Controls HIL infrastructure upgrade at FSU to support advanced evaluation framework for distributed control of emerging power and energy systems

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Overview

• CHIL capabilities and challenges
• Evaluation of large-scale distributed controls
• HIL throughout the control life cycle
• CHIL interface standard
• Controller mapping: instantiating, partitioning, development
Current PHIL and CHIL

FSU-CAPS
3 x 5 MW Facility

Added Controller-HIL capabilities ...

Challenge of large-scale CHIL remains
Distributed Controls at CAPS

Current
Distributed controller HIL (dCHIL) capabilities
- 6 x86 embedded PC-cluster with small scale OPNET tied to RTDS
- 18 NI “myRIO” cluster tied to kW-scale lab and RTDS

[Option]
Multiple controller instances on a single hardware platform

Need
Infrastructure of [50-100] platforms for meaningful large-scale CHIL environment
Different Flavors of CHIL

Traditional

**Focus**: control algorithm on field deployed target platform

Surrogate

Representative host

More flexible, reusable

Open platforms

**Focus**: control algorithms implementations, distributed, networked, multi-use target platforms, large scale

Implementation and evaluation levels of interest
“Surrogate” CHIL

• Controller HW not necessarily intended for field deployment
  => “Surrogate” CHIL
  • May not have exact characteristics of deployed control HW (e.g. ruggedness)

• Flexible controller environment for developing and evaluating controls
  • Easily adapted to different configurations
  • Easily automated for systematic evaluation
  • Wider variety of development tools

• Focus is control algorithms and interactions with power system

Different levels of control development

Abstract Control Algorithm(s)

Code (E.g., Simulink, C++, VHDL)

Object Code

Processor(s)

I/O

D/A A/D Ethernet

Power System
“Controls” v. “Controllers”

- Decouple software and hardware
  - Hardware is a means to instantiate and run controls, controls primary focus

- Physical, processor-based board interfaced in some way (average-value or switching) to a real-time simulator or power device

- Network connection (e.g. Ethernet) and communication protocols to other controllers
CHIL Valuable Throughout Control Lifecycle

Control Development
(Model based design)

HIL Evaluation
System relevant environment

HIL Evaluation
Unit test environment

Deployment

Physical Evaluation

Maintenance and Upgrades
IEEE 1676-2010, Guide for Control Architecture for High Power Electronics (1 MW and Greater) Used in Electric Power Transmission and Distribution Systems, Recommended architecture for power electronics applications (Fig. 1)

Advocating new interface as a standard component

Enabling development-testing through common interface.
Mapping of Controls Across Simulation Hardware

**Digital Real-Time Power Simulator**

**Simulated Sources (ext. control)**

**Simulated Loads (ext. control)**

**Simulated Controls**

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**System Control**
- Operating mode determination
  - ≥10 ms

**Application Control**
- Overriding control & measurements
  - 1 ms - 1 s

**Converter Control**
- PLL synchronization
- Coordinate transformations
- Current controls
  - 10 µs – 1 ms

**Switching Control**
- Modulator
- Converter switching logic
- 2nd level protection
  - 1 – 10 µs

**Hardware Control**
- 0.1 – 1 µs

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**Deployment choices**

**Network Emulation**
- (OPNET, OMNeT, ...)

**Controller**

**Controller**

**Controller**

**Remote Surrogate Controller**

**Virtual Surrogate Controller**

**Network Interface**
Instantiating and Partitioning Controls in HIL Environment

• Suitable form for automated instantiation
• Similar functionality to test sites
• Complementary evaluation (not the sole means, e.g., schedulability)
• Potentially first relevant environment to integrate multiple controls
• Representative timing characteristics

Functional

Hardware control layers
  Above switching control layer differences across applications and more numerous as traversing upward

Temporal

Driving criterion

Functional and temporal partitions often occur at the same boundaries.
Enable Controller-Controller Interactions

Simulator-Controller Interface
- An artifact
- Still custom solutions
- In range of time step (10s µs)

Controllers
- Scaling \( n \): 20, 50, 100?
- Level of detail?
- *Allow for future expansion*

Networks
- Not always perfect – enable analysis via hardware or emulated
- Ethernet interface likely

Remote connections
- Labs and cloud resources (CHIL Superlab)
Control Loop Time $\rightarrow$ Interface

**Cycle Time**
- $< 100 \ \mu\text{sec}$ $\rightarrow$ Analog or FPGA (High-speed digital)
- $1+ \ \text{msec}$ $\rightarrow$ Packet Interface
  Preferred with large # of controllers and signals

**Issues**
- **Analog** – noise and resolution, controller CPU must also support
- **FPGA** – Controller CPU will usually need auxiliary I/O hardware
- **Dual Ethernet** highly preferred for packet interface
Development Options

- **Programming**
  C, C++, Python, etc.

- **Model-based design**
  Matlab/Simulink (Windows/Linux)
  National Instruments Labview

- **Controller-to-controller interoperability**
  Message passing libraries/APIs:
  MQTT, ZeroMQ, DDS (Data Distribution Service), RTPS (Real-Time Publish Subscribe)

**Example x86-control platform:**
Low-power Intel Celeron N2930 quadcore, fan-less, dual Ethernet, with or w/o I/O (500.- vs. $2k)

**Example **ARM**-control platform:**
Beaglebone TI-X15, 4x32-bit Programmable real-time units with FPGA high-speed link, dual ethernet

**Example Single-board RIO:**
System-on-Chip including FPGA
Example PHIL and CHIL Application

MVDC Microgrid:
Operation and fault management

Future Distributed Control Network and PHIL at CAPS