An Overview of Collaborative Testbeds Within the Future Renewable Electric Energy Delivery and Management Center

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Abstract:

The Future Renewable Electric Energy Delivery and Management (FREEDM) Center hosts three collaborative testbeds for the simulation and validation of distribution systems. These testbeds are illustrated in the "three-plane" diagram shown in Figure 1.

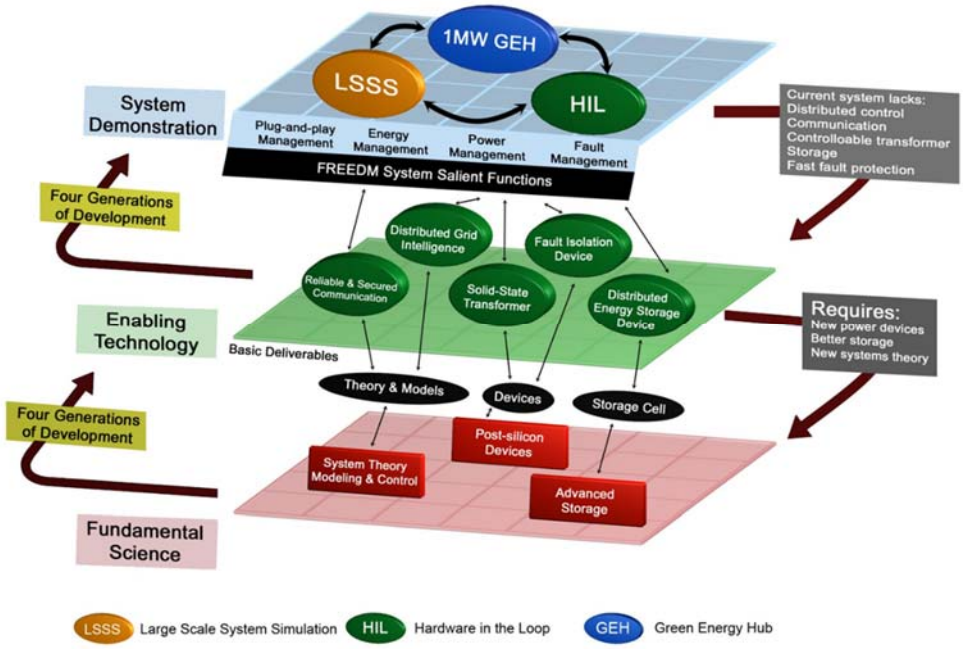

Figure 1: The FREEDM three-plane center thrust diagram

The testbeds span the spectrum of hardware and software platforms. The testbeds are the Green Energy Hub (GEH), Hardware-in-the-Loop (HIL), and the Large Scale Simulation System (LSSS). The three testbeds provide the ability to demonstrate the FREEDM system at graduated scales and degree of functionality and fidelity.

Green Energy Hub

The main objective of the GEH testbed is to develop a physical, fully operational, FREEDM System at a MW scale that is, (1) sufficient to demonstrate functionality of key components of the system, (2) validate the operational concept, and (3) confirm the soundness of the key underlying theories. The physical system

will also serve as a platform for the assessment of the communications and control functions and a testbed for future hardware and software systems that complement the FREEDM System.
The Green Energy Hub (located at NC State) has the objectives of (1) integrating Center-developed technologies and demonstration of the FREEDM system functionality, (2) serving as a testbed for third-party technology integration and demonstration site, and (3) powering the ERC headquarters with green and sustainable energy. As technologies are developed, including the solid-state-transformer (SST), solid-state fault interruption device (FID), smart-meter-based SCADA, and a distributed grid intelligence control system, state-space-based models are developed that are then ported into one of the simulation platforms. This provides physical validation of all operating modes of the system components.

Hardware in the Loop

The overall objective of the hardware-in-the-loop (HIL) testbed project is to provide a flexible platform that facilitates the design, analysis, and demonstration of FREEDM concepts using both physical and simulated devices. The HIL allows real-time validation of:

- a fault detection and reconfiguration module for the distributed grid intelligence (DGI) system,
- real-time communication networks,
- system controllers including the SST control, a distributed energy storage device (DESD) controller and FIDs, and
- improve the average value, real-time SST model that is used to exercise DGI and demonstrate FREEDM protection concepts.

The HIL testbed fills the gap between the other two testbeds by providing a platform to study physical and simulated devices together. When compared to a testbed that features only physical devices, this mixture of real and simulated hardware allows researchers to analyze cyber-physical systems in a safer and more controlled environment.

Large Scale Simulation System

The LSSS is a scalable distribution system modeled in both PSCAD (for short-term dynamics) and OpenDSS (for long-term dynamics) for the simulation of dynamic behavior that requires multiple nodes or wide geographic spacing, in order to demonstrate the following attributes:

- Fault protection and restoration
- Dynamic component interactions and mitigations
- Power Management functionalities

To validate component models for different time-scale platforms, to provide common virtual testing and demonstration platforms for the FREEDM Center, and to validate use cases that include load profiles, renewable energy profiles, faults, and topologies.

The LSSS testbed provides the capabilities to test and validate system-level FREEDM capabilities. The LSSS testbed complements the HIL and GEH testbeds by addressing the scalability. Through large scale simulation it is possible to analyze and ultimately predict how a future FREEDM system will operate with deployment of a wide variety of loads, SSTs, energy storage devices, and renewable energy sources. This testbed allows FREEDM researchers to benchmark new approaches against a traditional non-FREEDM distribution system. The testbed models are validated against both hardware and other modeling platforms (such as Matlab/Simulink) to assure high fidelity of results. The LSSS has been used to benchmark system-level volt-var control strategies, the pilot protection approach, a new design methodology for SST system control, SST dynamic capabilities and stability, and as a simulation tool for the control robustness project.

Taken together, these three testbeds span the spectrum of functionality to provide the most accurate prediction of system behavior possible.