**Project Objectives and Outcomes**

The objective of this program is to fundamentally change the way that power distribution system engineering is performed, in order to facilitate the widespread adoption of microgrids, high-penetration renewables, and other distributed energy resources. Once completed, this program will improve the state-of-practice for power systems studies, proof-of-concept and prototyping development, equipment and controller selection, systems integration, and commissioning testing of large microgrid deployments.

This will be accomplished by developing a new power systems engineering approach based around real-time simulation and controller hardware-in-the-loop testing. This system is called the Hardware-In-the-Loop Laboratory Testbed and Open Platform (HILLTOP).

We are facilitating interoperability and industry standardization with our complementary work on open-access models, test feeders, and test scripts, which are part of our Electric Power HIL Controls Collaborative (EPHCC). We are also key contributors to the IEEE P2030.7 microgrid controller functional standard and P2030.8 microgrid controller test standard. In future years, we plan to use this tool for system studies and to help regulators on policy development.

Lastly, next year we plan to broaden adoption by developing coursework for power engineering schools – starting with MIT – and training materials for early adopters.

**Significance and Impact**

The significance and impact can be captured from the feedback of various stakeholders in industry, utility, and government.

- Utility distribution engineers have said that the MIT-LL HIL approach addresses a major gap in modern distribution engineering practices. It allows distribution engineers to test the
controls behavior of new technologies, enabling them for the first time to evaluate their safety and reliability impacts.

- Eight (8) organizations have downloaded the HILLTOP source code; have ported it into their simulation platforms; and have either incorporated it into their product offerings, used it to perform their own power systems studies, or performed pre-commissioning tests on planned microgrids:
  - Schneider Electric, Eaton, Schweitzer Engineering Laboratory, Typhoon HIL, OPAL-RT, Sustainable Power Systems, Raytheon, and Carnegie Mellon University
- Schneider Electric’s Global Solutions Architect, Mark Evlyn, initial work with HIL testing came when he worked with MIT-LL to integrate Schneider’s microgrid controller with HILLTOP in FY15. Mark recently announced that hardware-in-the-loop testing will become core to Schneider’s power systems business strategy, systems integration work, project deployment, and testing service offerings. This means that elements of the HILLTOP system will be incorporated into Schneider’s product offerings.
- After hearing about EPHCC, industry leaders encouraged our work, noting the government could play a key role in organizing the industry, labs, and utilities to develop a shared repository of device models, controller interfaces, real-life test feeders, and test scripts.
- EPHCC was selected as the “pilot program” for the larger GMLC Open Library.
- There were 250 attendees at the first Microgrid Controller Symposium hosted by MIT-LL and the MassCEC in October 2015. A second symposium is planned for February 2017 with 300-400 attendees.
- MIT-LL performed a webinar on HILLTOP for OPAL-RT. The company noted that the webinar was, by far, their most well-attended webinar and that the HILLTOP platform “would be one of our best sellers if it were commercially available.” MIT-LL has recently made the HILLTOP source code publicly available on github.
- The City of Boston is encouraging its host utility, Eversource, to use the HILLTOP platform for development, systems integration, and pre-commissioning testing of the Boston Marine Industrial Park microgrid.
- The City of Boston has hired a Chief Resilience Officer whose first task is to perform community engagement in the proposed microgrid sites identified by the MIT-LL citywide energy resilience study.

The MassCEC intends to apply the citywide energy resilience study to other communities, starting with Springfield, MA, the first step of its state-wide microgrid deployment solicitation.

**Technical Approach**

Following the MIT motto “Mens et Manus” (mind and hand), MIT-LL has a three-part strategy to keeping its program focused, innovative, relevant, and capable of technology transition:

1. Hold an annual symposium demonstrating the technology integrated with industry controllers
   - As a non-profit FFRDC, MIT-LL is uniquely qualified to lead collaborative efforts in technology development that will culminate each year in a symposium. This public demonstration brings together industry, regulating bodies, and academia to review progress in groundbreaking changes to distribution systems engineering and ensures an operational and refined “product” at the end of every year.
• Working closely with industry throughout the year to prepare for the symposium continually ensures that our work is relevant to industry needs and important capabilities are prioritized.
• Integrating with industry lays the foundation for subsequent rapid technology transfer.

2. Create a collaborative platform through open-source software
• Posting MIT-LL’s code as open-source provides others with good documentation and thoroughly tested models and controllers, which can be used as references.
• Posting our code as open-source fosters collaboration with university students and engineers working in industry and fills a critical unmet need for vetted models and test feeders.
• Microgrids are typically “brown field” installations, with legacy equipment. This frequently requires vendors to integrate with their competitors’ equipment. MIT-LL and the DOE can fill a key role, unmet within industry, to accelerate integration through this shared modeling and testing resource.

3. Perform university and industry education
• Changing the state-of-practice in an industry requires a long-term strategy, so it must include education of students who will enter the industry and support for early adopters from industry with quality training materials.
• As with many open-source efforts, university students are likely going to be the earliest adopters and the most active contributors.
• A university design-build course would address multiple objectives: engage with industry and utilities, gain access to equipment and test feeder data, educate students, and populate the EPHCC repository.

Lastly, public symposia, publicly-shared source code, and an education initiative will all showcase our DOE sponsor’s contributions to the state-of-practice, increasing the program’s visibility and potential impact.

**Technical Progress and Results**
The technical progress to date and results are broken out into tasks 1 through 6.

**Task 1 Develop HILLTOP Commissioning Platform**
MIT LL has developed an advanced test platform, integrated vendor equipment, and has demonstrated their real-time operation on a realistic microgrid test feeder, and organized the public Microgrid and DER Controller Symposium in Boston to demonstrate the technology to 250 attendees. The HILLTOP test platform includes several integrated Woodward generator controllers; models of a combined heat and power engine, diesel engine, battery inverter, PV inverter, and relays; and a test feeder based on an actual site data and high-resolution load measurements. MIT-LL continues to improve the models and is integrating real relays from Schweitzer and power converter controllers from EPC. MIT-LL is working with MassCEC, National Grid, EPRI, and the DOE to organize the second Microgrid and DER Controller Symposium on February 16, 2017.

**Task 2 Establish Electric Power Controls Consortium**
MIT-LL has established a GitHub repository of the code and documentation for the 2015 symposium (https://github.com/PowerSystemsHIL). An organizing committee with industry and national labs has been formed and meets bi-monthly. A draft of the data sharing legal
agreement has been developed. The repository structure for multi-user and multi-HIL platforms of various devices has been created and will be populated with models and documentation from industry, academia, and national labs. MIT-LL has already populated the shared repository with the software and controller interfaces from the 2015 Symposium. Next, MIT-LL will curate the repository by collecting relevant models from around the country and will form technical working groups.

**Task 3 IEEE Support**
A MIT-LL group leader is the Vice Chair of IEEE P2030.8 (Microgrid Controller Test Standard), led all of the weekly working groups in FY16 for P2030.7 (Microgrid Controller Functional Standard), and has contributed sequence diagrams, test scripts, and stakeholder and services information, and other content to both standards.

**Task 4 TAG Support**
MIT-LL develop the FOA 997 Test Plan Evaluation Rubric and performed detailed technical reviews of multiple iterations of the test plans from all seven FOA 997 awardees. Three MIT-LL reviewers provided over 300 detailed technical comments on these test plans and provided guidance to the FOA Technical Advisory Group (TAG) about the awardees’ test plans.

**Task 5 City of Boston Microgrids: BMIP Microgrid Conceptual Design**
The City of Boston is in the process of hiring a developer based on the MIT-LL resilience analysis and city wide energy study.

**Task 6 Cyber Security Scoping Study**
Over the past two weeks, MIT-LL began working with Jason Stamp and Abe Ellis at Sandia National Laboratory on a cyber security scoping study for DoD CONUS installation energy systems. MIT-LL has proposed a reference communication, controls, and cyber security architecture based on industry best practices, past research, and DoD performance gaps identified by the Assistant Secretary of Defense for Installations Energy & Environment (ASD IE&E).

**Project Collaborations and Technology Transfer**
MIT-LL continues to collaborate with a wide range of industry players, utilities, national labs, Department of Defense entities, state government entities, and universities.

**Industry:** (listed by level of engagement, decreasing order)
- Schneider Electric (technology development, equipment integration, testing, public demonstrations, tech transfer)
- Typhoon HIL (technology development, model development, EPHCC, tech transfer)
- Eaton (technology development, equipment integration, testing, public demonstrations, tech transfer)
- Schweitzer Engineering Laboratory (EPHCC, test plan development, model development, equipment integration and testing, tech transfer)
- EPC Power (equipment integration and testing)
• Sustainable Power Systems (equipment integration, tech transfer, site testing of San Nicolas Island microgrid)
• Raytheon (site testing of Joint Base Cape Cod microgrid, technology development, tech transfer)
• OPAL-RT (model development, EPHCC, tech transfer)
• ABB (EPHCC)
• Woodward (equipment integration and testing)
• Green Energy Corporation (equipment integration)
• ICETEC (equipment integration, test plan development)
• Speedgoat (tech transfer)

Laboratories:
• EPHCC: Sandia, INL, NREL, ANL
• Cybersecurity Scoping Study: Sandia
• City of Boston study: LBNL

Utilities:
• National Grid (symposia, EPHCC, technology demonstration, education & training)
• Eversource (prototype deployment)

Department of Defense:
• Army Corps of Engineers ERDC-CERL (model development, technology demonstration, standards development)
• CERDEC (model development, technology demonstration)
• ASD IE&E (cyber security study, FOA test plan evaluation rubric development)
• ONR (algorithm development, standards development)

State Government:
• MassCEC (symposia, technology demonstration, outreach)
• Boston Redevelopment Authority (symposia, technology demonstration, outreach, prototype development)
• City of Boston Mayor’s Office (symposia, outreach, prototype development)

Academia:
• Carnegie Mellon University (model development, algorithm development, tech transfer)
• MIT (model development, algorithm development, technology demonstration, City of Boston study)

Other:
• IEEE PES Boston Chapter (technology demonstration, education & training)
• DHS S&T (FOA test plan evaluation rubric development, HILLTOP platform development)
• EPRI (symposia, outreach, technology demonstration)