CURENT
CENTER FOR ULTRA-WIDE-AREA RESILIENT ELECTRIC ENERGY TRANSMISSION NETWORKS

CURENT
Overview and State of the Center
April 2023

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Director of CURENT

Conference Overview

Tuesday

- **Pre-conference tutorials – completed this morning**
- **Center overview**
- **Plenary speeches**
  - Ben Kroposki (NREL) "*Grid-forming Inverters and the UNIFI Consortium*"
  - Daniel Brooks (EPRI) "*Grid Capabilities and Technologies to Enable a Net-Zero Economy by Mid-Century*"
  - Jeffrey Csank (NASA) "*NASA Lunar Surface Operations and Power Grid*"
- **Faculty research overview**
- **Student paper presentations**

Wednesday

- **Student paper presentations**
- **Plenary speeches**
  - Wolfgang Demmelbauer-Ebner (Volkswagen): "*Electrification in America - Volkswagen's Journey to Zero Emissions*"
  - Juan Castaneda (Southern California Edison): "*Pathway 2045- SCE Road Map to Full Decarbonization*
- **Lab demo and poster session**

Brief History
CURENT – An NSF/DOE ERC

- Selected by National Science Foundation (NSF) and Department of Energy (DOE) from a few hundred proposals across all engineering disciplines.
- First and still the only ERC devoted to power transmission.
- Center began Aug. 15^{th} 2011; Graduated Nov. 2021.
- Industry partnership program (33 members as of Spring 2023).
- Total funding since inception ~$100M (core and other projects).
- Broadening research mission since graduation.

State of the Center

- **Research**
  - Annual expenditures around $8M in Fiscal 2022. Around 27 new proposals awarded with a valued of $4.9M
  - Annual publications more than 100.
- **Industry and innovation**
  - 33 dues paying industry members (~$700K/year).
  - 15 invention disclosures in last year. Over 40 patent applications since inception.
- **Infrastructure**
  - Unique testbed facilities (Hardware Testbed and Large-scale Testbed), FNET, MW universal power tester and other lab facilities
  - Extensive real-time simulation capabilities; extensive power system simulation facilities – Andes (CURENT developed) DigSilent, GridDyn, OPAL-RT, PSS/E, PowerWorld, PSLF, RTDS, TSAT and others

State of the Center

- **Education**
  - Over 130 Ph.D. and 100 MS graduates since inception
  - Worked with 120 cumulative REUs among which 49% were URMs.
  - Over 80% of YSP participants since inception have gone on to major in engineering or science fields

- **Awards and Recognition**
  - Recognized as one of the top power and energy Centers in the world
  - Core power faculty includes – Governor's chair, 4 NAE members, 5 IEEE Fellows, 2 Chancellor Professors, 7 named professorships

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Industry Program

Hitachi Energy
NREL NATIONAL RENEWABLE ENERGY LABORATORY
Dominion Energy
Danfoss
EPRI ELECTRIC POWER RESEARCH INSTITUTE
pjm
EnerNex A CESI Company
epb
GE
New York ISO Independent System Operator
conEdison
Sandia National Laboratories
aps
ISO new england
SEVEN STATES POWER CORPORATION
KUB
NRECA
OPAL-RT TECHNOLOGIES
Lawrence Livermore National Laboratory
MISO
OSIsoft
OAK RIDGE National Laboratory
UL
EATON
TVA
edd
New York Power Authority Generating more than electricity

Research Plans

- **Research portfolio**
  - Responsive to industry members and other funding sources
  - Maintain identity and build on research strengths
- **Vision**
  - Emphasize unique expertise in power systems and power electronics.
  - Research areas
    - Increased emphasis on cybersecurity and other resilience issues of National concern
    - Data-driven system approaches using Artificial Intelligence
    - Extend system operations into distribution systems (small commercial and residential)
    - Electrification of transportation
    - Energy storage
  - Balance new research directions without losing focus
    - Operation of fully inverter based systems, such as, aircraft powered, ships, microgrids, etc.
    - Power system interfaces to other infrastructures – e.g., buildings, transportation

Some Highlights

- **Major research proposals – Center-wide**
  - Major Research Instrument (MRI) – NSF not funded
  - Grid-forming Inverter Consortium – DOE invited (not funded)
  - Grid-resilience University Consortium – DOE invited (pending)
  - Mid-scale Research Infrastructure-2 – NSF preliminary proposal
- **Testbeds**
  - Primary effort that remains Center-wide activity.
  - LTB
    - Expanded dispatch capabilities
    - New visualization options
  - HTB
    - Flexible manufacturing plant (FMP) emulation
  - HTB and LTB integration

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LTB Overview

Motivation:

- To develop a comprehensive platform that includes both dynamic and market
- To enable dispatch-dynamic interfaced co-simulation

Structure:

Hybrid symbolic-numeric power system modeling and simulation

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Dynamic Modeling and Simulation

Data messaging between multiple power system components

DiME

Multi-terminal Data Streaming

AMS

Dispatch Modeling and Simulation

Dynamic information interfaced dispatch modeling and simulation (ongoing)

AGVis

Energy System Visualization

Geographical visualization for energy system

Updates of CURENT LTB

- Models: extended model library
- Interfaces: dispatch, distribution
- Features: snapshot, memory management

- Usability: documentation, video tutorials
- Features: customized function, multilayer, independent data reader

ANDES

Dynamic Modeling and Simulation

AGVis

Energy System Visualization

AMS

Dispatch Modeling and Simulation

DiME

Multi-terminal Data Streaming

- Flexible dispatch modeling
- Scalable dispatch-dynamic co-simulation

- Usability: documentation
- Quality: software tests

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Highlight: dispatch-dynamic co-simulation

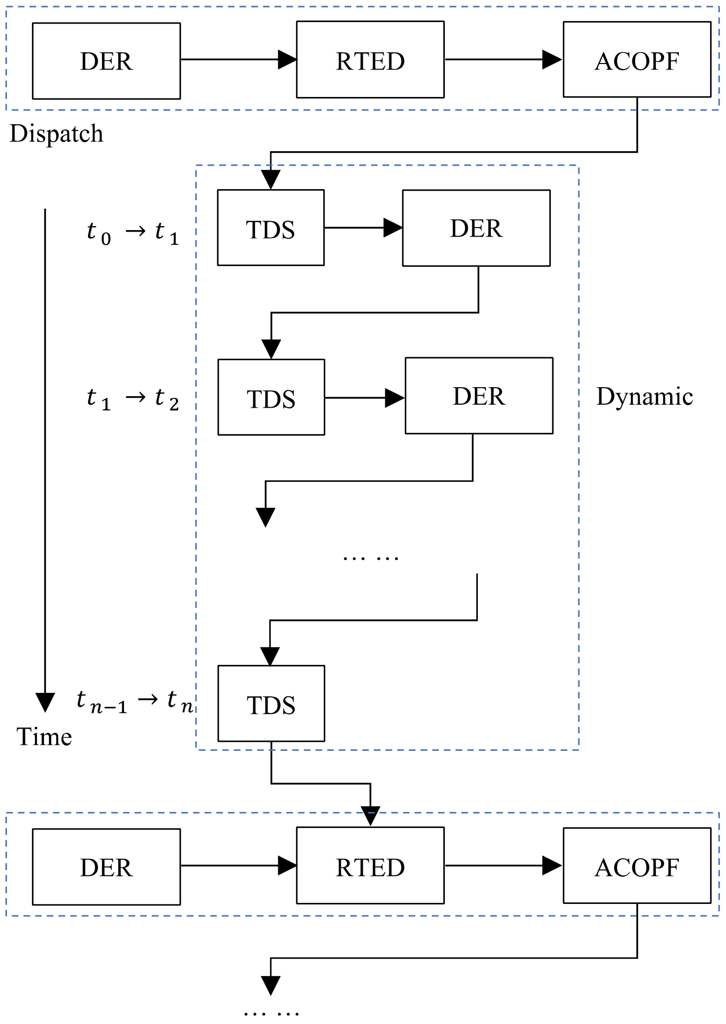


Fig. RTED-TDS co-simulation framework

Benefits

1) Smooth transition from dispatch to dynamic
2) Quantify results of both economic and dynamic

Demo

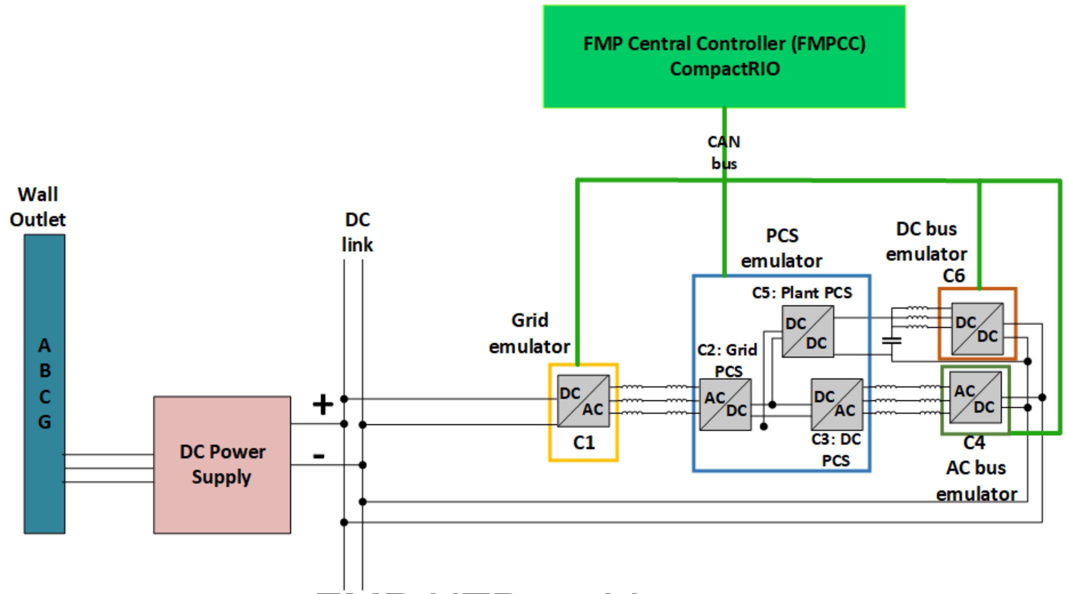
1) EV secondary frequency regulation provision
2) Virtual inertia scheduling scheme

Settings

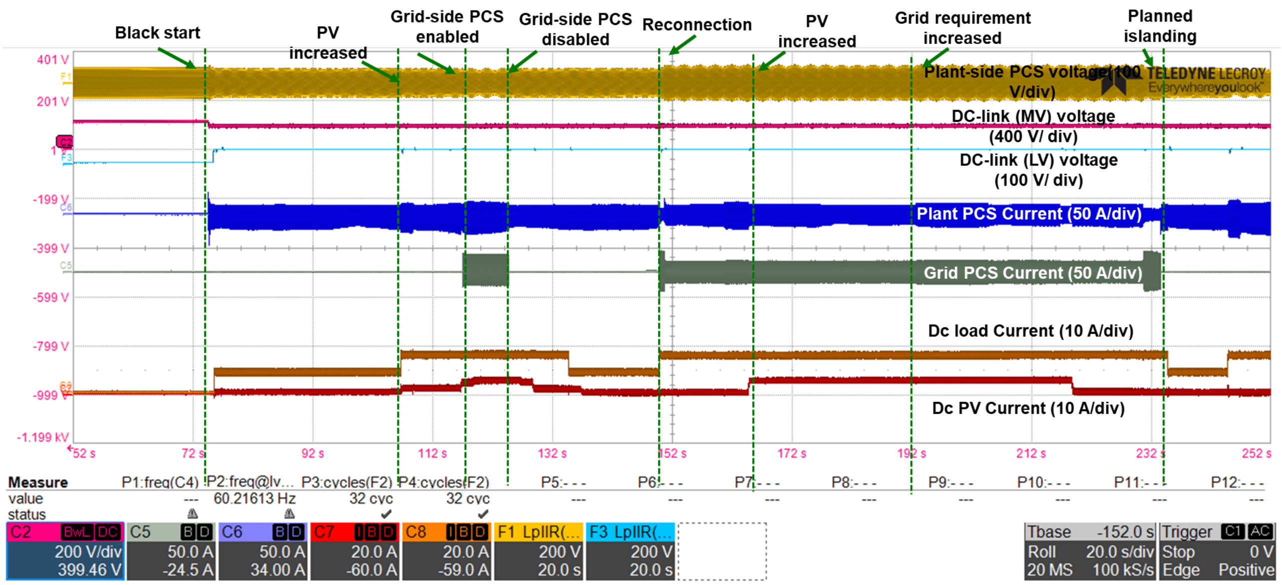
- IEEE 39-bus system with load profile from PJM
- Real-time economic dispatch (RTED) with time domain simulation (TDS)

FMP Demo

- HTB is used to emulate a flexible manufacturing plant (FMP) with a back-to-back connected power conditioning system (PCS)
- FMP controller is placed in HTB for function evaluation
- FMP controller testing includes steady-state operation (grid-connected mode and islanded mode) and mode transitions (black start, planned islanding, reconnection)



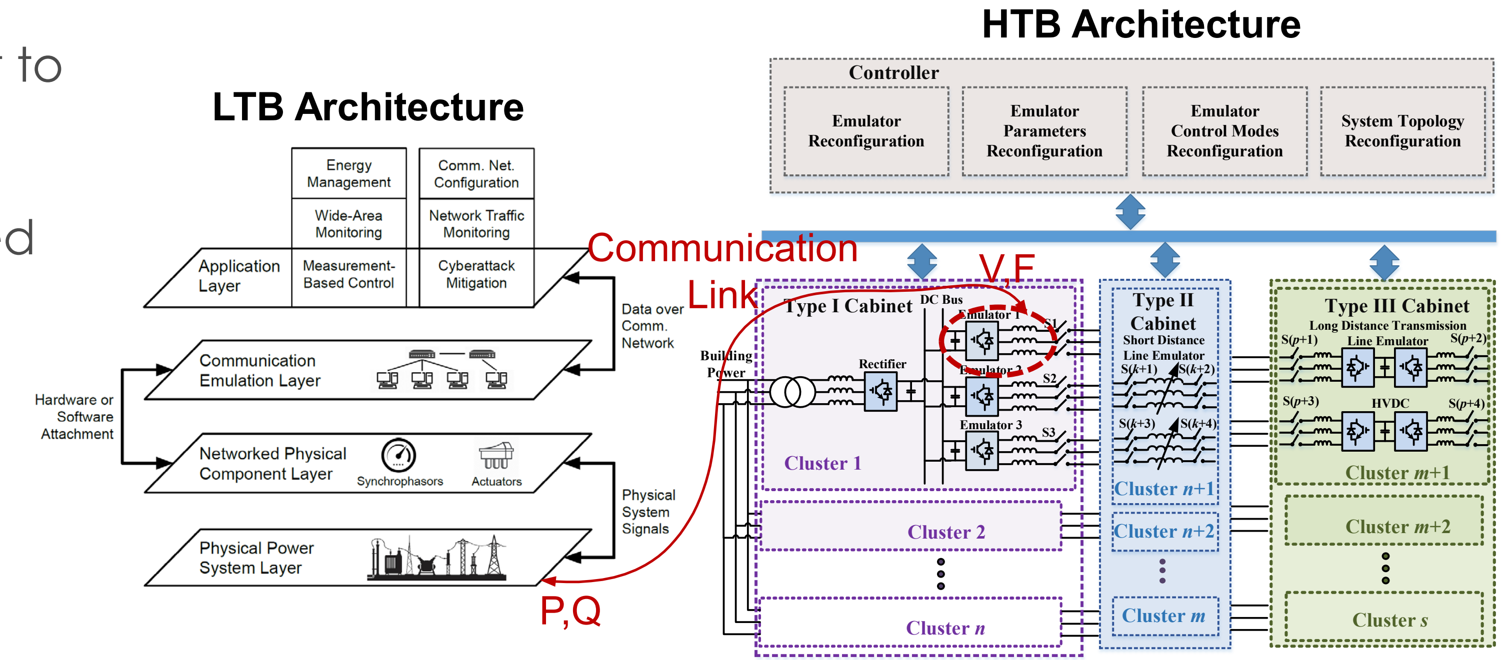
FMP HTB architecture



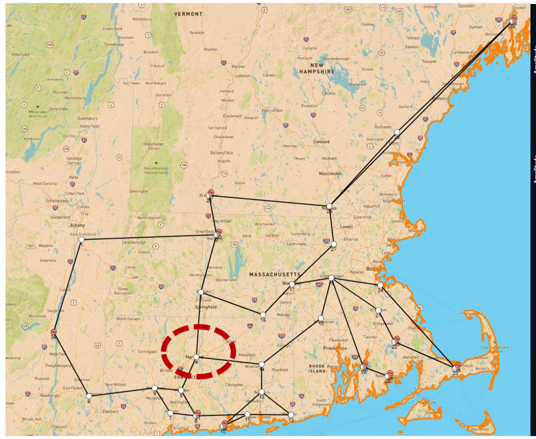
Real-time measurement for the overall demo

HTB LTB Co-simulation

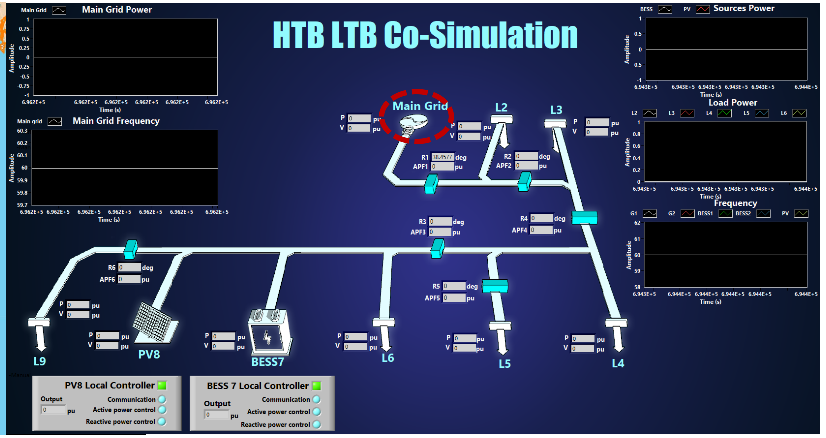
- HTB LTB Co-simulation platform is built to combine the advantages of both testbeds.
- The Co-simulation is established based on the communication link between HTB and LTB with synchronized data exchange.



- IEEE 39 bus system is implemented in LTB, and distribution system is implemented in HTB. Main grid in HTB connects to bus 4 in LTB system.
- Black start, inertia support function in HTB, and frequency regulation function in LTB will be demonstrated.



IEEE 39 bus system in LTB



Distribution system in HTB

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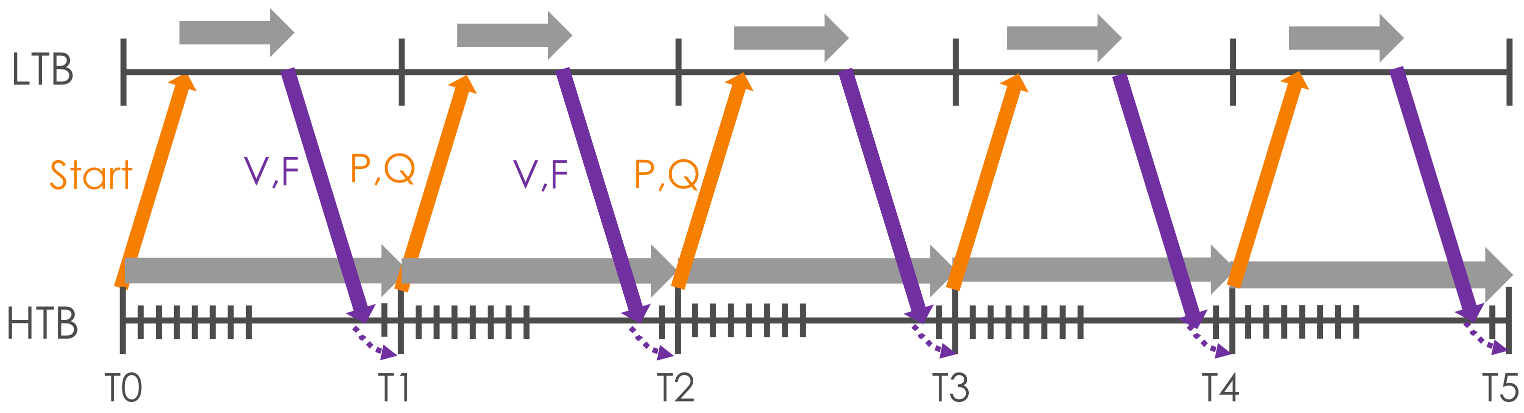
HTB LTB Co-simulation

- HTB initializes co-simulation and works as current source to inject P and Q to LTB, and LTB works as voltage source to provide V and F.
- HTB control cycle is 100us, LTB control cycle is 33ms.
- LTB runs faster than real-time due to communication delay, HTB will not use V and F until runs to each synchronization point (T1, T2, T3…).



HTB LTB co-simulation interaction protocol