European Research Infrastructure supporting Smart Grid Systems Technology Development, Validation and Roll Out

TRANSNATIONAL ACCESS
USER PROJECT FACT SHEET

USER PROJECT	
Acronym	**Smart beats Cooper**
Title	**Smart Grids Testbed for Hardware and Software in the Loop Testing of PV Integration into a Future DSO Network based on a Secure Energy Information Network**
ERIGrid Reference	**01.008-2016**
TA Call No.	**1**

HOST RESEARCH INFRASTRUCTURE			
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1. USER PROJECT SUMMARY (objectives, set-up, methodology, approach, motivation)

Objective:

The Smart Grids Research Group at Ulm University of Applied Sciences (HSU) investigates several grid components and control strategies, especially PV inverters, their control strategies and communication interfaces, considering real grid data obtained from the grid operator in the area of Ulm[1]. Such strategies can have high complexity and thus must be evaluated and analyzed extensively in a laboratory environment before they can be realized in a field test and thereafter in the real grid. However, performing a pure hardware test with only physical components in laboratories can be too complex for certain grids and requires an extensive budget. Therefore, a system setup based on a combination between software and hardware in the loop (SIL and HIL) environments was suggested to be implemented in the Smart Grids Lab of HSU. The system setup was realized with a complete quasi-static simulation in software (i.e. DIgSILENT-PowerFactory) as well as a hardware test of an equipment under test (EUT). This combined setup includes a power interface and measurement system to parallelise the SIL and HIL simulations, and form a so called power hardware in the loop (PHIL). The first experiment of Smart beats Cooper aimed at validating and comparing the developed setup with a more common system setup available at AIT, considering several criteria, such as required components, possible time resolution for the simulation as well as the reaction to a change in the simulated system variables (e. g. voltage). In the second experiment, the proposed system setup was examined in a holistic test scenario evaluating a centralized control system including its communication systems and the required interfaces, representing a future smart grid control strategy.

Power-Hardware-in-the-Loop Setups:

Two system setups have been investigated in the performed experiments (see Figure 1), which include a PV-Inverter with active Q(U) control for both cases:

- **System Setup A:** The system setup available at AIT for real-time simulation is based on a linear signal amplifier (i.e. Spitzenberger Spies PAS) as power interface which simulates a grid connection point from the simulated grid. This power interface (PI) receives an analogue voltage signal from the digital real-time simulator (DRTS) (i.e. Opal-RT), which generates the signal according to the parameters of the simulated grid connection point (e.g. voltage U_{pcc}). These parameters are calculated within a real-time dynamic simulation with a high-time resolution of typically 10-50 μs, based on a code-generated model converted from a MATLAB/Simulink model. To close the simulation loop, the DRTS is fed back with analogue current measurements, which are converted internally to digital values to be entered into the simulation model. These transient measurements correspond to the feed-in power of the PV inverter (i.e. EUT: Fronius PV inverter), which is connected physically to the power interface representing the point of common coupling (PCC) of the grid. For the purpose of recording the simulation results, an external measurement system is connected to the PCC (i.e. Dewetron).

[1] https://www.ulm-netze.de/

- **System Setup B:** This setup proposed the utilization of the steady-state load flow calculation of a power system analysis software (i.e. DIgSILENT PowerFactory). The calculated voltage value at a predefined bus bar in PowerFactory is passed as a new voltage set point to the PI, which is a switched-mode voltage source (i.e. Regatron TC.ACS). For sending the set values, an interface has been programmed in C# language which utilizes the API provided by the manufacturer to communicate with the PI. A PV inverter (i.e. Fronius) has been connected physically to the voltage source as EUT and feeds-in power to the grid. The active and reactive power of the PV inverter has been captured by a measurement device (i.e. Janitza UMG96). The measurements were fed back to the power system simulation as digital values to form a closed loop. For this measurement feedback, an interface has been programmed in Python utilising Modbus/TCP functionality of the measurement device. In order to control the voltage in the simulation of PowerFactory, an external function is programmed in Python. In order to control the voltage in the steady-state load flow calculations of PowerFactory, another external Python function is developed for the control and synchronisation of these calculations.

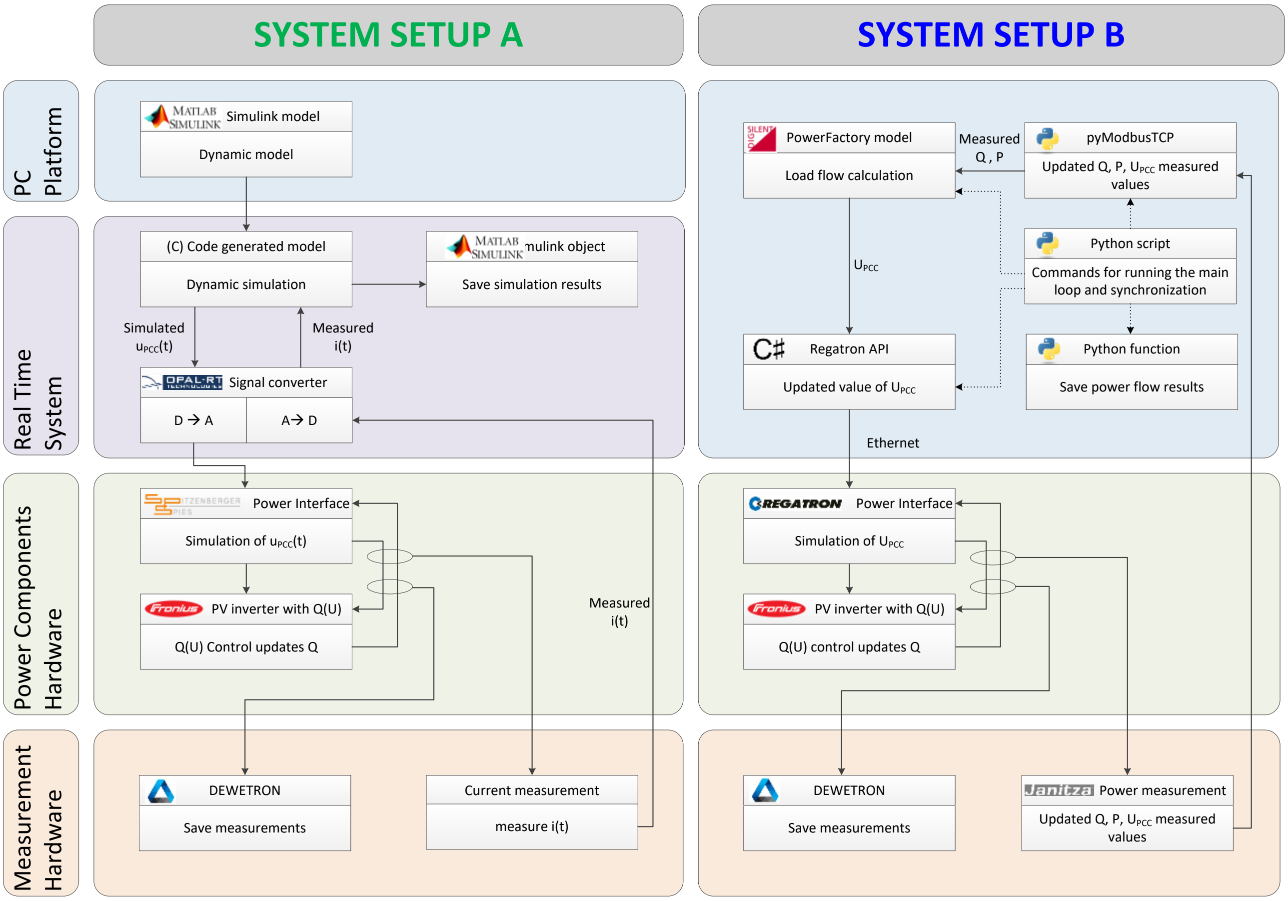

Figure 1: Comparison of the architecture of the used system setups: System Setup A -- Opal-RT RT-LAB based system with Spitzenberger Spies PAS. System Setup B -- Digsilent PowerFactory based system with Regatron TC.ACS.

Motivation:

Considering the available equipment in the Smart Grid Lab, there is a necessity to combine real time simulation with HIL tests in order to perform the planned tests. Given the opportunity provided by ERIGrid Transnational Access, a diversity of equipment and possible setups are available at AIT, so that the targeted setups can be realized and validated. In addition, the experience and know-how by both AIT and HSU, which was accumulated over years through performing many lab experiments, can be exchanged and further developed.

Methodology:

The individually used experiments are depicted in Figure

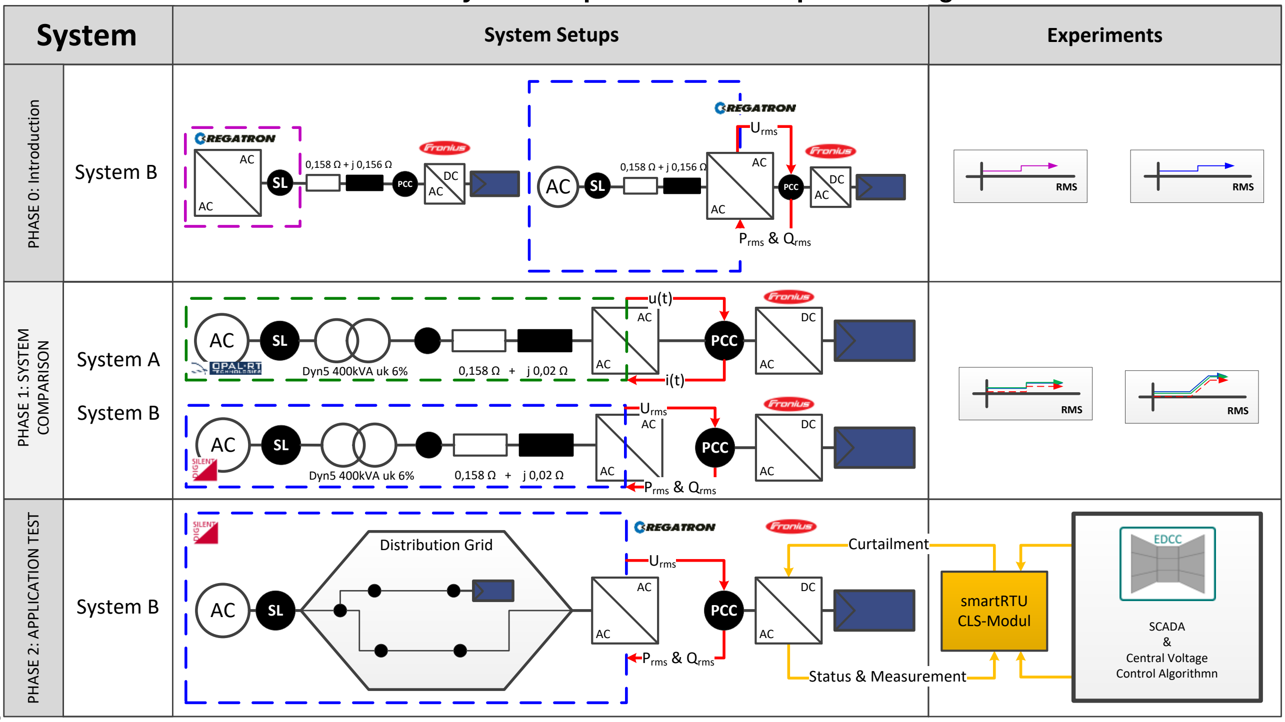

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Figure 2 which also shows the system setups and the used grid model. The depicted experiments are grouped into three parts. These are the previous described tests for the comparison of system setup A and B which are called Phase 1. Phase 1 has been accompanied with a preliminary test to characterise the system setups which is referred to as Phase 0. The subsequent tests were performed as a case study in Phase 2 (see Figure 3). In the case study, EUT has been a Fronius PV inverter with its active power feed-in regulated by a coordinated voltage control strategy. The inverter has a nominal active power of 20 kW, due to active power restriction, the nominal value was limited to 10 kW during the experiment. The Q(U) setting applied to the EUT is the same as in the previous Phase 1.

The examination of both used system setups has been carried out by comparing the response of the systems within three different scenarios. These were:

- **Step Function:** Voltage deviation at the slack bus bar from 1.04 p.u. to 1.08 p.u. in a step. This represents the most extreme change of a parameter in the modelled system. It has been chosen to evaluate the difference in the dynamic behavior of the systems in the time domain of seconds.
- **Transient Behavior of the Step Function:** The voltage change of the two setups is evaluated regarding the transient behavior of the system.
- **Ramp Function:** Voltage deviation at the slack bus bar from 1.04 p.u. to 1.08 p.u. as a voltage ramp over the course of 1 to 10 minutes. These are typical changes which can be deployed to examine the stability of systems in varying conditions.

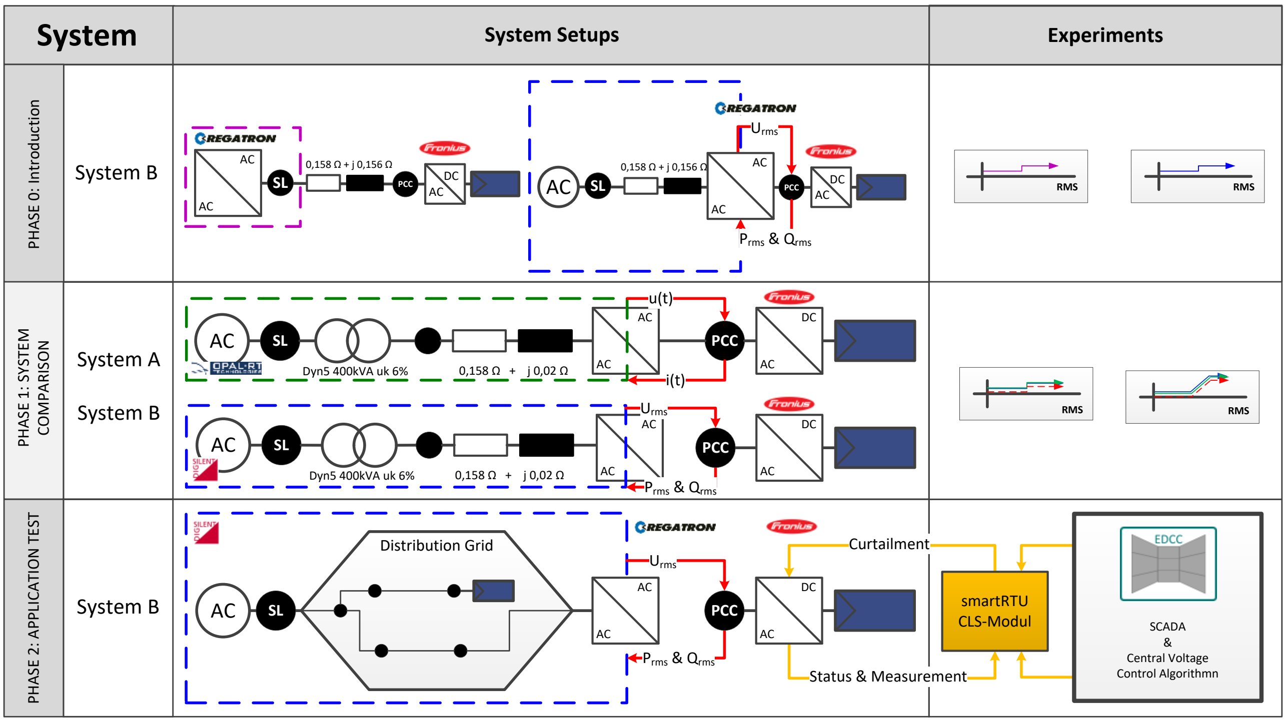

Figure 2: Schematic overview of the test scenarios for the comparison of the system response which is split in three phases. The system setups and the implemented grid models as well as the individual experiments and the carried comparisons are shown.

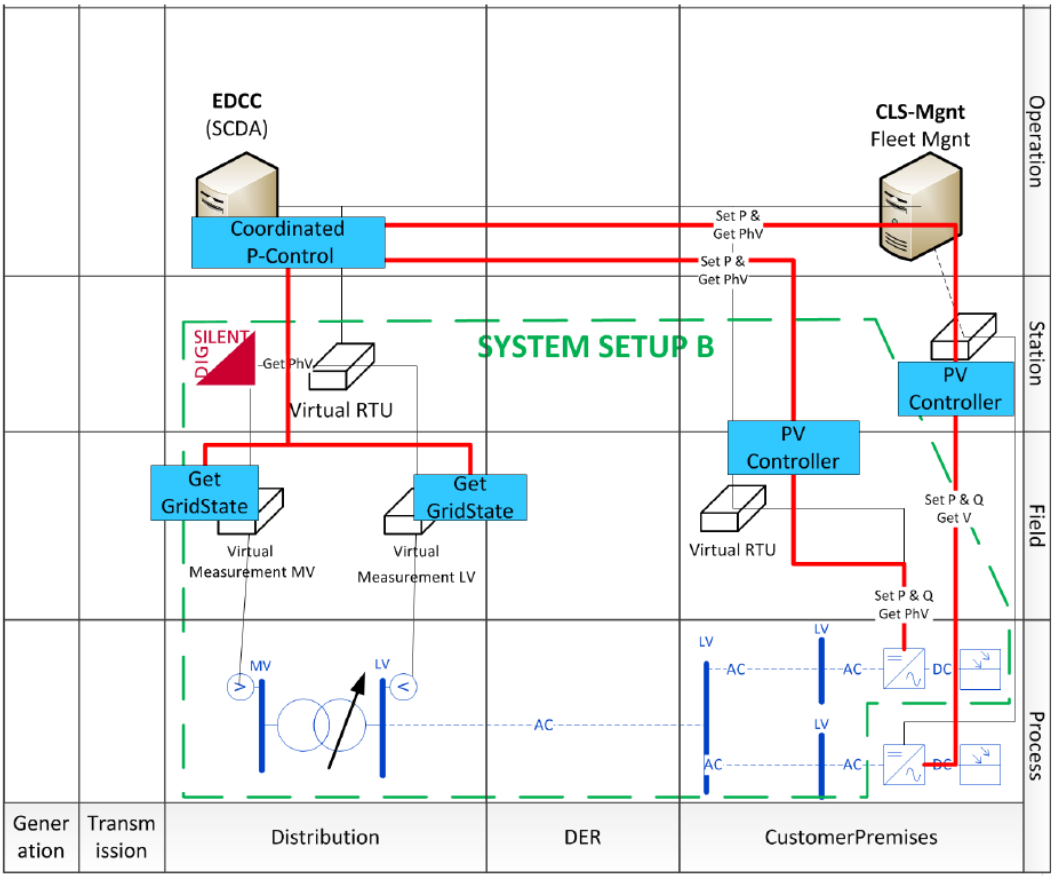

Figure 3: Combined SGAM-layer-diagram of the implemented case study. The base layer depicts the real and the simulated components as well. The boundary of the PHIL setup is illustrated as a green dashed line. The utilised functions are depicted in blue boxes.

2. MAIN ACHIEVEMENTS (results, conclusions, lessons learned)

Results:

- **Comparison of the Dynamic System Response for Voltage Step:**

Both system setups (A & B) were compared in the context of a voltage step considering the interaction with the Q(U) control by the PV inverter as shown in Figure 4.

The varying time constants of the Q(U) control could be observed when looking at the different responses of the PV inverter to the voltage step. For system setups A and B, the inverter reacted immediately with a small time constant with a reactive power in-feed when the voltage changed. Smaller time constants resulted in faster reach of a steady state. For both setups, the reaction of the inverter was immediate when small time constants were used. In contrast to that was the calculated reaction to the changed reactive power in-feed by the system setups. For system setup A, the reaction of the voltage happened immediately due to small time steps of the PHIL-setup, whereas for system setup B, the reaction was delayed in more discrete steps which corresponds to the cycle time. The time constant suggested by the manufacturer is $T_C = 5\ \mathrm{s}$ which results in a highly damped system response.

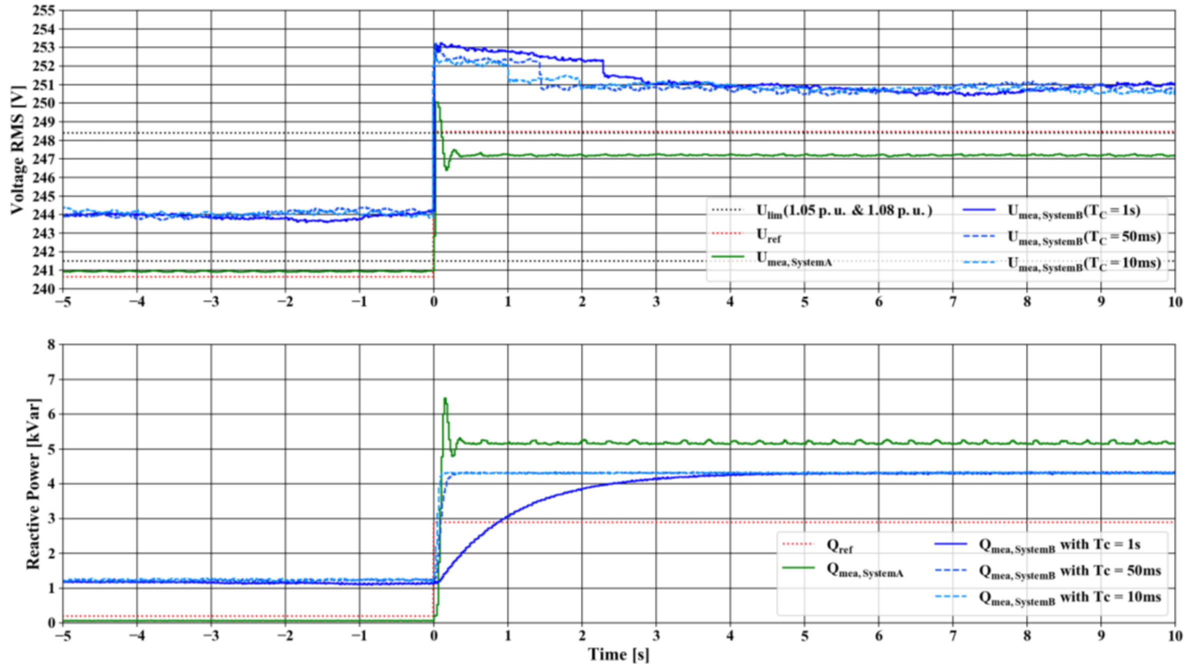

Figure 4: Comparison of the different system responses to the deviation voltage step. The reference curve is constructed by using the steady state results for given Q(U)-control. For system setup B varying time constants T_C for the Q(U) controller of PV inverter are presented. The depicted values are RMS-values calculated on a 1 period time frame. The dashed line represents the values for 1.05 p.u. as well as 1.08. p.u. which in turn are the set points for the break of the slope of the Q(U) controller.

- **Analysis of the Cycle Time for the Examined Setups**

System setup A was able to meet the time requirements due to its real-time control loop with a cycle time well below 50 μs. For system setup B, the cycle time was significantly higher and required a more detailed analysis. As shown in Figure 5, the total cycle time remained under one second. The cycle time t_{PHIL} for system setup B consisted of the control loop in the main loop, the calculation of the new setpoints in PowerFactory, the control of the switched-mode amplifier (Regatron) and the feedback of the measured values in the SIL. Overall, t_{PHIL} with a median of 420 ms could be achieved with system setup B. The density representation in Figure 5 shows 2 respectively 3 clusters for the cycle time with the highest density around the median. The second cluster is in range of 0.2 s to 0.3 s. Due to the added IEC61850 simulator function used in the case study this cluster is moved towards the median.

Conclusion:

The outcome of the experiments was that both systems are capable of providing a suitable simulation environment for the evaluation of an EUT, such as a PV system. The fundamental difference between both systems were the calculation principles which are phasor calculation for system setup A and the use of steady-state simulation for system setup B. System Setup A leads to a higher accuracy and continuity of the output signal than System Setup B. Howeverthis leads also to a more complex system regarding modelling, setup and operation. The differences were apparent for the reaction of the Q(U) controller of the PV inverter within the test environment. If the time constant of the Q(U) controller is significantly lower than the cycle time, System Setup B shows discrete steps of the voltage and the stabilization time is prolonged. If this criterion is not decisive, like in the case study carried out in the second phase, then System Setup B is sufficient.

As an overall statement, the presented System Setup B is suitable as a test simulation environment at the HSU, after considering its capability regarding the time resolution.

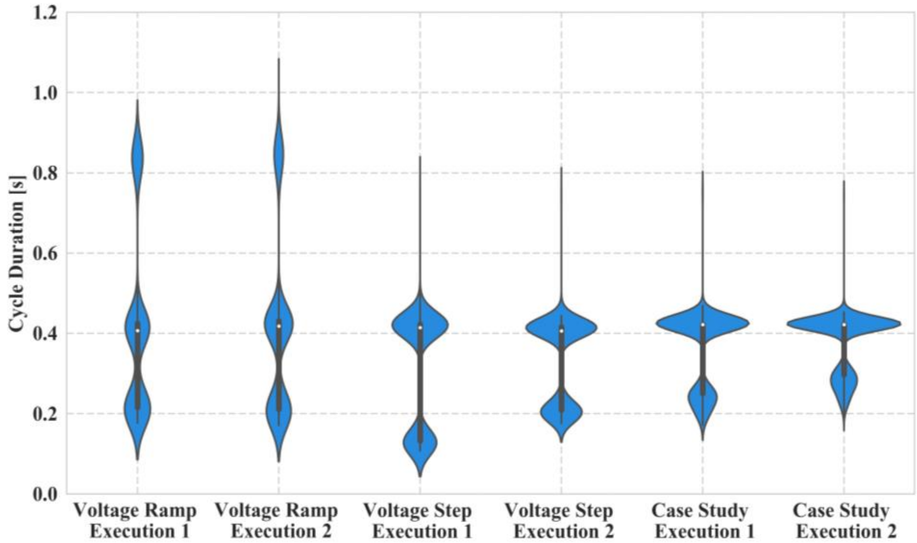

Figure 5: Illustration of the cycle time t_{PHIL} for system setup B for use in the evaluations of Phase 1 as well as for use in Phase 2. The white circle represents the median of the violin plot, the bold line represent the interquartile range and a density representation.

Lessons learned:
An important challenge faced when performing the experiments is an offset (deviation) between the set-point sent to the PI (i.e. Regatron ACS.TC) and the actual voltage measured at its terminal in the range of 2 to 3 V. Based on an analysis, considering several loading cases of the voltage source, it is suspected that this problem is caused by the high immanent impedance of system setup B. The linear amplifier (i.e. Spitzenberger Spieß) had a negligible voltage deviation between the set and the realized values. This problem should be considered when performing future tests and will be tackled in cooperation with the manufacturer.

3. PLANNED DISSEMINATION OF RESULTS (journals, conferences, others)

Journals:
Comparison of Power Hardware-in-the-Loop Approaches for the Testing of Smart Grid Controls, Ebe F.; Idlbi, B.; Casel, M.; Kondzialka, C.; Chen, S.; Heilscher, G.; Seitl, C.; Bründlinger, R.; Strasser, T. A. - MDPI Energies - Special Issue: (in Press)

Conferences:
An approach for validating and testing micro grid and cell-based control concepts - Ebe F.; Idlbi, B.; Casel, M.; Kondzialka, C.; Chen, S.; Morris, J.; Heilscher, G.; Seitl, C.; Bründlinger, R.; Strasser, T. A. - Proceedings of the CIRED Workshop 2018- 7/8.06.2018 - Ljubljana - Slowenia

Presentation:
Comparison of Power Hardware-in-the-Loop Approaches for the Testing of Smart Grid Controls – Falko Ebe - IRED side-event “Laboratory-Based Methods for Smart Grids”- 16.10.2018 - Vienna – Austria