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Validation of the PRP Grid-Forming Control using HiL on the Kopernikus ENSURE Co-Demonstration Platform

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KOPERNIKUS ENSURE PROJEKTE
Die Zukunft unserer Energie

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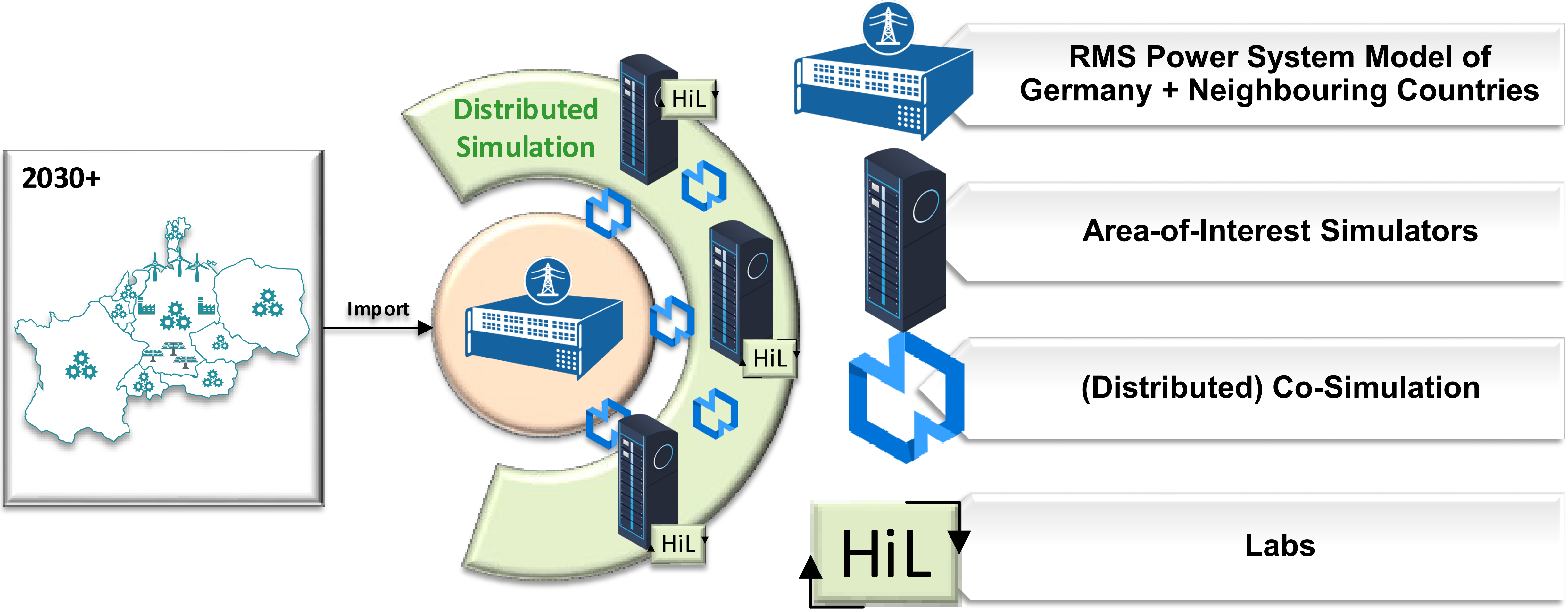
Co-Demonstration Platform

- The idea of a large distributed real-time co-simulation platform with Hil and PHiL capabilities across Germany was born in the project Kopernikus ENSURE (2016-2026)
- Within the project ENSURE the platform is used to **demonstrate** and **validate** technologies on a system level
- The project aims to build **Europe's largest real-time platform**
- Essential tools for the platform are **co-simulation** with VILLASNode and various **power system models**
- Platform should continue to exist after the project, e.g. as a **simulation community** or even a **national real-time center**, European extension is in discussion

Co-Demonstration Platform



Principle of PRP-Control

- New control strategy for a grid forming converter to attain power system stability with focus on
  - Constant frequency
  - Global stability
- This control idea generates the nominal network frequency at steady state and attains frequency stability by always returning directly to the nominal value

From Taylor series expansion:

Non-zero

Mathematically, all co-efficient with higher than linear order are zero

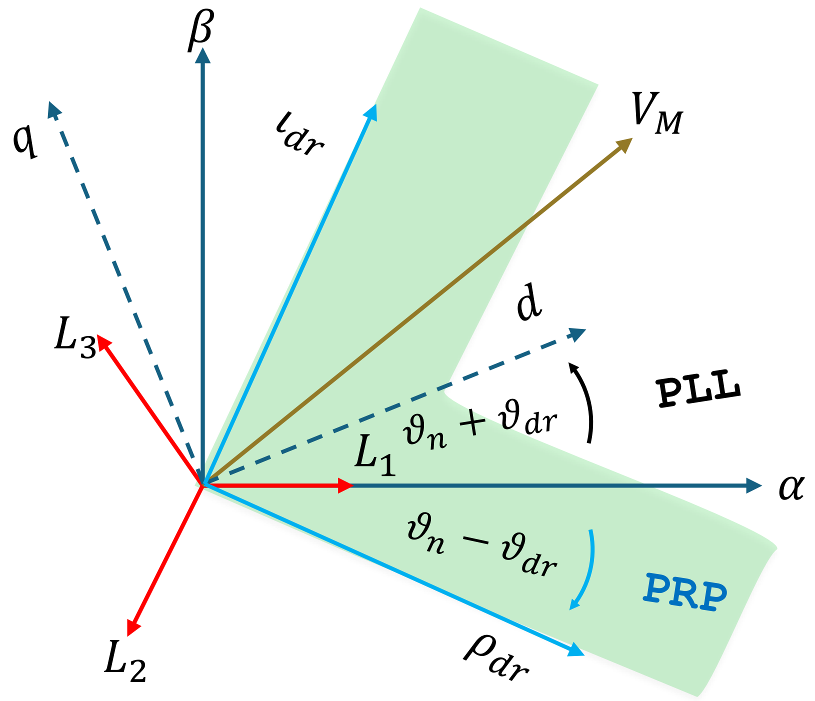
$$\emptyset(t) = \emptyset_0 + \emptyset_1 \frac{t}{1!} + \emptyset_2 \frac{t^2}{2!} + \cdots$$

$\emptyset_0$ is the phase of the voltage related to load flow and $f := \emptyset_1 = \frac{d\emptyset}{dt}$ represents the steady state frequency

Phase Restoring Principle (PRP) represents the phase part of a voltage in Grid Forming principle

Principle of PRP-Control

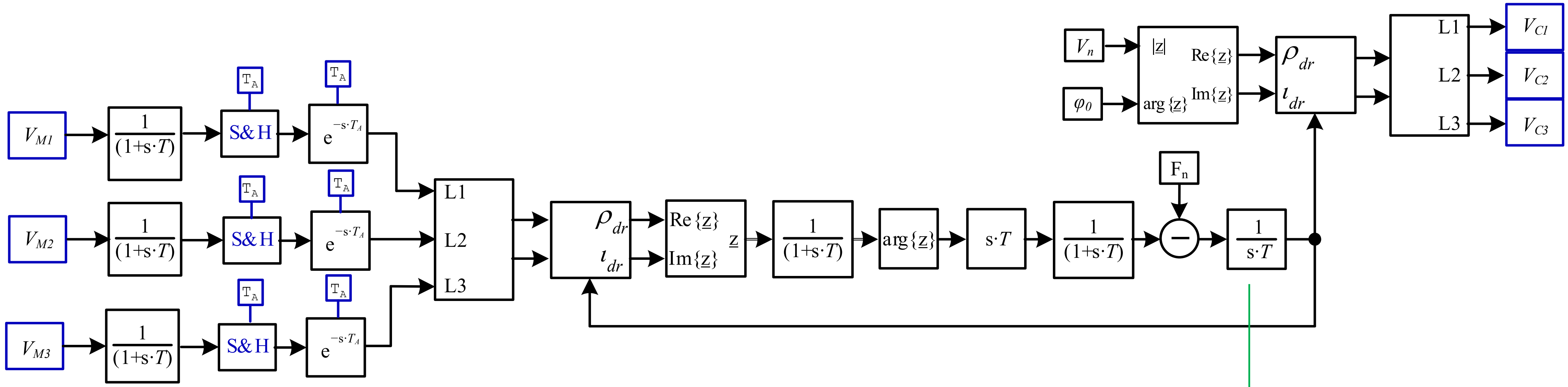
- PRP is the essential building block of new GFM approach from power system stability perspective
- PRP counteracts to disturbances inherently providing voltage stabilization
- PRP acts on the phase keeping by itself frequency constant



- Basic principle is an angular transformation of the reference frame in the opposite direction to a perturbation (from $\alpha\beta$ to $\rho_{dr}\ \iota_{dr}$)
- Power system frequency is imposed by PRP
- PRP reacts in phase and (constant) magnitude of voltage
- PRP participates in voltage stabilization by creating output voltage response towards post disturbance operating point

Principle of PRP-Control

Reference values (V_n, φ_0) are manipulated based on the phase drift ($\vartheta_n - \vartheta_{dr}$) to the new coordinate system and cross-referenced to the rotating $\alpha\beta$, to obtain converter voltage (V_C)



Three-phase input voltages (V_M) related to the converter's measurement node, smoothed out and discretized over a sample and hold block (S&H) with an inherent converter control delay

Input signals are converted from $\alpha\beta$ reference to a new reference frame represented in terms of the frequency drift.

A raw drift is emulated via the differentiator with the phase of the complex input voltage

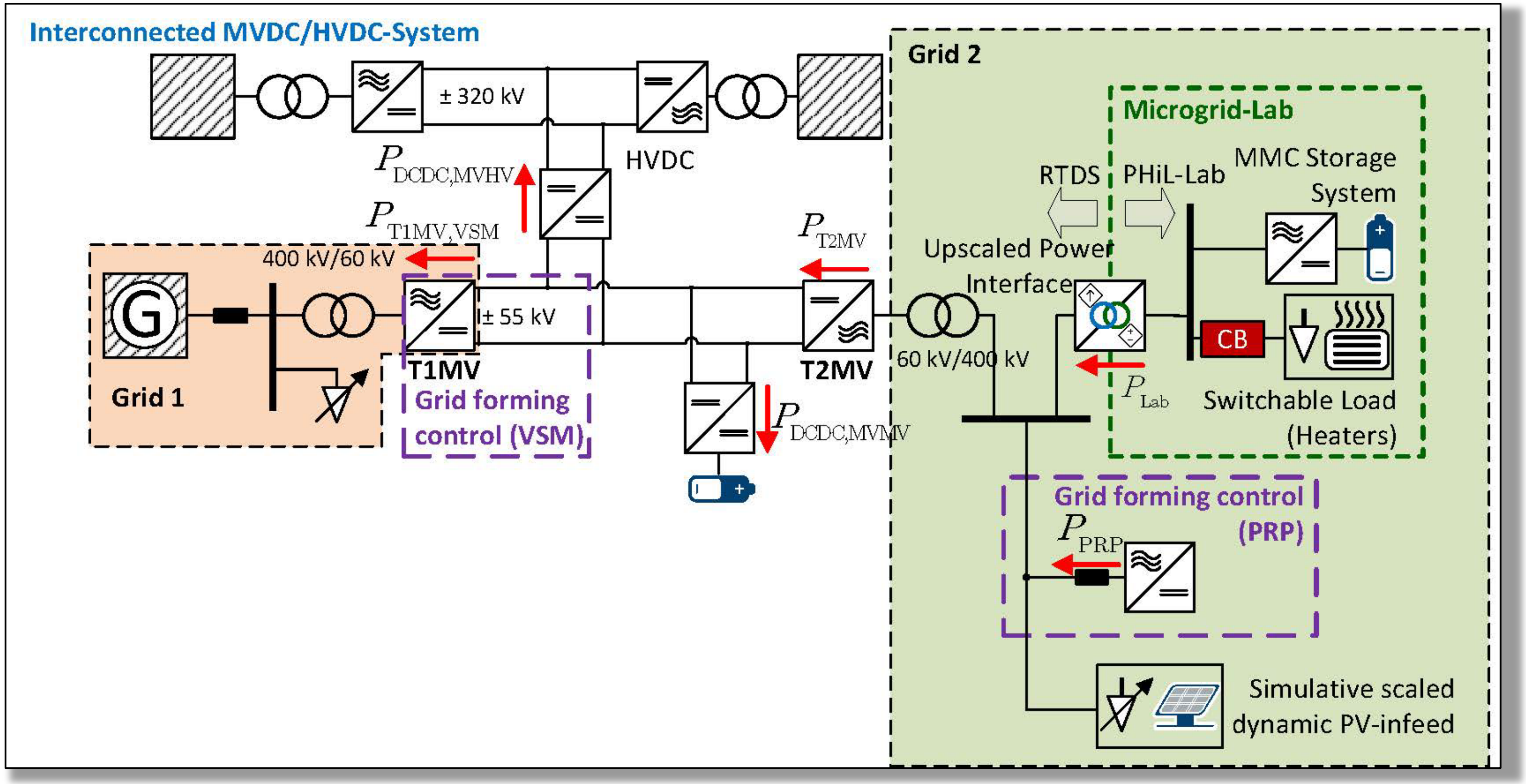
The integrator computes the linear part of the transformation angle over the control feedback loop

HiL Test System

- Multiterminal MVDC/HVDC test System, running on 8 NovaCor 1.0 cores (10 with transmission grid section)

Is parallel operation of PRP and PHiL MMC without control interactions possible?

How do VISMA and PRP operate together?

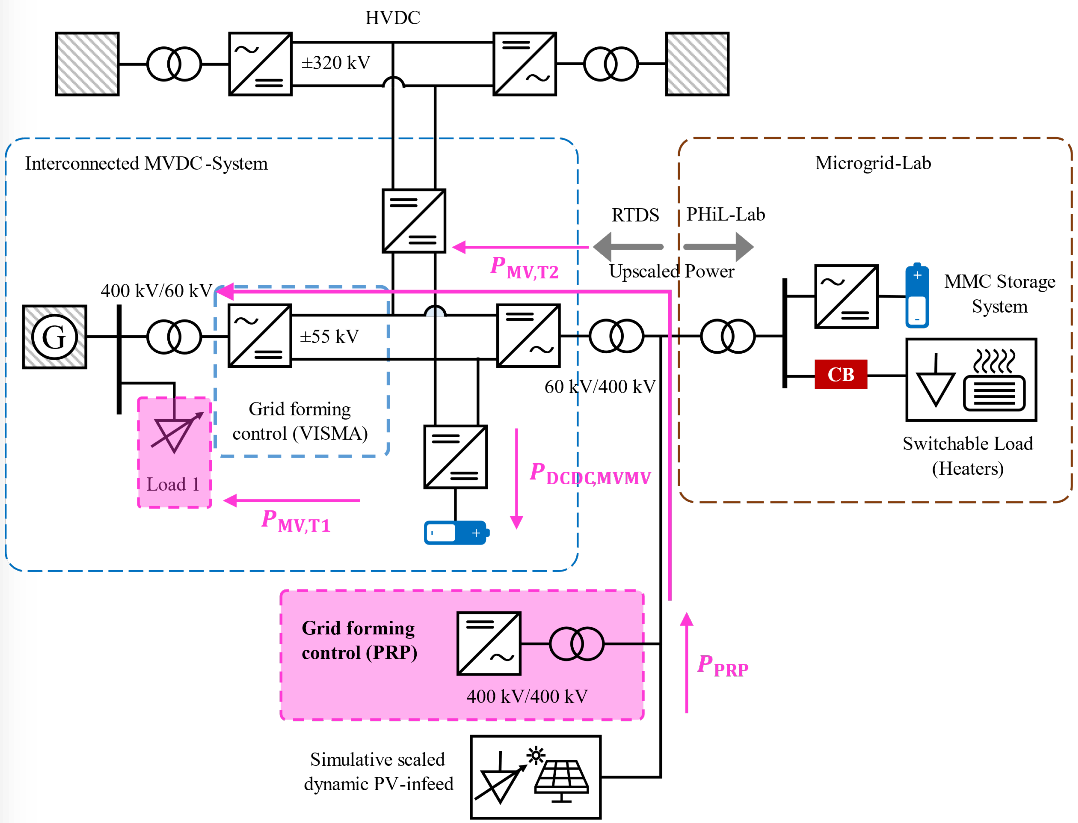


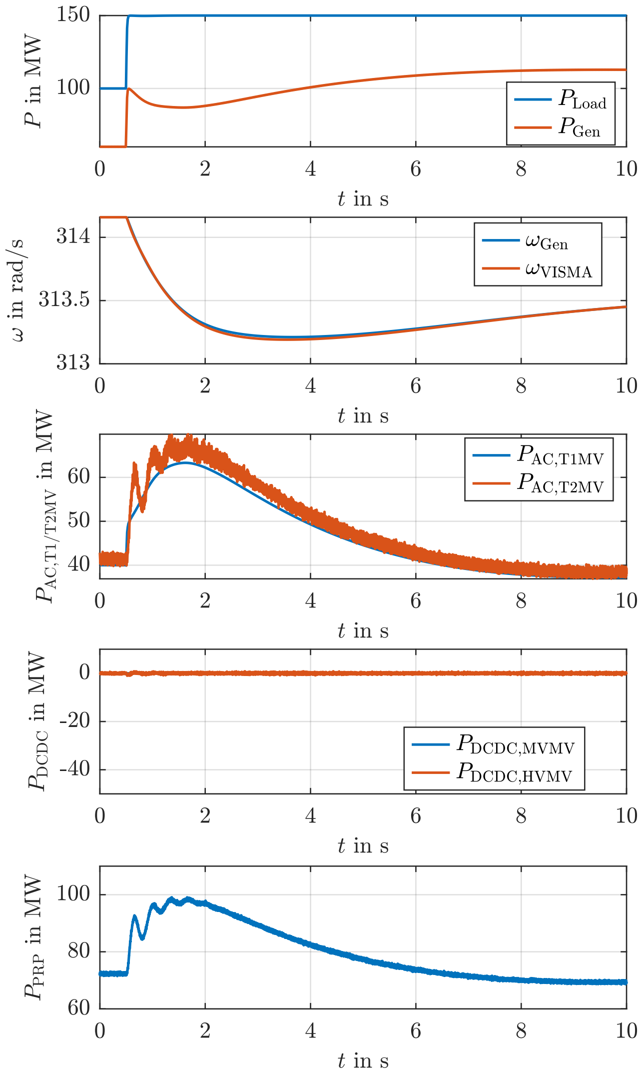
Results

Scenario 1:

Frequency reduction in grid 1 due to load jump

- The VSM control of station 1 provides additional virtual inertia in addition to the generator
- Power is provided from AC grid 2 via the PRP (alternatively also possible via storage and HVDC)
- To avoid local area oscillations between the VSM-controlled converter and the upscaled generator in grid 1, the VSM is extended by a power system stabilizer



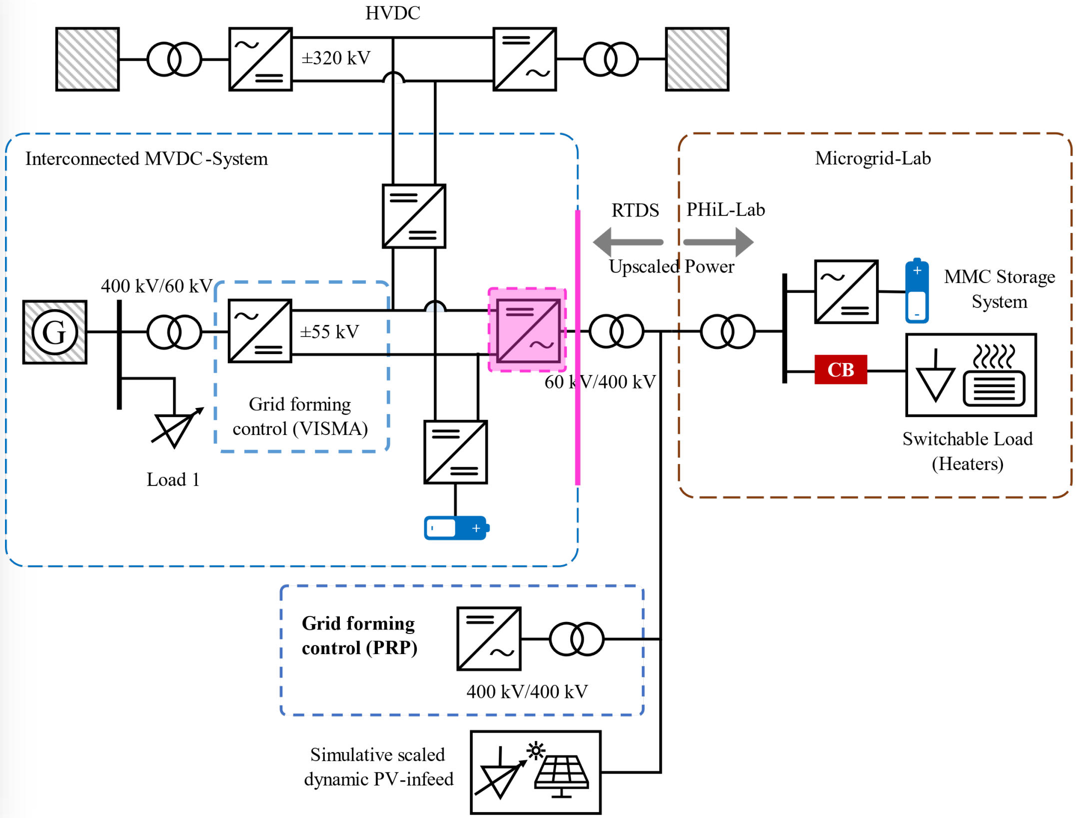


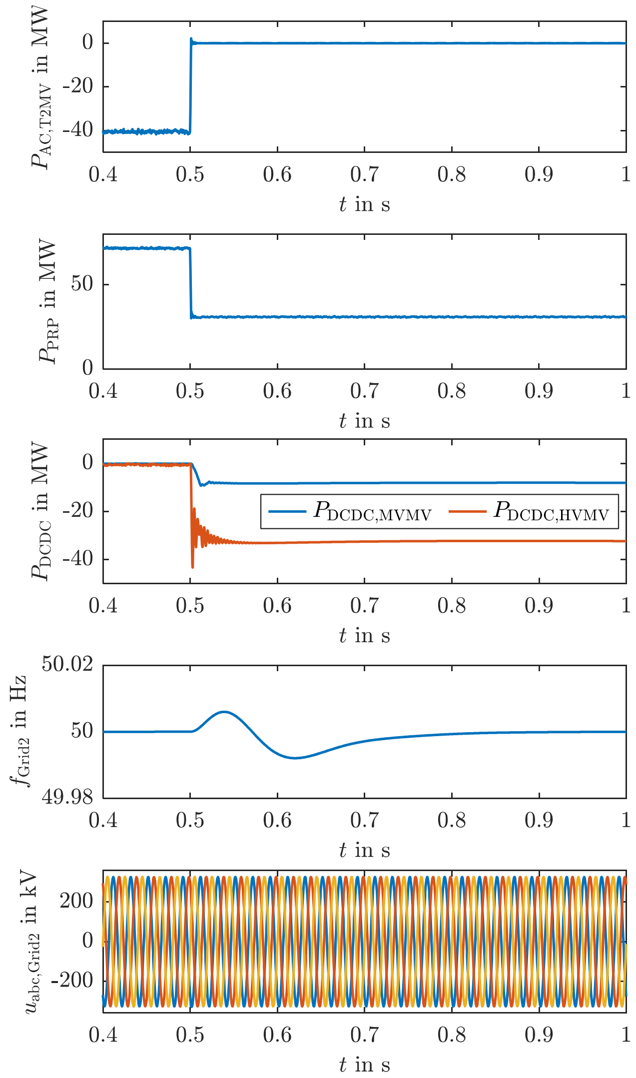
Results

Scenario 2:

Block of converter T2 and island operation of grid 2

- PRP control build and stabilized the AC grid 2 in island operation. Operation of the MMC laboratory inverter (grid-following) was not impaired
- In the multi-terminal DC grid, the power loss of station T2 can be fully compensated by power redistribution (power is provided by the HVDC and the battery)





Outlook and Literature

Outlook:

- PRP Control will be implemented on a Plant Controller running on SICAM A8000
- Grid Forming Plant Controller will be integrated into the test-system

Literature:

- A. Kuri, R. Zurowski, G. Mehlmann, D. Audring and M. Luther, "A Novel Grid Forming Control Scheme Revealing a True Inertia Principle," in *IEEE Transactions on Power Systems*, vol. 36, no. 6, pp. 5369-5384, Nov. 2021, https://doi.org/10.1109/TPWRS.2021.3071126
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- G. Mehlmann, U. Kühnapfel, F. Wege, et al., "The Kopernikus ENSURE Co-Demonstration Platform," in IEEE Open Journal of Power Electronics, vol. 4, pp. 987-1002, 2023, https://doi.org/10.1109/OJPEL.2023.3332515

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Thank you for your attention!

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