Performance Evaluation of an Advanced Distributed Energy Resource Management Algorithm

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HIL Evaluation Overview

- Objective: Validate the control and optimization solution against a simulated real-word distribution system in a realistic testing environment
  - Accurate modeling of distribution system, power hardware inverters, communications
    - Co-simulation
    - Grid Optimization algorithm
    - Communication interface
    - PHIL with 6 DER Racks
    - Cap bank controller
  - Software controller interacts with the real-time simulation model and hardware inverters as if the controller were interacting with a real-world system
Schematic Diagram of the HELICS Architecture

- **SE Agent**
  - OMOO Agent
  - OpenDSS Agent

- **OMOO**
  - Vmeas, Pmeas, Qmeas

- **OpenDSS**
  - V, \( \theta_v \), I, \( \theta_i \)
  - Pmeas, Qmeas, Pfeeder

- **SE**
  - Vmeas, Pmeas, Qmeas

- **SOC**
  - P*, Q*
  - V*

- **Modbus Agent**
  - P*, Q*
  - (Modbus)

- **Modbus Interface**
  - P*, Q*
  - SOC

- **DER Hardware Inverters**

- **Grid Simulators**

- **OPAL**
  - Pfeeder, Qfeeder, Vfeeder, Ifeeder, Pload, Qload
  - Vmeas, Pmeas, Qmeas, Paval

- **OPAL Agent**
  - P*, Q*
  - V, \( \theta_v \), I, \( \theta_i \), Pfeeder, Qfeeder

- **OPAL-RT**
  - To-OPAL
  - OPAL-RT
  - From-OPAL (UDP)

- **CT & PT**
Experimental Setup – DER Racks
# Experimental Setup – DER Racks

<table>
<thead>
<tr>
<th>Rack</th>
<th># Devices</th>
<th>Physical Devices</th>
<th>Total capacity</th>
<th>Simulated PV capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>PHIL-1</td>
<td>14</td>
<td>(1) 3 kVA PV, (1) 5 kVA PV, (12) 320 VA μPV</td>
<td>11.84 kVA</td>
<td>23.5 kVA</td>
</tr>
<tr>
<td>PHIL-2</td>
<td>14</td>
<td>(1) 3 kVA PV, (1) 5 kVA PV, (12) 320 VA μPV</td>
<td>11.84 kVA</td>
<td>19 kVA</td>
</tr>
<tr>
<td>PHIL-3</td>
<td>14</td>
<td>(1) 3 kVA PV, (1) 5 kVA PV, (12) 320 VA μPV</td>
<td>11.84 kVA</td>
<td>93.9 kVA</td>
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<tr>
<td>PHIL-4</td>
<td>14</td>
<td>(1) 3 kVA PV, (1) 5 kVA PV, (12) 320 VA μPV</td>
<td>11.84 kVA</td>
<td>67.6 kVA</td>
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<tr>
<td>PHIL-5</td>
<td>14</td>
<td>(1) 3 kVA PV, (1) 3 kVA PV, (12) 320 VA μPV</td>
<td>9.84 kVA</td>
<td>119.2 kVA</td>
</tr>
<tr>
<td>PHIL-6</td>
<td>14</td>
<td>(1) 3 kVA PV, (1) 3 kVA PV, (12) 320 VA μPV</td>
<td>9.84 kVA</td>
<td>54 kVA</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>84</strong></td>
<td></td>
<td><strong>6 PCCs</strong></td>
<td></td>
</tr>
</tbody>
</table>
Experimental Setup – Each DER Rack/PCC

Hardware setup and connections for one DER rack

PHIL interface algorithm implemented in OPAL-RT
Experimental Setup – Capacitor Bank Controller

Reference voltage for capacitor bank controller (RMS)

Sinusoidal wave generation

Scaling down

Analog output

OMICRON Amplifier

Switch of cap bank

Control logics

Analog input

Cap bank controller

Controller to be tested

Real-time simulation in OPAL-RT
Experimental Validation – Voltage Regulation

– Distribution feeder from Hawaiian Electric Company
  • Over 2,000 nodes
  • 211 loads and 211 PVs (6 PCCs with hardware PV inverters and 205 simulated)
  • 50% PV penetration

– Testing details
  • Simulation time 12:00-14:00 2-hour run at high solar irradiance

– Testing Scenarios
  • Smart Inverter – Volt/Var
  • 100% PV being controlled
  • 30% PV being controlled
Experiment Results

Real-time implementation details

• Var Priority
• Triggered every 1 s with simulation time step 5 ms
• In total 211 PVs
• Add a deadband (0.005 p.u.) for the two slopes (0.95-0.97) and (1.03-1.05)

Results of system voltages with three scenarios
Experiment Results

Results of Total PV measurements

PV curtailment:
- 0.08% for volt-var
- 0.4% for 100% PV
- 0.24% for 30% PV

Results of one selected simulated PV
PHIL Experiment Results of 30% PV Being Controlled

Performance of State Estimation and OMOO

PHIL evaluation of three DER Racks (#1-#3)
PHIL Experiment Results of 30% PV Being Controlled

PHIL evaluation of another three DER Racks (#4-#6)

Results of capacitor bank controller
Conclusions

• Successful Power-hardware-in-the-loop (PHIL) testing with GO-Solar platform
  • 84 hardware DER inverters
  • standard communication protocols
  • real responses of hardware inverters
  • stability and dynamics of the GO-Solar platform
• Evaluated voltage regulation performance of the GO-Solar platform in real-time simulation
• HIL captures key real-world aspects and forced us to refine the approaches taken for GO-Solar that were not seen with the artificially tight data coupling from single feeder simulation.
• Results: Once tuned, GO-Solar Platform performs better than the smart inverter volt-var:
  • fewer voltage violations
  • reduced system voltages and improved energy savings (CVR)
  • precise voltage regulation, etc.