NANYANG TECHNOLOGICAL UNIVERSITY SINGAPORE

ENERGY MARKET AUTHORITY
Smart Energy, Sustainable Future

CAMBRIDGE CARES

Office of Naval Research GLOBAL Science & Technology

Power Hardware In the Loop Study of Hybrid Energy Storage System in DC Microgrids

Introduction

- In Power hardware in the loop (PHIL), one part of the system is numerically simulated in OPAL-RT and other part is the actual hardware under test .
- The OPAL-RT and hardware under test are interfaced together using a power amplifier.
- The PHIL is an excellent way to validate the performance of the system as the effect of the physical hardware in the system can be monitored in real time.

System Architecture and Operation

- The power amplifier is used to interface between the OPAL-RT and hardware under test.
- The lithium ion battery with bi-directional DC-DC converter are considered as hardware under test.
- The DC microgrid with PV system, SC system and DC load is simulated in OPAL-RT system.
- The voltage reference from the OPAL-RT simulation is sent to the power amplifier through an optical fiber link.
- The power amplifier emulates the DC link voltage.
- The power is exchanged between the power amplifier and battery system based on the DC link voltage output from power amplifier.
- The current measurement from the battery system is feedback to the OPAL-RT system and the simulation is updated in real-time.

Advantages of PHIL Study

- Shorter setup time.
- Lower development cost.
- Easier to reconfigure for rapid prototyping.

System Parameter for PHIL Study

<u>PV Specifications</u> *Open circuit voltage* *Short circuit voltage*	<u>Values</u> *320V* *40 A*
<u>Battery specifications</u> *Nominal voltage* *Rated energy*	<u>Values</u> *260* *10kWh*
<u>SC specifications</u> *Terminal voltage* *Capacitance*	<u>Values</u> *300V* *5.8F*
<u>PA specifications</u> *Power capacity* *Peak current* *Maximum DC output voltage*	<u>Values</u> *45kVA* *616A* *424V*
<u>Converters Parameters</u>	L_p = 2 mH, L_{bat} = 6.3 mH, L_{scap} = 5 mH, R_L = 200 Ω, C_b = 2200 μF, C_{pv} = C_s = 500 μF
<u>Controller Parameters</u>	K_{p_pv} = 0.1, k_{i_pv} = 1 K_{p_b} = 0.1, k_{i_b} = 1 k_{p_sc} = 0.4, k_{i_sc} = 150 k_{p_v} = 1, k_{i_v} = 10
<u>Reference values</u>	v_{ref} = 400 V, f_{sw} = 10 kHz LPF cut-off freq = 2π5 rad/s T_s = 25 μs (OPAL-RT simulation) T_s = 20 μs (dSPACE 1103 controller)

Experiment setup and Results

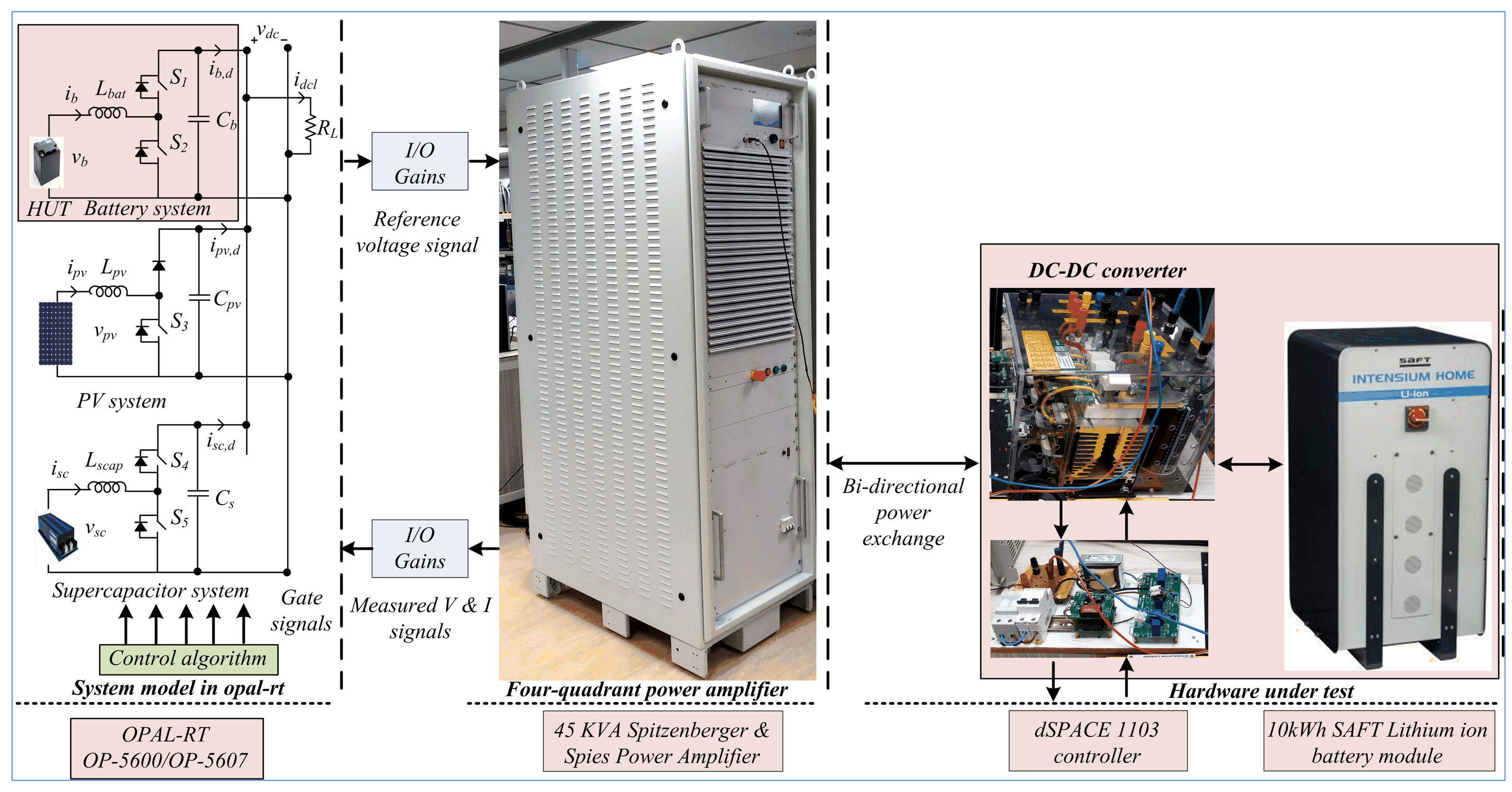

Figure 1: Experiment setup for PHIL study.

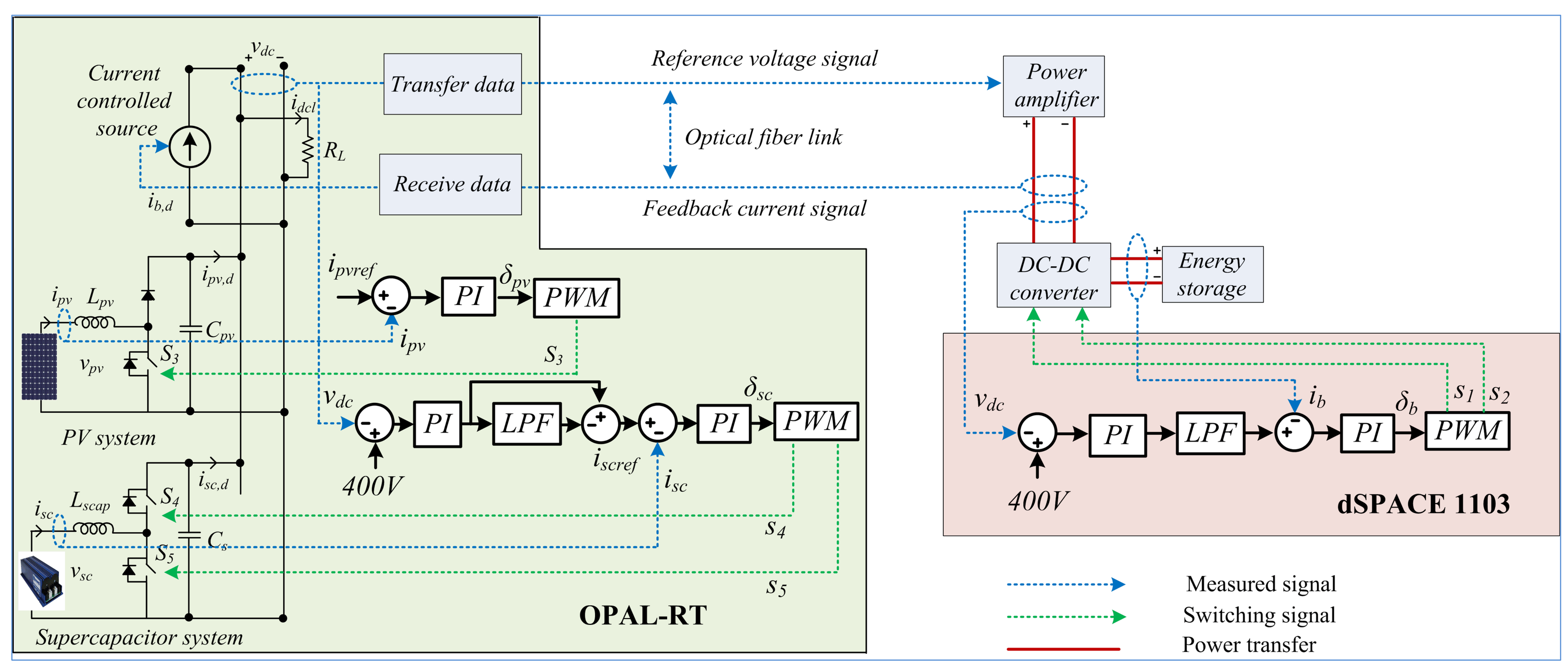

Figure 2: Closed loop system architecture for PHIL study.

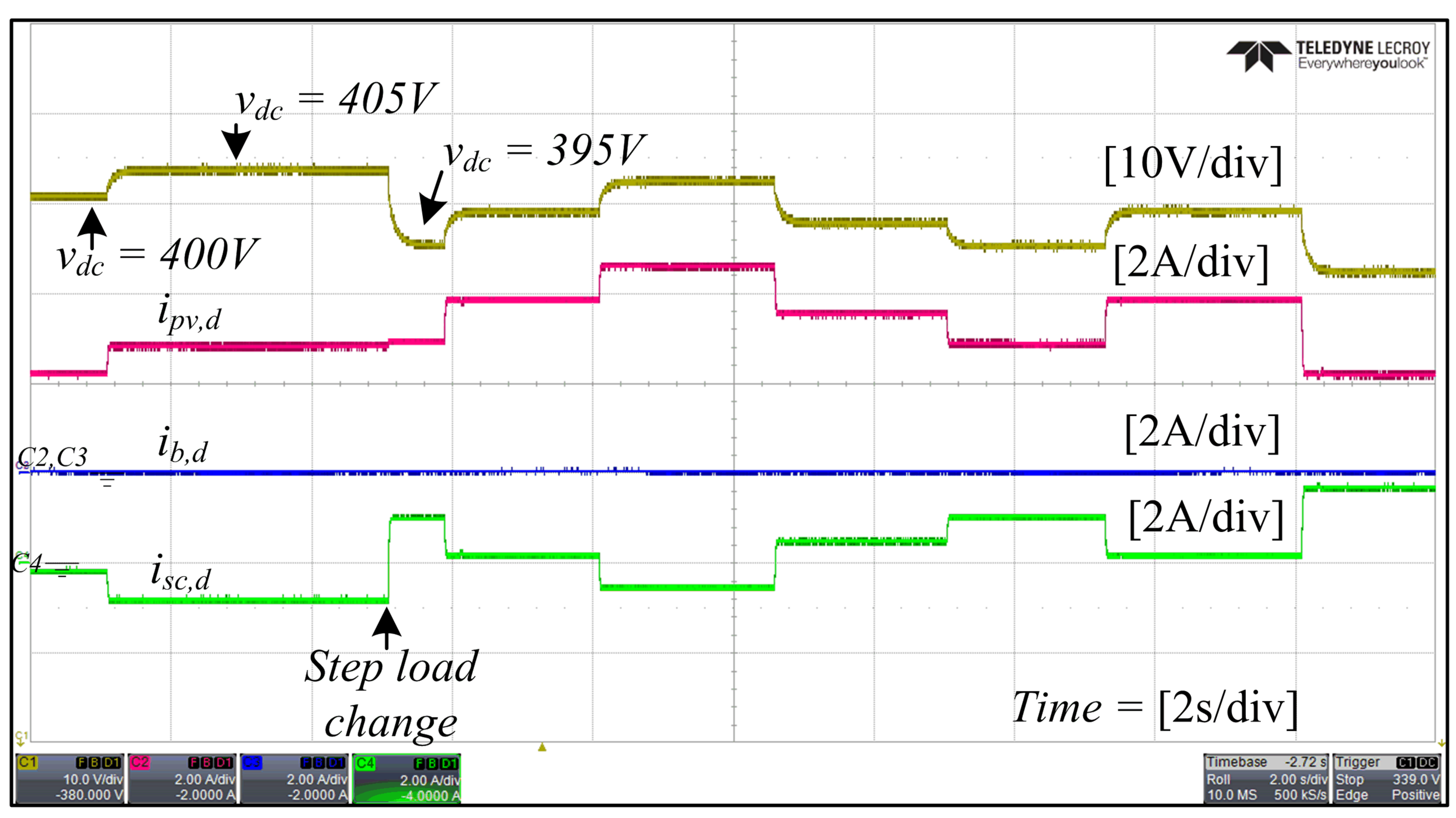

Figure 3: PHIL experiment results without battery system

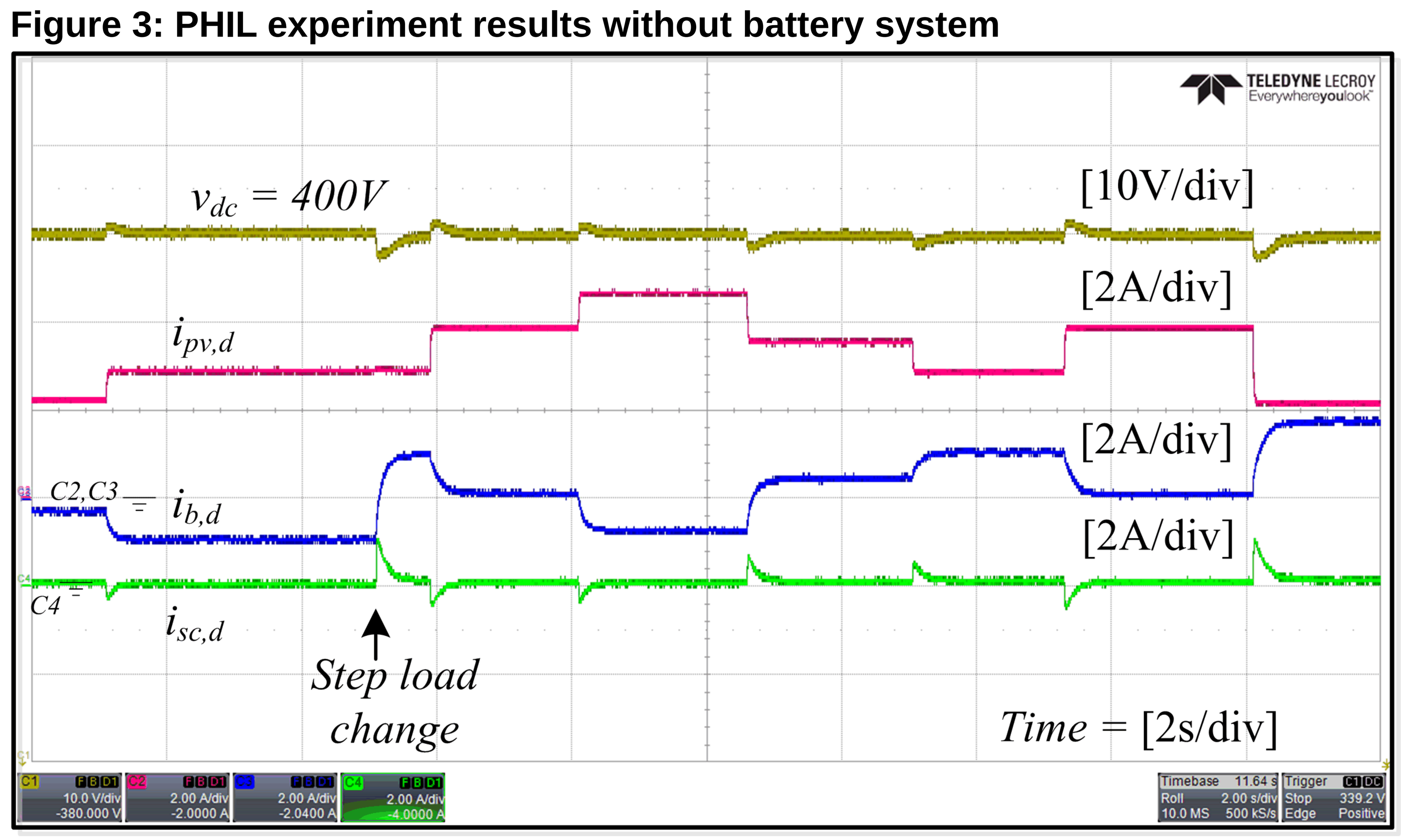

Figure 4: PHIL experiment results with battery system

Conclusion

- The closed loop operation is achieved such that the DC link voltage is well maintained at v_{dc} = *400V* in-spite of the DC load change and the PV current variations with battery system.
- The voltage deviation during the step load change is *2V* , and the voltage is restored to its reference value in less than *400ms* with the battery system.
- The presented PHIL experiment is effective for testing the energy storage devices for high power applications where the actual DC microgrid is not available.

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