Power Hardware-in-the-Loop Studies for Transmission Network Stability Behaviors

R. Brandl, ron.brandl@iwes.fraunhofer.de, Fraunhofer IWES, Germany
Dr. T. Degner, Fraunhofer IWES, Germany

I. Advanced PHIL Investigation

This work presents the approach to utilize a Hardware-under-Test (HUT) for representing a full wind park with its dynamic behaviors connected to a scientific respected transmission network simulation of the IEEE 9-Bus system. The network simulation model was adapted to European conditions and modified as explained later. Different experiments were carried out to study interfaces between the virtual (numerical) simulation and physical HUT in case of bidirectional influence focusing realistic scenarios. Two test scenarios will be presented, with the focus to analyze the impact of new control strategy for wind park controllers on network stability.

Combining different system together with bidirectional data exchange, several points has to be considered to run realistic and save experiments:

- Real-time capability
- Resonance and error damping
- Emergency circuit system
- Accurate bidirectional coupling

A. Virtual PHIL Setup for Transmission Studies

Fig. 1 presents the schematic diagram of the investigated scenario, where the Virtual Simulated System (VSS) is simulating the IEEE 9-Bus System for frequency and short-term voltage instability investigations. By an interface algorithm voltages at a specific network bus will be outputted via a power amplifier to the HUT. The HUT is a programmable inverter, where different control strategies are implemented according to the test scenario.

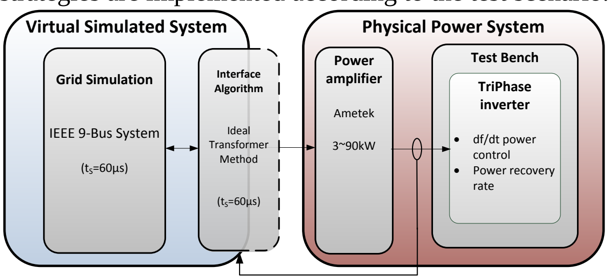

Fig. 1 PHIL system scheme showing the virtual and physical domain and their interface.

As seen in Fig. 3 the IEEE 9-Bus System was simulated in the virtual domain (black). For investigating the behavior of the different control strategies, the physical inverter was connected to Bus B1 and is replacing partial or the complete Generator G1 in meaning of the prospective shut down of conventional power plants and increase of RES.

During the experiments the HUT was adapted to a higher power level to represent the behavior of a wind park, respectively the connection point of the HUT to the network model was adapted to emulate realistic network impedances to generate representative results.

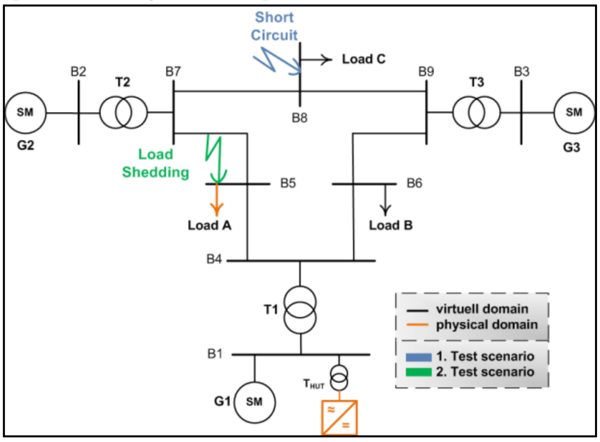

Fig. 3 Different test cases using the IEEE 9-Bus System in a PHIL environment including a physical inverter on Bus B1.

B. Physical PHIL Setup for Transmission Studies

The descripted virtual setup was implemented in the laboratory of the Fraunhofer IWES SysTec, where a flexible PHIL test infrastructure was built up to study several possible aspects:

- Component testing with more realistic network scenarios
- Network simulations including physical black-box or prototype devices
- Component independency testing in embedded network simulation
- Extensions to physical LV or MV test networks
- …

Fig. 4 Real-time system and 3 connected power amplifier (up to 270kVA) at the Fraunhofer IWES SysTec laboratory.

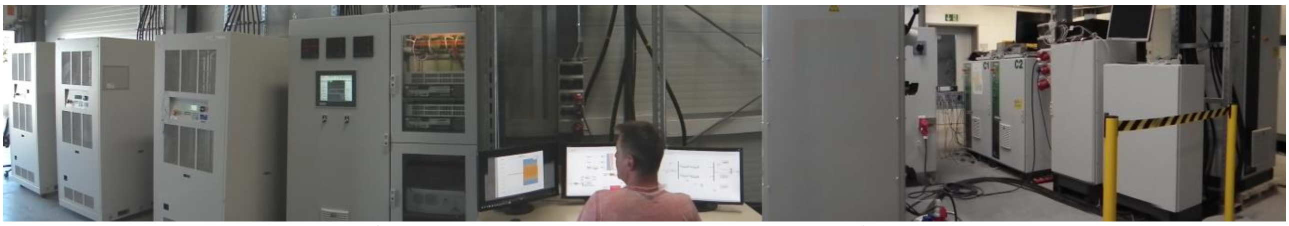

Fig. 2 Entire setup of the Power Hardware-in-the-Loop test bench at Fraunhofer IWES Systec laboratory.

II. Experimental Investigations

A. *Case 1 – Active Power Recovery Rate after Fault-Ride-Through*

1) Description

Due to guidelines for integrating distributed energy resources (DER) to the network, different conditions are made to support network behaviors. According to the German Grid Codes in the specific case of power recovery after a Fault-Ride-Through (FRT) network event, the gradient of active power is set to at least 10% P_N per second.

DER are mostly able to provide faster rates of power recovery. The support of different power gradients will be the subject of investigation in this test case. Therefore the network model was extended with more realistic loads by replacing them with dynamic synchronous machines. A short circuit was generated on Bus B8, whereby a line surge occurs. For this experiment the entire power of Generator G1 was replaced by the HUT.

The experiment was executed with two different fault clearing times for 5 times each and three test variants: With active Generator G1 (1), fast recovery rate (2) and slow recovery rate (3).

2) Results

Tc= 86ms	Test 1	Test 2	Test 3	Test 4	Test 5	Stable
(1)	✔	✔	✔	✔	✔	100%
(2)	✖	✖	✖	✖	✖	0%
(3)	✖	✖	✖	✖	✖	0%
Tc= 85ms	Test 1	Test 2	Test 3	Test 4	**Test 5**	Stable
(1)	✔	✔	✔	✔	✔	100%
(2)	✔	✔	✔	✔	✔	100%
(3)	✖	✖	✔	✔	✖	40%

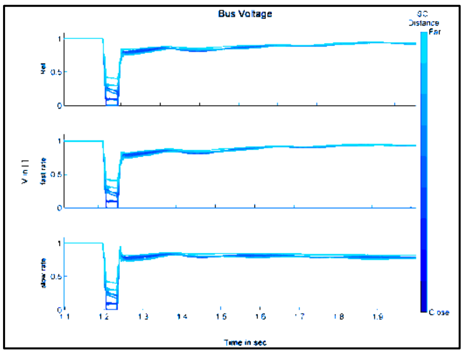

Fig. 5 Bus voltages of Test 5 at T_C=85ms. The darker the color, the close the distance to the short circuit event.

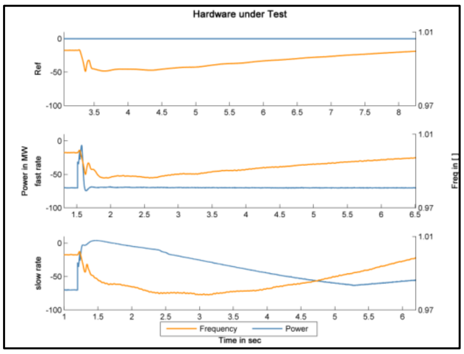

Fig. 6 Injected power of the HUT (blue) and frequency (orange).

B. *Case 2 –Inertia Emulation after Power Imbalances*

1) Description

Due to further increase of DER in the power system, their contribution of ancillary services has to be increased too. Aim of this experiment is the investigation of the impact of a wind park controller with electronic inertia emulation connected to a transmission network. The network model was extended with additional generator controller for more realistic conditions (for Generator G2 and G3).

To investigate the contribution the power level of Generator G1 was replaced with different levels of [0;10;20;30]% P_N from the HUT.

2) Results

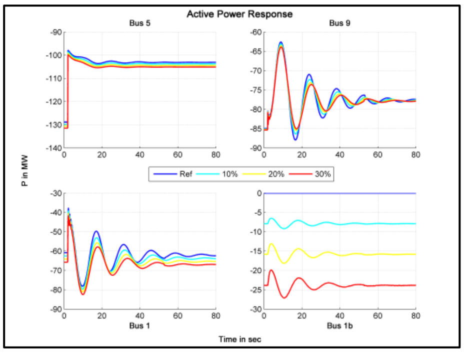

Fig. 7 Power at different busses for each test case.

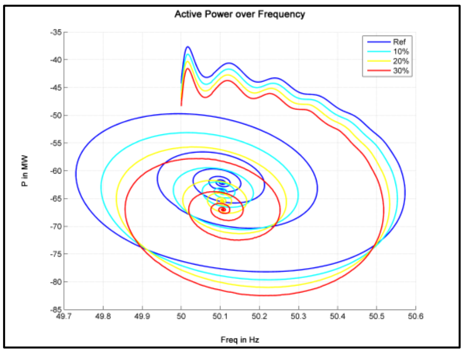

Fig. 8 Power over frequency curves for each test case.

C. *Conclusion*

1) Active Power Recovery Rate

Analyzing the results of the experiment those conclusions can be made for the analyzed IEEE 9-Bus test system:

- A system with active Generator G1 leads to higher network stability
- For slow power rates (compared to faster rates) the bus voltages drops again after the FRT event, which leads the frequency to rise to instable conditions

2) Electrical Inertia Control

In case of a non-active generator controller (G1) a wind park support with electrical inertia emulation will increase network stabilities.

Acknowledgement

We acknowledge the support of our work by the German Ministry for the Environment, Nature and Nuclear Safety and the Projektträger Jülich within the project "DEA-Stabil: Beitrag der Windenergie und Photovoltaik im Verteilungsnetz zur Stabilität des deutschen Verbundnetzes" (FKZ 0325585).

Furthermore this work is partly supported by the European Community's Horizon 2020 Program (H2020/2014-2020) under project "ERIGrid: European Research Infrastructure supporting Smart Grid Systems Technology Development, Validation and Roll Out" (Grant Agreement No. 654113).