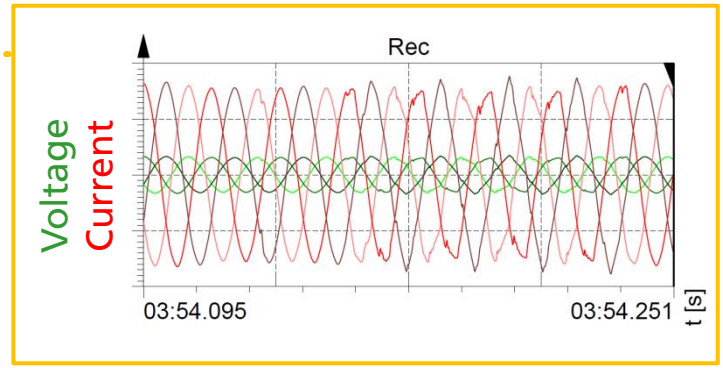
Island – Current Limiting











Fraunhofer ISE

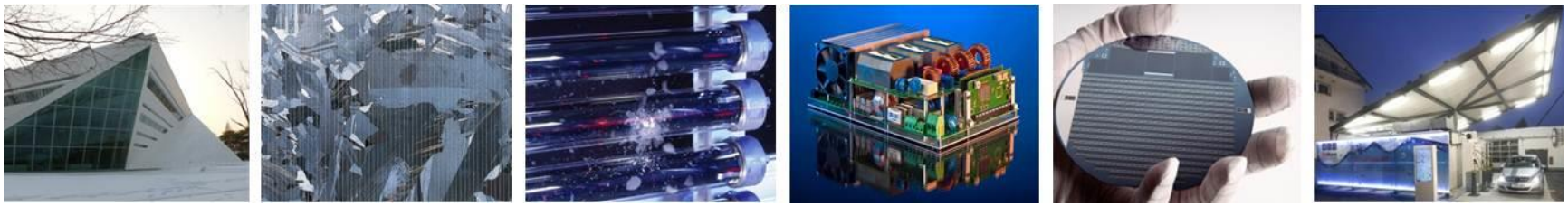
Summary and Outlook
Summary

- Grid-Sustaining Droop Control implemented on 2 inverters with 1 MVA / 725 kVA
- The Control has been tested successfully in a MV-Micro-Grid laboratory setup, regarding the following aspects:
  - Parallel Operation with the mains grid
  - Power Sharing with other Sources as there are…
    - Diesel Genset with Droop Control
    - Other Grid-sustaining Inverters
  - Current Limiting in Over-Load-Situation
  - Parallel Operation with other non grid-sustaining power sources (e.g. CHP, PV-inverters, …)
  - Black Start capability

Summary and Outlook
Outlook

- In future Measurement Campaigns the following should be tested:
  - Inverter under asymmetric load
  - Grid Connected LVRT
  - Resynchronization of the Micro-Grid to the mains grid
  - Tests with additional secondary control

Thank you for your attention



Fraunhofer Institute for Solar Energy Systems ISE

Roland Singer

www.ise.fraunhofer.de, www.testlab-pe.de

roland.singer@ise.fraunhofer.de