Advanced Power-Hardware-in-the-Loop Evaluation of Inverter-based Resources (IBRs)

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Background

- **Power-hardware-in-the-loop (PHIL) evaluation of IBRs** has become more and more important as it provides reliable testing results.
- A successful lab PHIL testing gives confidence of hardware system to be deployed and de-risk technology integration prior to field deployment.
- A general HIL platform for system evaluation
Requirements and Applications

• Dynamic/electro-magnetic transient
  – Study stability of IBRs, transient dynamics, inverter spontaneous responses
  – Replicate the actual current and voltage dynamics in the inverter
  – Large utility IBRs, feedback current

• Phasor domain
  – Study collective grid services provided by IBRs (e.g., voltage regulation)
  – Multiple inverters and PCCs, compromise between stability and accuracy
    - Behind-the-meter IBRs, feedback power
Example I: Evaluate dynamic transients of IBRs

**Objective**: demonstrate whether a microgrid system, including a specific commercial microgrid controller, is able to meet the functional requirements for Borrego Springs Microgrid.

- Disconnection
- Resynchronization
- Steady-state frequency and voltage in islanded mode
- Dispatch
- Enhanced resilience (e.g., fault)

Dynamic transients, need to feedback current
Stability issue of the PHIL interface

• Parasitic resonance that exists due to the interaction between the grid simulator inductance and the inverter filter capacitance.
  – Instability of PHIL current loop due to the resonance and the loop time delays

• Voltage difference between simulated voltage and reconstructed voltage

• Illusionary effect in P and Q due to time delays
Solution for the Stability Issue

- Address the challenges of distribution systems especially associated with high penetrations of distributed PV, such as voltage stability

\( G_{\text{comp}} \): Notch filter; \( G_{\text{Reg}} \): PR control

Figure from [1]

Implementation of the PHIL interface

- Develop standard AFBs that can be used as an interface between PHIL simulation and hardware. AFBs can be reused and reconfigured for various applications.

Figure from [2]

**Experimental Results**

Utility voltage
277 V

Simulated voltage

CT & PT

Photos by NREL
Example II: Evaluate Grid Services Provided by IBRs

- **Objective**: evaluate the voltage regulation performance of Distributed Energy Resource Management Systems (DERMS) in a realistic lab environment.

- **Requirements**: large scale PHIL with multiple PCCs, and DERMS interacts with hardware inverters with standard communication protocols.

Figure from [3]

Implementation of Multiple PCCs for PHIL

- **Approach**: decouple the dynamics and interactions between inverters under test.
  - Regenerate the simulated voltage
  - Use feedbacked power instead of current (power is the important variable for grid service rather than EMT transients)

- **Implementation**: standard Application Function Blocks (AFBs)
  - Only change voltage level
  - Reuse for other PCCs and different projects for similar purposes/applications.
Hardware Setup

Photos by NREL
Experimental Results

CHIL and PHIL testing

• Setup configuration
  – 11,000 node distribution feeder (IEEE 8,500 node test feeder and a modified EPRI Ctk7 test feeder)
  – 532 simulated PV in OpenDSS
  – 6 PCCs in OPAL-RT with PHIL testing of 6 DER Racks (90 DER hardware inverters)
  – 2-h from 11:00-13:00
  – Voltage regulation performance

Baseline and Controlled voltages

Total PV Active and Reactive Power

6.55% curtailment
Experimental Results

PHIL results: DER Rack #1-4

PHIL results: DER Rack #5-6

Results of two selected simulated PV
Thank You

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NREL/PR-5D00-80575