Devices and Integrated Systems
Portfolio Overview

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National Renewable Energy Laboratory

April 18, 2017
Arlington, VA

U.S. DEPARTMENT OF ENERGY

Devices, Integrated Systems, and Energy Services

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

Devices - individual technologies (e.g. generation, storage, delivery, and consumption) that connect to the electric grid

Examples: PV, wind, EVs, storage, building loads, appliances, HVAC systems, lighting, fuel cells, electrolyzers, engines, microturbines, wires, cables, switches, transformers

Integrated Systems – networks of devices that are physically connected and linked by control systems

Examples: microgrids, building and industrial facility loads that respond to the grid, distribution systems, transmission systems

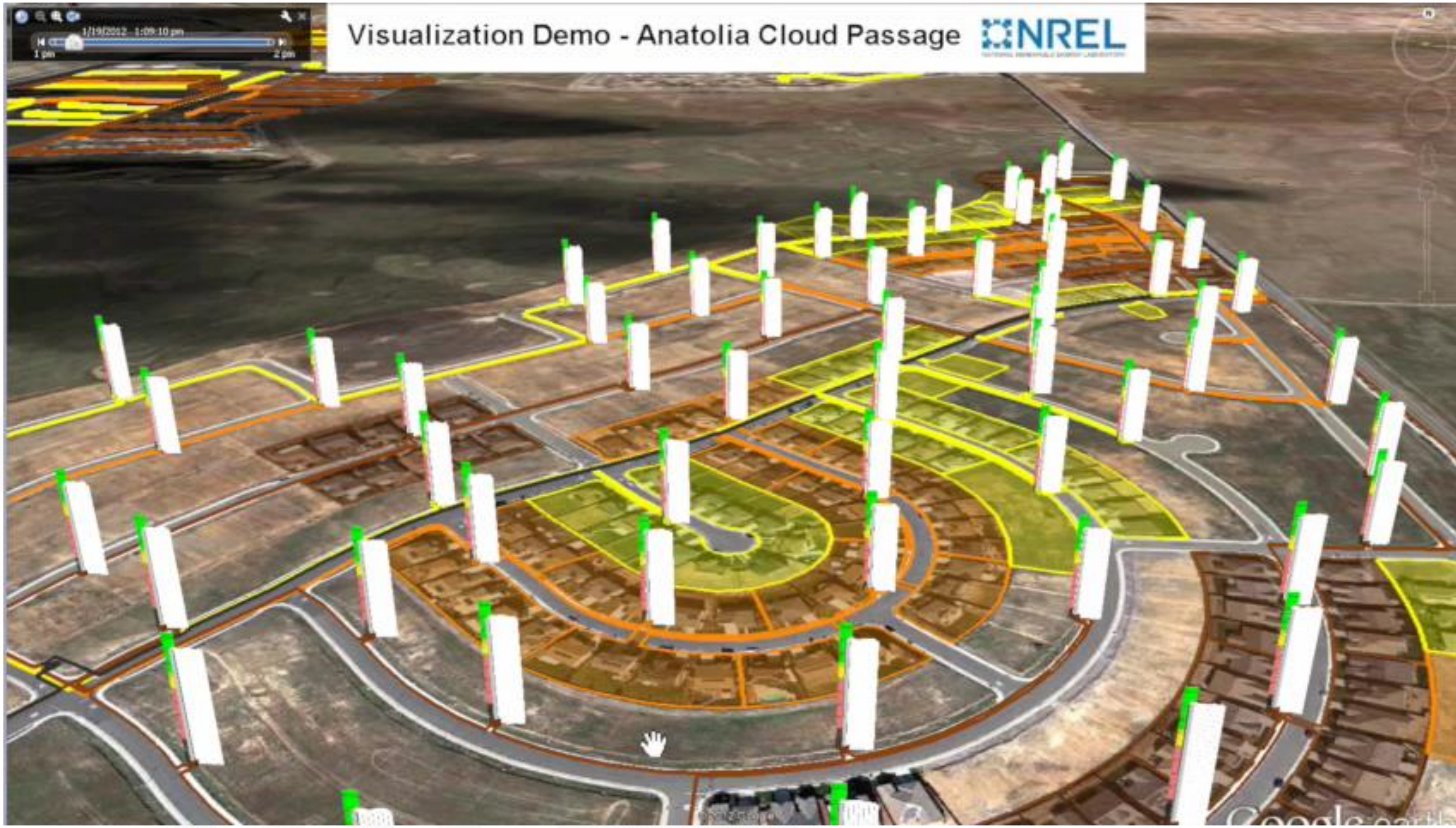
Grid Services - energy, capacity, and ancillary services needed to maintain normal grid operations

Examples: Energy, Capacity, Frequency Regulation, Voltage Management, Inertial Response, Blackstart

What is the Problem?

- New technologies are increasingly being integrated into grid
- Inconsistency across technologies for interconnection, interoperability, and provisioning of grid services
- Need to improve reliability, resiliency, security of grid

Issues with uncoordinated integration of DER



Video shows effect of clouds on distribution voltage when PV inverters are not allowed to actively regulate voltage

Devices and Integrated Systems Summary

Four Focus Areas

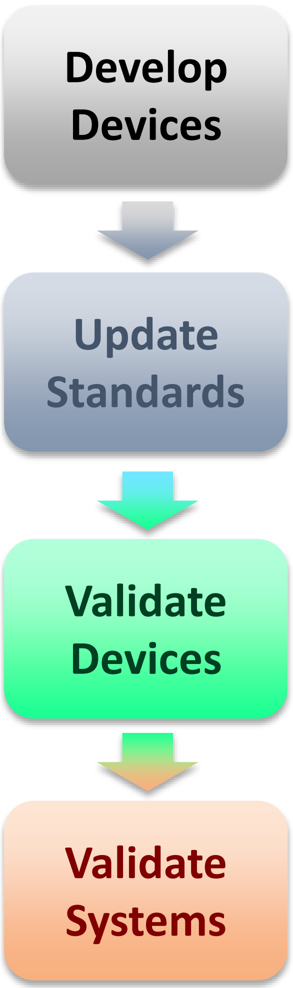
- **Develop Advanced Storage Systems, Power Electronics & other Grid Devices**
- **Develop and Update Integration Standards & Test Procedures**
- **Build Capabilities and Conduct Device Validation**
- **Conduct Multi-Scale Systems Integration and Evaluations**

Expected Outcomes

- **Increase ability of new technology to provide grid services** for reliability, resilience and increase utilization of infrastructure
- Coordinate interconnection, interoperability standards and grid services **across all element of the grid**
- Validate secure and reliability grid operation with **all forms of energy** at multiple scales (microgrids to transmission systems)

Federal Role

- National labs offer cutting edge capability to validate end-to-end interoperability and validate new technology services
- Integrated strategy and common approach across labs and industry test-beds for effective validation of emerging technologies
- Provide an unbiased method for common/open interoperability and interconnection standards and test procedures with industry / vendor community



Activities and Technical Achievements
MYPP Activity and Goals

MYPP Area	Goals
Develop Advanced Storage Systems, Power Electronics, and other Grid Devices	Increase electric grid flexibility, reliability, resiliency, and asset utilization by making step changes in the performance of grid-connected devices and technologies.
Develop Standards and Test Procedures	Work with standards development organizations (SDOs) to accelerate the development and validation of standards and test procedures for device interconnection, interoperability, and grid services.
Build Capabilities and Conduct Device Testing and Validation	Develop capabilities and validate device performance in both the laboratory and the field using the developed standards and test procedures.
Conduct Multi-Scale Systems Integration and Testing	Ensure that integrated systems of devices and controls are able to connect, communicate, and operate in a coordinated fashion at multiple scales.

Connections and Collaborations

Foundational and Program Projects

17 Partnership Projects between National Labs – Industry – Universities

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MYPP Area	Foundational Projects	Program-Specific Projects (EERE and OE)
Develop Advanced Storage, Power Electronics, and other Grid Devices		GM0060 - Improving Distribution Transformer Efficiency GM0204 - Inverter Driver Interface for VOLTTRON SI-1583 - Grid-Forming Distributed Inverter Controllers SI-1689 - Additively Manufactured PV Inverter SI-1699 - Combined PV/Battery with High Freq Magnetics Power Electronics
Develop Standards and Test Procedures	1.2.2 Interoperability 1.4.1 Interconnection/Interoperability Standards 1.4.2 Grid Services from DER	SI-1695 - Accelerating Codes and Standards WGRID-05 - Support to Achieve Large Amounts of Wind Power
Build Capabilities and Conduct Device Testing and Validation	1.2.3 GMLC-TN 1.4.1 Interconnection/Interoperability Standards 1.4.2 Grid Services from DER 1.3.29 Frequency support in HI	GM0130 - Demo for Battery Secondary Use GM0222 - HV Testing and Modeling of Transformers WGRID-49 - Short-term Energy Storage and Large Motor Loads for Active Power Controls by Wind Power
Conduct Multi-Scale Systems Integration and Testing	1.3.29 Frequency Support in Hawaii	GM0008 - Energy Storage Demonstrations GM0237- Advanced Distribution Management System (ADMS) Testbed

Foundational Projects

1.2.2 Interoperability – Overall strategy

- High level strategy for Interoperability across the entire grid
- Drafted declaration of interoperability principles and obtained stakeholder consensus on project plan
- Align Interoperability vision and complete roadmap

1.2.3 GMLC – Testing Network

- Developed framework for organizing testing network and open library of device and system models
- Enable national labs to drive innovation more effectively and synergistically
- Catalog of lab capabilities and stand up open library

1.4.1 Interconnection and Interoperability Standards and Test Procedures

- Developed Interconnect/Interoperability Gap Analysis
- Clear prioritization and identification of interdependencies of standards to influence development of testing procedures
- Address gaps with updated standards

1.4.2 Procedures for Grid Services

- Characterizing grid service capabilities from a variety of DER
- Reviewed framework for grid services at first industry meeting
- Draft recommended practice for grid services - vetted by utility & device industries

Regional Partnership Project

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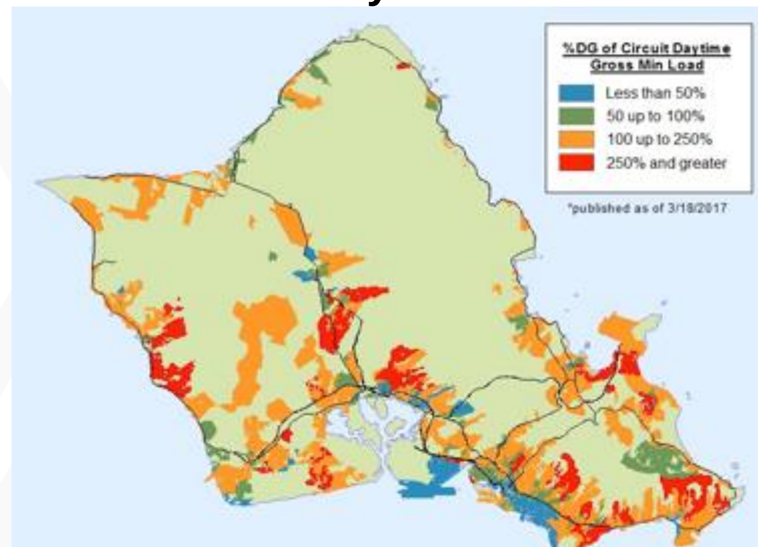
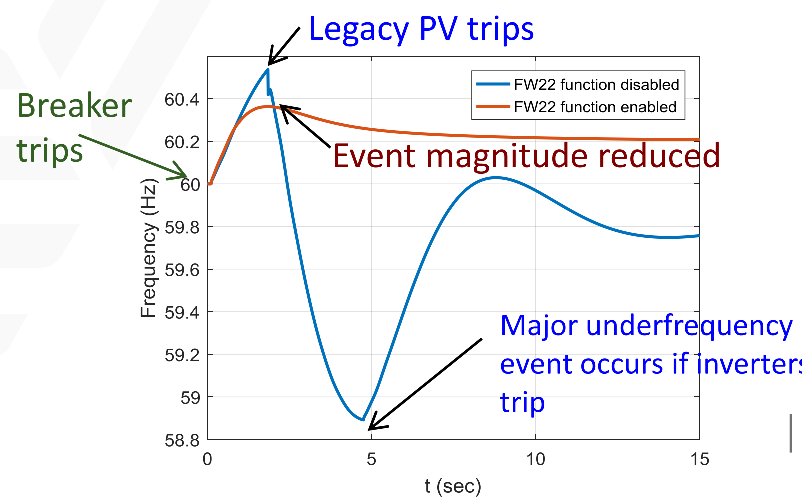
1.3.29 Grid Frequency Support from Distributed Inverter-Based Resources in Hawaii

- Investigate, develop, and validate ways that distributed PV and storage can support grid frequency stability on the fastest time scale (starting a few line cycles after a contingency event).
- Solutions for Hawaii's present-day problems will become relevant to the rest of the country in the future when they reach higher penetrations.
- Simulation results to date demonstrate need for adding frequency responsive functionality to interconnection requirements – results shared with IEEE workgin group
- PI: Andy Hoke, NREL
- Participants: NREL, Sandia, HECO, Enphase Energy, FIGII, Energy Excelerator

% DG of Circuit Daytime Gross Min Load

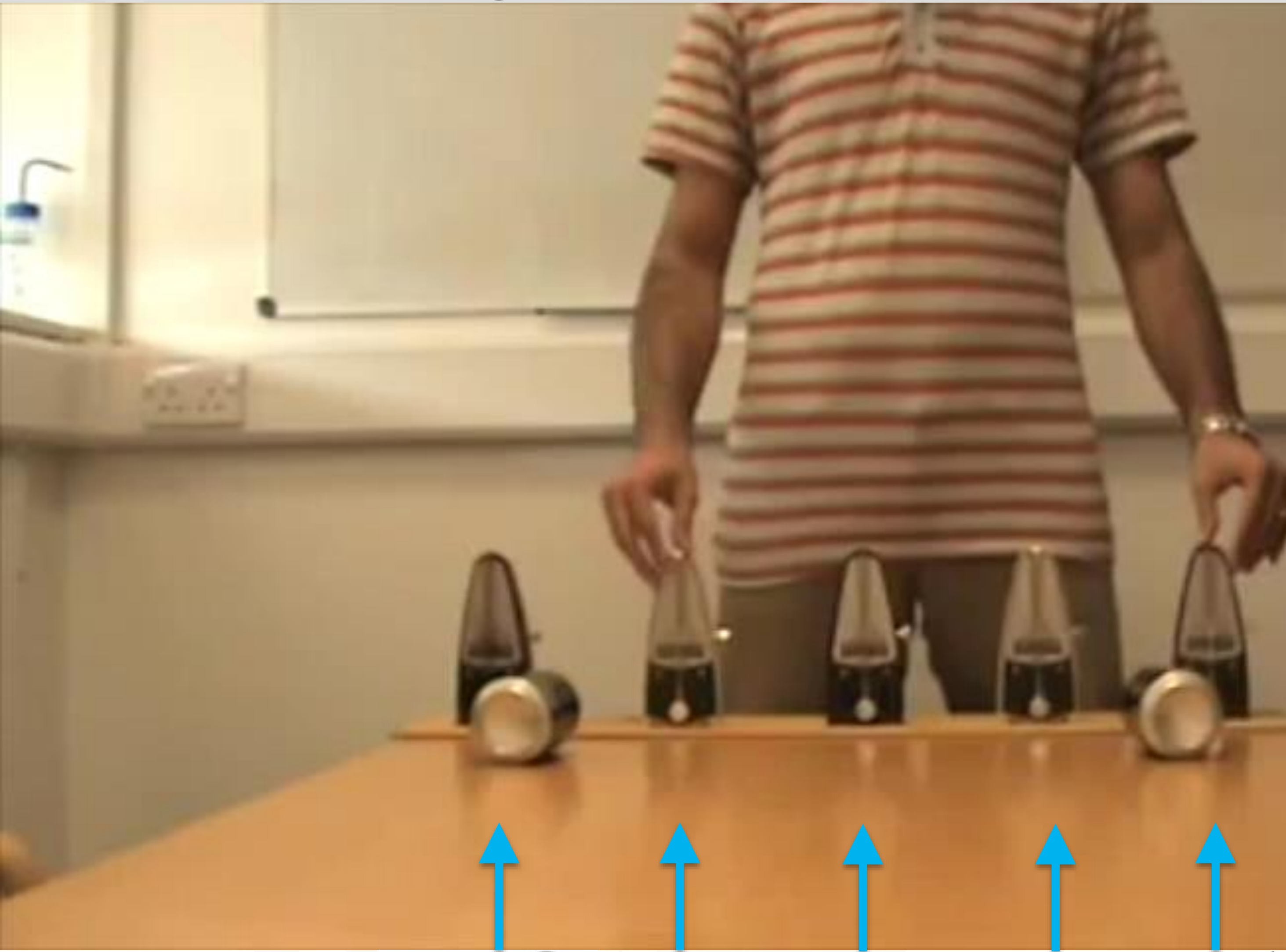


Source: Hawaiian Electric Company



Program Specific Projects:

SI-1583 Grid-Forming Distributed Inverter Controllers



Using these physics principles, **Virtual Oscillator Control (VOC)** Allows for self-synchronizing inverters

B. B. Johnson, S. V. Dhople, A. O. Hamadeh, and P. T. Krein, "Synchronization of Parallel Single-Phase Inverters With Virtual Oscillator Control," *IEEE Trans. Power Electron.*, vol. 29, pp. 6124–6138, November 2014.

Program Specific Project: Energy Storage - Validation and Operational Optimization

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Objective: Perform analysis and optimization for four Energy Storage projects in VT, OR, NM & TN

- Characterize reliability/resiliency benefits
- Quantify operational savings
- Address impediments to widespread adoption of energy storage technologies

Accomplishment: Operational data collection and analysis underway at three projects; fourth project is in construction.

Labs: SNL, PNNL, ORNL

Partners: DOE Program Offices, state and municipal agencies, utilities, vendors, CESA

Collaborative Projects – *Collectively making an Impact*

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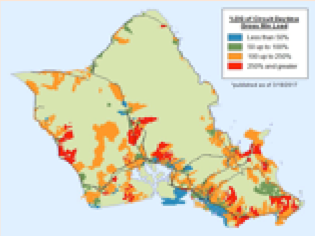
1.3.29 Frequency Regulation Support in HI



1.2.3 GMLC-TN

Lab evaluations of new DER capabilities influences standards development

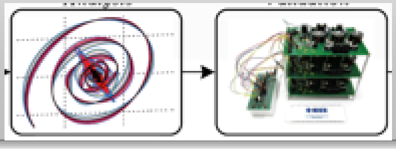
SI-1695 - Accelerating Codes and Standards

Updates to IEEE 1547 to allow sub-second frequency droop

1.4.1 Interconnection and Interoperability Standards and Test Procedures

Inputs to Gap Analysis

SI-1583 - Grid-Forming Distributed Inverter Controllers



SI-1689 - Additively Manufactured PV Inverter

Foundational Projects
Year 1 - Accomplishments and Impact

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- **Interoperability Strategy** - Drafted declaration of interoperability principles, strategic vision, measurement & roadmap tools to ensure grid modernization
- **Interoperability Standards and Testing for DER** – Developed Interconnect/Interoperability Gap Analysis, reviewed with industry, and prioritized Y2-Y3 research to address gaps
- **Grid Services from DER** - Reviewed framework for grid services with industry and developed draft testing procedures
- **GMLC – Testing network and Open Library** – Cataloged national laboratory capabilities and set up open library framework
- **Hawaii Partnership – Frequency Support from DER** – Completed simulations that show how enabling frequency-watt function of distributed PV resulted in significant improvement in HECO's frequency response – sent updates to IEEE 1547 Interconnection working group

Thank you

GRID MODERNIZATION INITIATIVE PEER REVIEW

GMLC 1.2.2 Interoperability

Steve Widergren, Pacific Northwest National Laboratory

19 April 2017

GMLC Peer Review Meeting

Sheraton Pentagon City, Arlington, VA

PNNL-SA-124939

1.2.2 Interoperability
High-Level Project Summary

The ability of two or more systems or components to exchange information and to use the information that has been exchanged.
ISO/IEC/IEEE 24765

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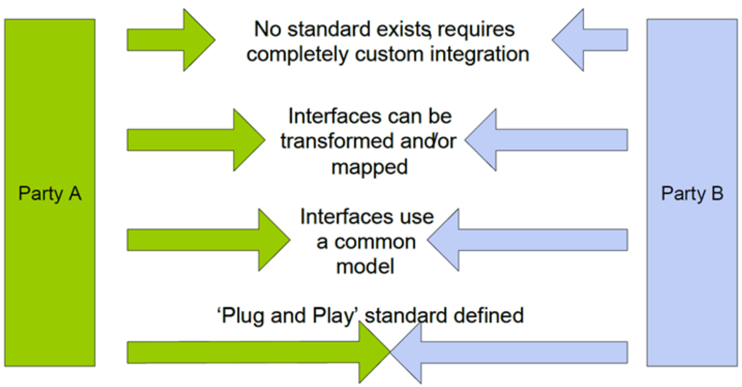
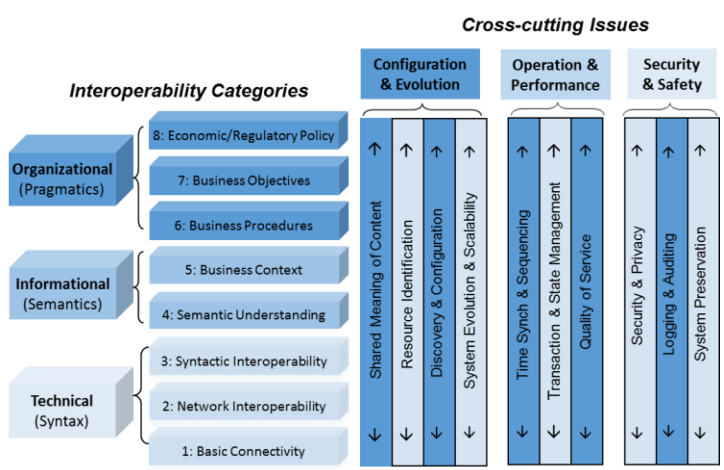
Project Description

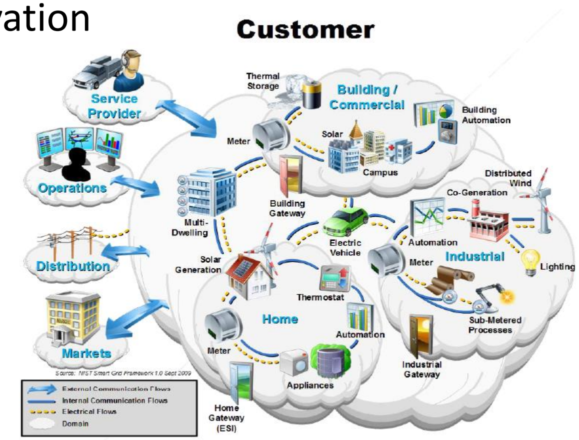
Align stakeholders on a strategic vision for devices and systems integration and develop measures and tools to support interoperability





Value Proposition

- ✓ Reduction of cost and effort for system integration
- ✓ Improve grid performance, efficiency and security
- ✓ Increase in customer choice and participation
- ✓ Establishment of industry-wide best practices
- ✓ Catalyst of innovation



Expected Outcomes

- ✓ Establish an interoperability strategic vision
- ✓ Describe the state, challenges, and path forward to advance interoperability
- ✓ Offer tools to facilitate gap analysis, develop roadmaps, and demonstrate vision concepts

1.2.2 Interoperability
Project Team

Project Participants and Roles

National Lab	FY16 Funding	FY17 Funding	FY18 Funding	Total Funding
PNNL	$500,000	$450,000	$500,000	$1,450,000
NREL	$200,000	$200,000	$200,000	$600,000
LBNL	$150,000	$200,000	$150,000	$500,000
ANL	$150,000	$150,000	$150,000	$450,000
Total	$1,000,000	$1,000,000	$1,000,000	$3,000,000

PNNL – lead, strategic vision, measurement tool
NREL – gaps and roadmap methodology
LBNL – support interop assessment (buildings)
ANL – support interop assessment (elec vehicles)

Partners: SGIP (now SEPA), NIST, GWAC, EPRI, IEEE, IEC, IIC, GSA, ENERGY STAR, USACE, SEI-CM, SAE, LonMark, NEMA, ASHRAE, CTA

1.2.2 Interoperability

Relationship to Grid Modernization MYPP

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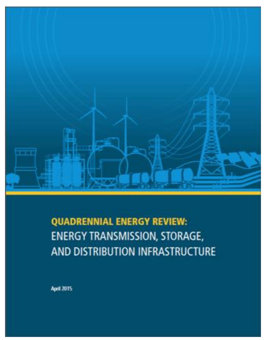
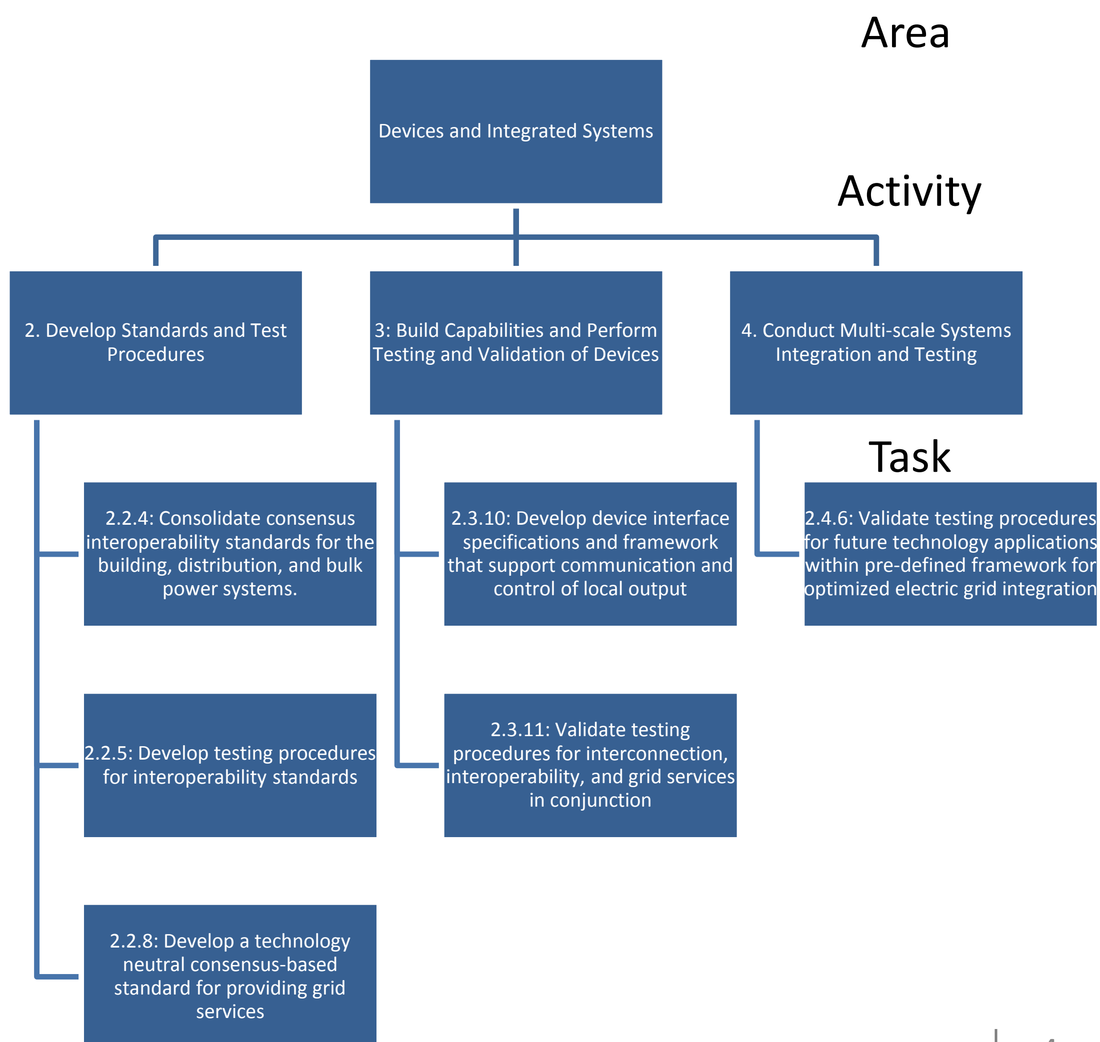
Quadrennial Energy Review (QER) 6th recommendation: *Improve grid communication through standards and interoperability*



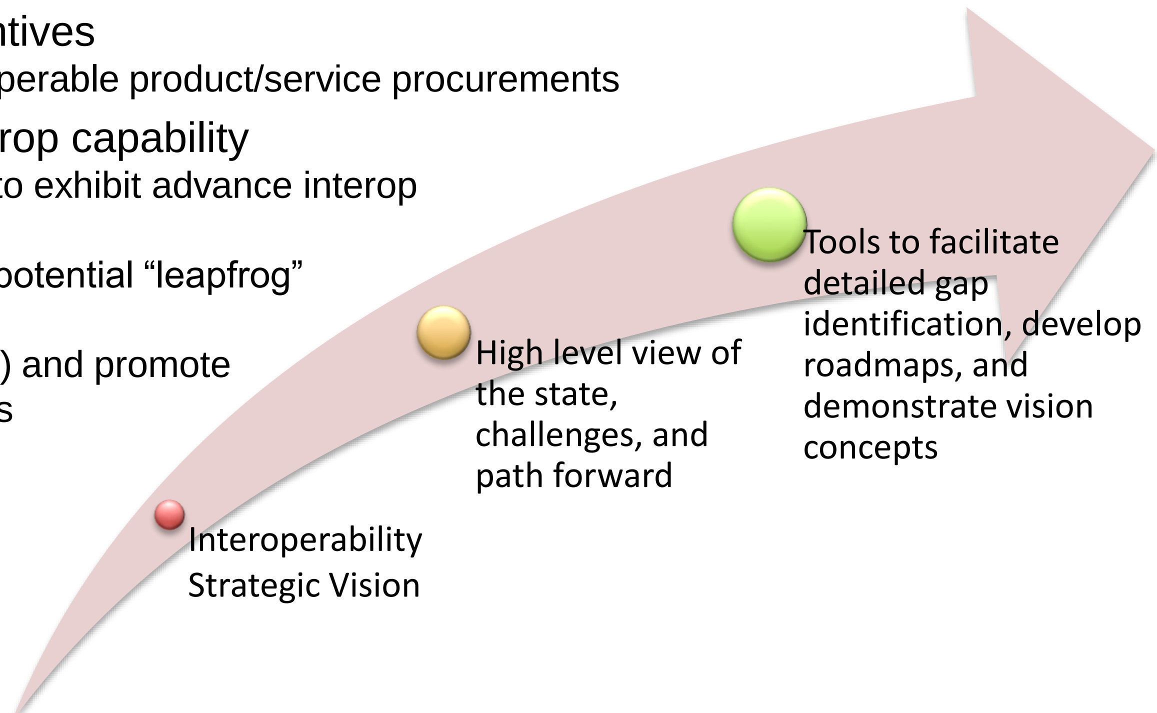
MYPP:

Frames interoperability as a fundamental quality that needs attention for grid modernization. The chart shows some of the main activities with linkages



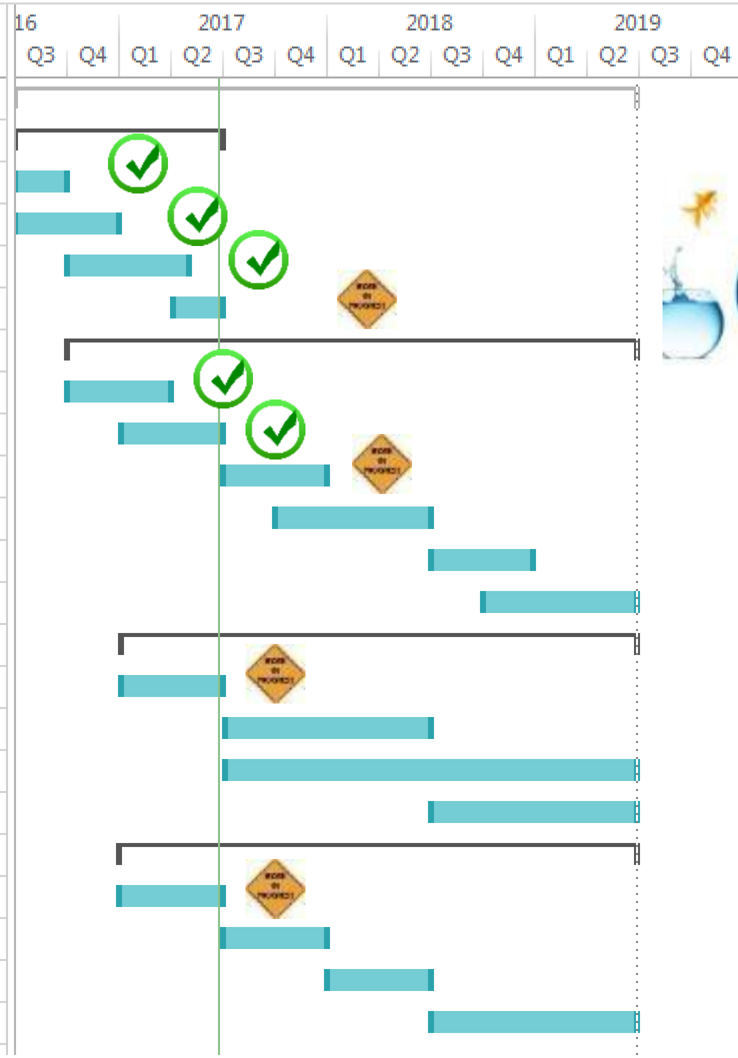
1.2.2 Interoperability
Approach

- Strategic vision
  - State of interoperability and desired integration experience
  - Document with stakeholder buy-in, socialization
- Gaps & roadmaps
  - Tools to measure interoperability/ease of integration
  - A roadmap methodology for technology communities to set goals and a path to achieve them
- Industry engagement incentives
  - Tools to encourage interoperable product/service procurements
- Demonstrate visionary interop capability
  - Industry directed contest to exhibit advance interop concepts
  - Identify priority gaps and potential “leapfrog” capabilities
  - Conduct project/contest(s) and promote results for follow-on efforts



1.2.2 Interoperability
Key Project Milestones

Task Name
Interop1-2-2Plan
Strategic Vision
Assemble Vision Team and Partners
Define Interop Requirements for Vision
Draft Strategic Vision
Socialize Strategic Vision & Assignments
Gaps and Roadmaps
Establish Tools to Gauge Interop Maturity
Define Interop Roadmap Methodology
Trial Interoperability Roadmap Methodology
Draft Interop GridMod Roadmap
Socialize Interop GridMod Roadmap
Support Domain Roadmaps
Industry Engagement Incentive Mechanisms
Identify Engagement Incentive Alternatives
Develop Interop Procurement Tools
Policy Support to Advance Interop
Measure Interoperability Progress Using IMM
Demonstrate Visionary Interoperability Capability
Plan Interop Challenge/Prize
Identify Priority Interop Gaps from Vision/Roadmap
Create Interop Gap Challenge/Prize
Conduct Interop Gap Competition



1.2.2 Interoperability
Accomplishments to Date

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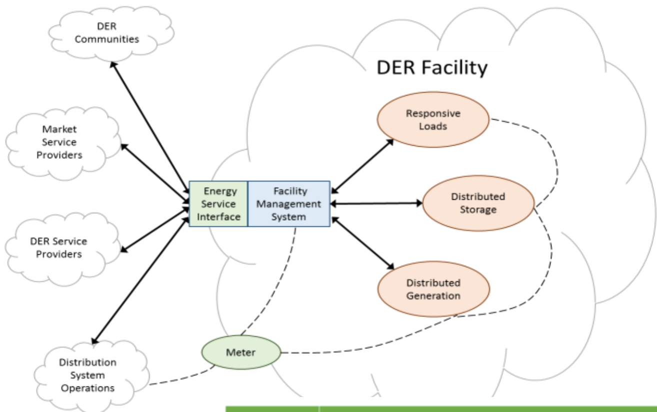
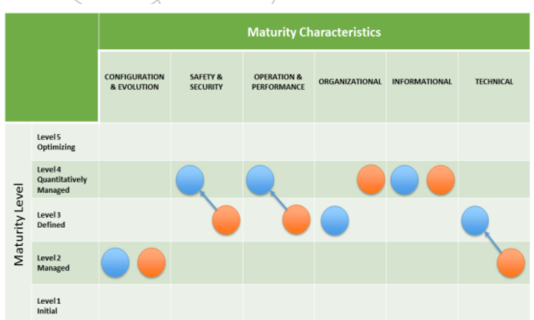
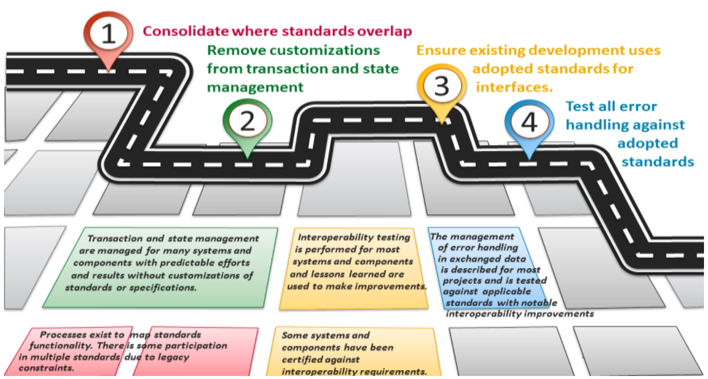
- ✓ Drafted interoperability strategic vision, measurement, and roadmap methodology
  - ➢ Declaration of Interoperability
  - ➢ Interoperability Strategic Vision
  - ➢ Interoperability Maturity Model (IMM)
  - ➢ Interoperability Roadmap Methodology
  - ➢ Public Utilities Fortnightly article, April 2017
- ✓ Demonstrable public stakeholder involvement
  - ➢ Established partnership with 16 organizations and held 7 web meetings
  - ➢ Sep 2016 stakeholder technical meeting with ~50 participants from diverse industry segments
  - ➢ Consensus voiced through unanimous vote in favor of the project's objectives and plan
  - ➢ Interoperability goals/requirements statements tested
  - ➢ Significant feedback on integration vision stories
  - ➢ Nov 2016 outreach at SGIP annual meeting reviewed Declaration, interop criteria, and roadmap methodology plan

1.2.2 Interoperability

A Strategic Vision Example: DER Integration







- ► Layered decomposition architecture =>modular, resilient coordination framework with less facility-grid interfaces => less standards
- ► Grid services ref. model => performance characteristics => external DER facility interfaces non-device type specific while internal interfaces evolve independently
- ► Vision provides direction across all DER device type ecosystems
- ► Interoperability maturity model measures DER ecosystem state and exposes gaps for roadmap consideration
- ► Roadmaps emerge for specific DER ecosystems

1.2.2 Interoperability
Response to November 2016 Program Review

Recommendation	Response
Please share the “Declaration of Interoperability Principles” and the progress made on the assessment tool more broadly across DOE to get feedback from program managers.	Coordinating with DOE leads to distribute introductory material and the Declaration with DOE program managers.
Please set up a webinar with DOE program managers to share the results of this project to date. We want to do the same with Grid Architecture and Sensing and Measurement.	Planning with DOE leads to hold 2, 90 minute meetings at DOE-HQ in late May or June. Will encourage follow-up discussion to incorporate interoperability concerns in respective programs.

1.2.2 Interoperability
Project Integration and Collaboration

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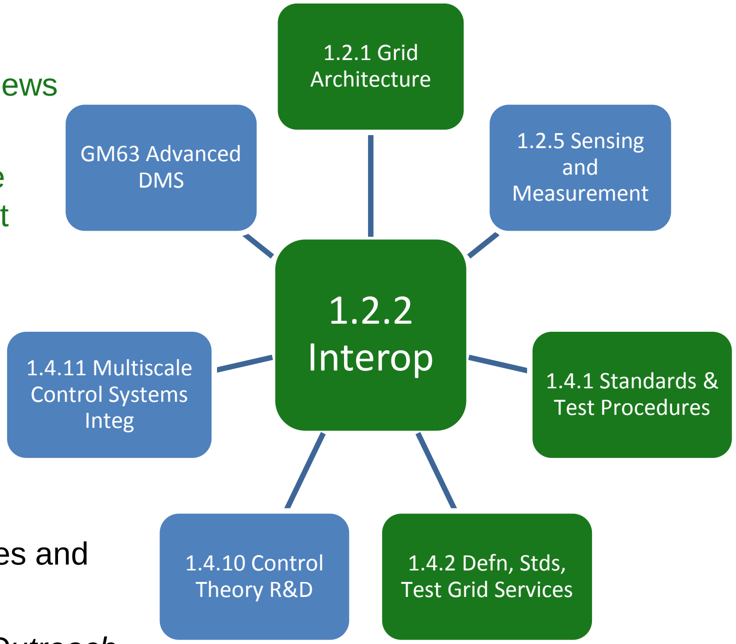
GMLC Project Liasons

- 1.2.1 Grid Arch: device/systems interface points, grid services, system views
- 1.2.5 Sensing & Measurement: sensor frameworks
- 1.4.1 Standards & Test Procedures for Interconnect and Interop: provide status assessment and gap identification tools & community engagement process
- 1.4.2 Definitions Standards and Test Procedures for Grid Services: coordinating on a common set of grid services
- 1.4.10 Control Theory R&D: consider control theory implications on interoperability
- 1.4.11 Multiscale Integration of EMS/DMS/BMS: consider control system interfaces that affect interoperability at different levels
- GM63 Advanced DMS: consider DMS interfaces to DER and field devices and integration implications



Communications

- Aug - Invitation to join project to advance interoperability
- Sep - stakeholder technical meeting with ~50 participants
  - Unanimous vote in favor of the project's objectives and plan
  - Interoperability goals/requirements statements tested
  - Declaration of Interoperability
- Nov - interoperability project session at SGIP, WA DC
- Jan - AHR Expo presentation to buildings community
- Feb - partner interaction at GWAC, San Diego
- GMLC website: https://gridmod.labworks.org/projects/interoperability

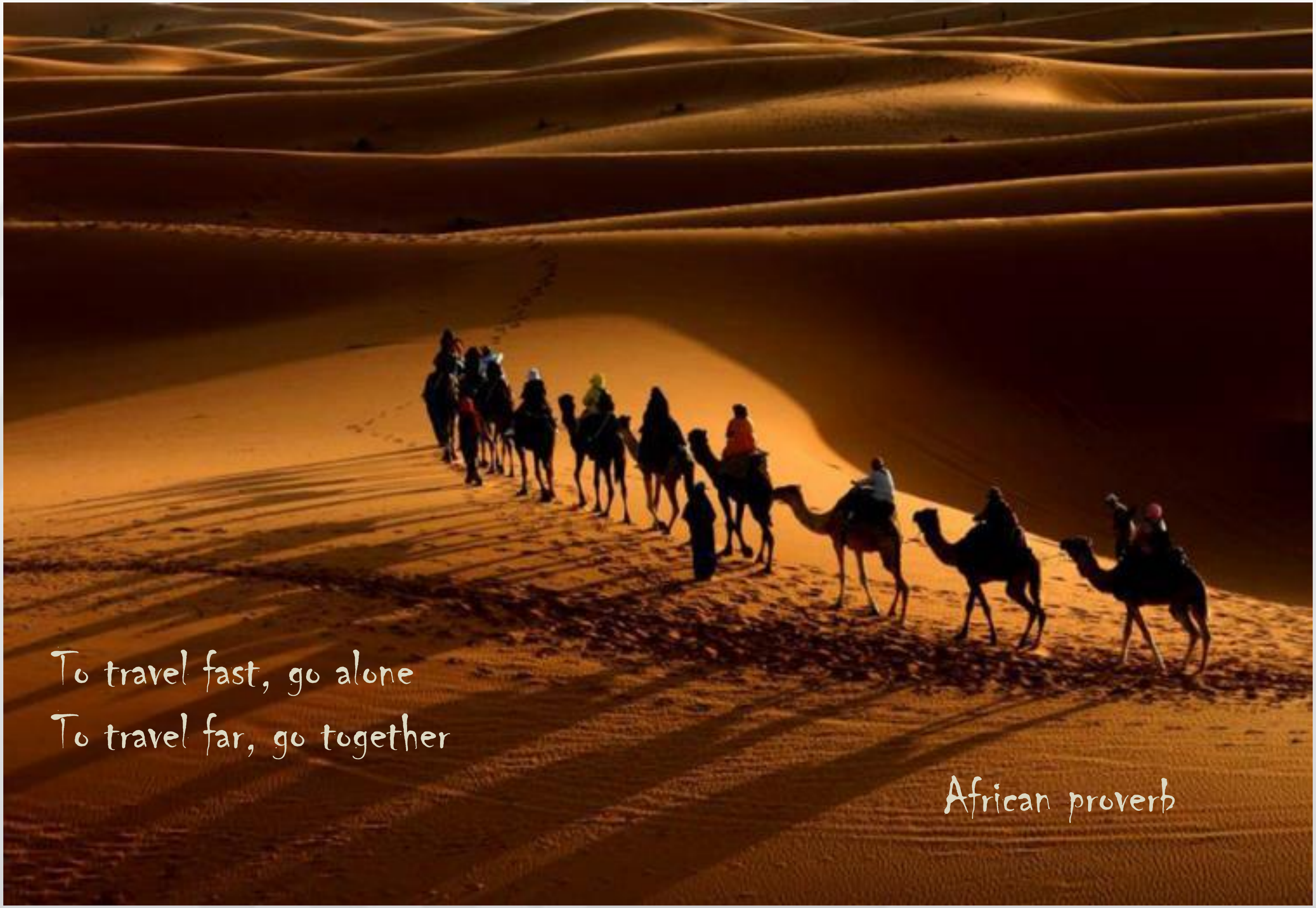
Upcoming Outreach

- Apr – article in Public Utilities Fortnightly
- Apr – IEEE ISGT panel presentation, Wa, DC
- May – stakeholder technical review meeting, Columbus, OH
- Jul – IEEE PES Smart Buildings, Loads, & Consumer Systems Committee meeting, Chicago, IL
- Jul – SEPA annual meeting, technical session, Wa, DC
- Jun – TES Conference, Portland, OR
- Continue regular partners web meetings

1.2.2 Interoperability
Next Steps and Future Plans

- **May 2017**: socialize an interoperability strategic vision document with vision scenarios and interoperability goals/requirements
  Impact – align stakeholder community on vision for integration
  - Technical Review Meeting, Columbus, OH, 10-11 May
- **September 2017**: complete an interoperability roadmap methodology with an interoperability assessment tool and trial in a technology domain (e.g., electric vehicle or automated buildings domains)
  Impact – demonstrate interop measurement and path forward
- **March 2018**: complete draft of interoperability procurement tools with industry stakeholders participation
  Impact – incentives for industry participation to advance interop
- **March 2018**: identify where commonality across technology domains can reduce the uniqueness in the number of DER interface agreements (standards) by 50%
  Impact – set course for standards convergence

Begin by Listening



Backup slides follow

Declaration of Interoperability

We, the participants in the GMLC Interoperability program, based upon our collective resolve and industry experience, set forth these principles, enumerated below, aligned with the Department of Energy's congressionally mandated charter to convene, adopt, and deploy tools and techniques to enable interoperability to create a more reliable, secure, affordable, flexible, sustainable, and resilient electric power system. We believe this industry-led approach can, by following these principles, develop the needed solutions to achieve these goals.

We recognize that a lack of cost-effective interoperability creates onerous and ongoing problems for system integration and operation.

> It wastes energy. **>** It wastes money. **>** It wastes time. **>** It impedes goals of renewable generation and grid performance.

Our future electric power system must easily integrate great numbers of an evolving mix of intelligent, interacting systems and components. Achieving this state requires the advancement of interoperability and the principles that support it; this is a shared challenge requiring alignment across all electric system stakeholders. It is therefore necessary to articulate interoperability goals and requirements and establish a strategic vision for interoperability.

Interoperability is "The ability of two or more systems or components to exchange information and to use the information that has been exchanged". Interoperability also refers to the steps required to achieve this state, which directly relates to the level of effort to successfully integrate systems or components. With this understanding, we recognize the following principles:

- Systems or components need to interact according to agreements at their interface boundaries.
- A system architecture description needs to clearly identify the interface points where systems or components may interact.
- Interoperability concerns need to pervade across a heterogeneous mix of technologies, business practices, and deployment approaches.
- Stakeholders need to participate in the process to develop, use, and maintain interoperability standards, conventions, and supporting capabilities such as certification programs, registries, and security policies.

The principles above require changes in today's technologies, business practices, and deployment approaches, to promote interoperability and simplify the integration experiences.

We hereby recognize that improving stakeholder agreement on clear interface definitions and mechanisms to simply and cost-effectively integrate systems and components will catalyze the realization of a more efficient and secure electric system sensitive to our operational, economic, and ecologic needs. And in response, we join in the efforts to advance interoperability of the future electric system and commit to changing technologies and business processes to accomplish this mission.

ISO/IEC/IEEE 24765: Systems and software engineering — Vocabulary. International Organization of Standards. 2010.

GRID MODERNIZATION INITIATIVE PEER REVIEW

GMLC Project 1.2.3: Testing Network and Open Library

MATTHEW LAVE AND ABRAHAM ELLIS,
SANDIA NATIONAL LABORATORIES

ROB HOVSAPIAN,
IDAHO NATIONAL LABORATORY

April 18-20, 2017
Sheraton Pentagon City – Arlington, VA

1.2.3 Testing Network and Open Library

High Level Summary

Project Description

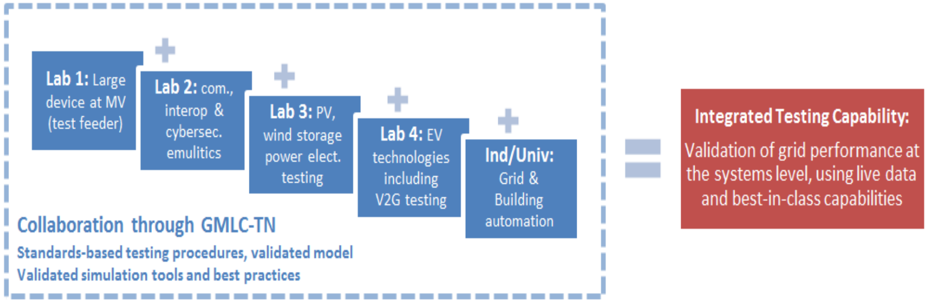
Accelerate grid modernization by **improving access to National Lab testing infrastructure for grid devices and systems, and related models and tools**. Enable national labs to drive innovation more effectively and synergistically.

Value Proposition

- ✓ Access to testing resources and validated models is vital to grid modernization
- ✓ Make optimal use of vast and growing set of grid-related testing and simulation resources at National Labs and beyond.
- ✓ Major opportunities to make an impact by improving information, accessibility, and collaboration

Project Objectives

- ✓ Establish a Testing Network (GMLC-TN) as a federated, lab-based resource for testing and performance validation of grid devices and systems
- ✓ Establish an Open Library (GMLC-OL) as a public repository for validated models, simulation tools and testing resources



1.2.3 Testing Network and Open Library

Project Team

Project Participants and Roles

SNL	Project lead, responsible for TN task
INL	Responsible for OL task
LLNL, ANL, PNNL, NREL, ORNL, LBNL, SRNL, BNL	Support TN and OL tasks, including partnerships & outreach; supply models, simulation tools and testing resources
Utilities, Natl. Labs, Academia, Manufacturers	Stakeholders

PROJECT FUNDING

Lab	FY16 $K	FY17 $K	FY18 $K
SNL	350	300	250
INL	150	200	250
NREL	75	75	75
PNNL	75	75	75
ORNL	75	75	75
ANL	75	75	75
LBNL	75	75	75
SRNL	75	75	75
BNL	25	25	25
LLNL	25	25	25

1.2.3 Testing Network and Open Library

Relationship to Grid Modernization MYPP

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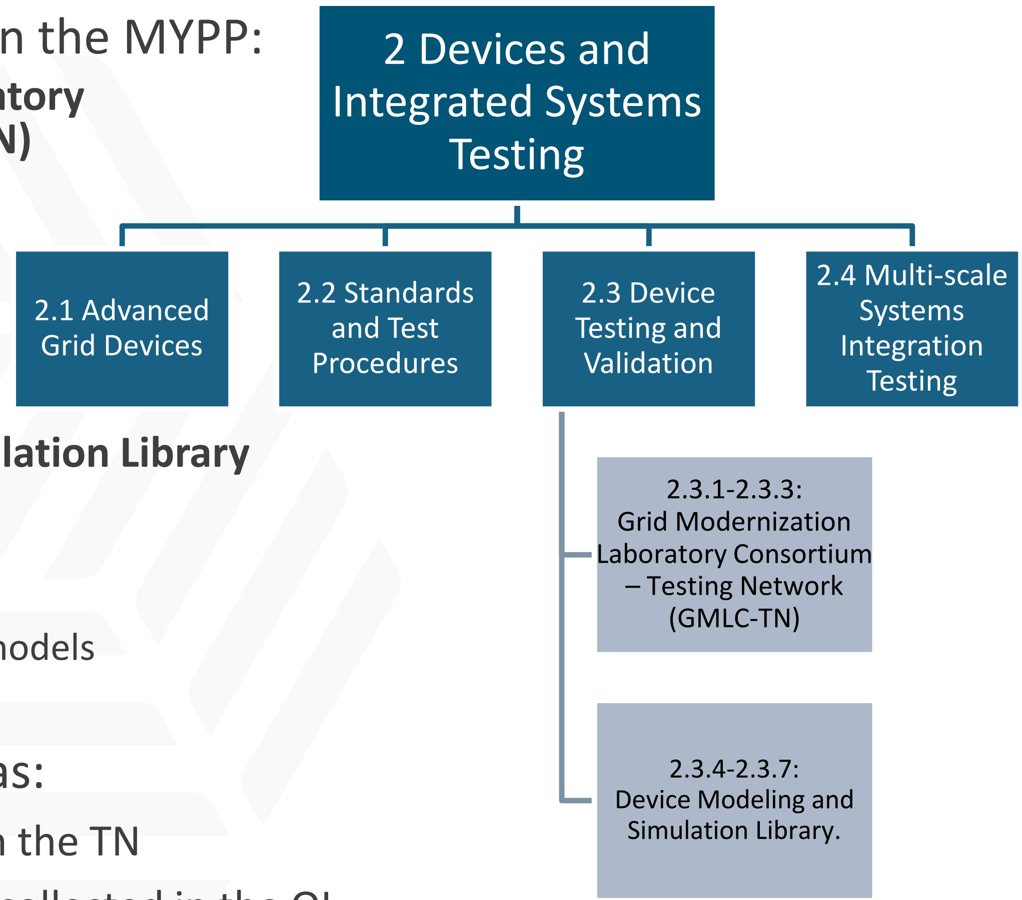
This project is specifically mentioned in the MYPP:

- **2.3.1 – 2.3.3: Grid Modernization Laboratory Consortium – Testing Network (GMLC-TN)**
  - Index of National Lab, university, industry resources.
  - Gaps between existing and desired capabilities.
  - Expand GMLC-TN to achieve desired capabilities.
- **2.3.4 – 2.3.7: Device Modeling and Simulation Library**
  - Unified model description
  - Open model library (OL)
  - Populate library
  - Simulation framework w/interoperable models



Also aligns with activities in other areas:

- Devices developed in 2.1 can be tested in the TN
- Test procedures developed in 2.2 can be collected in the OL
- Multi-scale testing in 2.4 can utilize the TN

1.2.3 Testing Network and Open Library
Approach

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Stakeholder outreach and coordination

	PY SMART Milestone
PY1 – Establish Foundations (Start: APR 2016) 1. Develop TN governance structure 2. Design common framework for testing capability and OL 3. Catalog and publish testing capabilities at DOE Natl. Labs 4. Engage existing consortia, conduct pilot to inform TN/OL	GMLC-TN framework draft documents will be completed provided to DOE, GMLC and EAB; GMLC-OL specifications will be published; catalog of Natl. Labs testing capabilities at will be published.
PY2 – Deploy GMLC TN/OL 1. Launch TN via Membership Agreement & website 2. Populate the OL with open-source resources and models 3. Catalog and publish testing capability information available <u>beyond</u> DOE Natl. Labs	GMLC-TN will be formally established through adoption of the GMLC framework by Full Members; a first version of GMLC-OL implementation will be accessible publicly.
PY3 – Ensure Future Sustainability 1. Expand OL and testing capabilities information databases 2. Enhance value proposition and business model	GMLC-TN procedures will be documented; a sustainable funding mechanism for baseline activities will be established and approved by DOE, GMLC and EAB; enhanced GNLC-OL will make models and testing resources publicly available.

>PY3 – Transition

1.2.3 Testing Network and Open Library

Key Project Milestones

Milestone	Status	Due Date
PY1		
GMLC-TN stakeholder workshop hosted and documented	Completed	9/31/16
Testing capabilities catalog for DOE National Labs	Completed	2/15/17
Common framework for device models	Completed	9/31/16
PY2		
First GMLC-TN General Assembly	Preparing	7/1/17
Assessment of testing capabilities beyond National Labs	Beginning	10/1/17
GMLC-OL published and populated	In progress	1/1/18
GMLC-OL model requirements published	In progress	3/31/18
PY3		
Operations and funding plan	Upcoming	1/1/19
Revised testing capability catalog	Upcoming	1/1/19
Test resources library (test procedures, scripts, equipment specs)	In progress	3/3/19

1.2.3 Testing Network and Open Library

Accomplishments to Date

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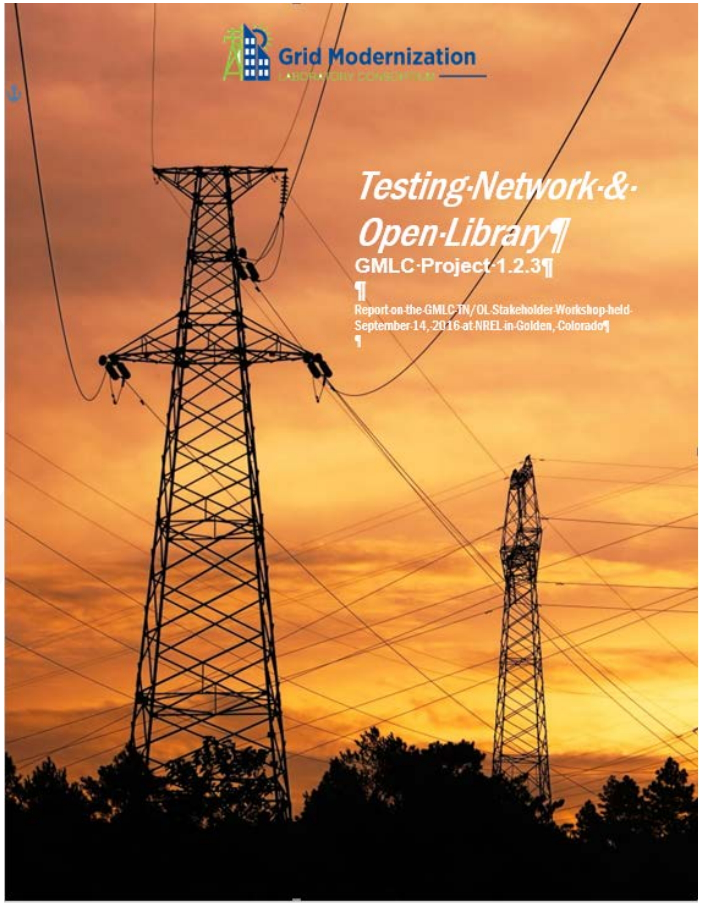
Full report delivered to DOE, public release in progress



Stakeholder Workshop

Sept 14, 2016 at NREL

- 35 attendees, ~1/2 from industry and academia
- Three parallel breakout sessions to solicit feedback, focused on industry stakeholders

GMLC-TN Main Messages:

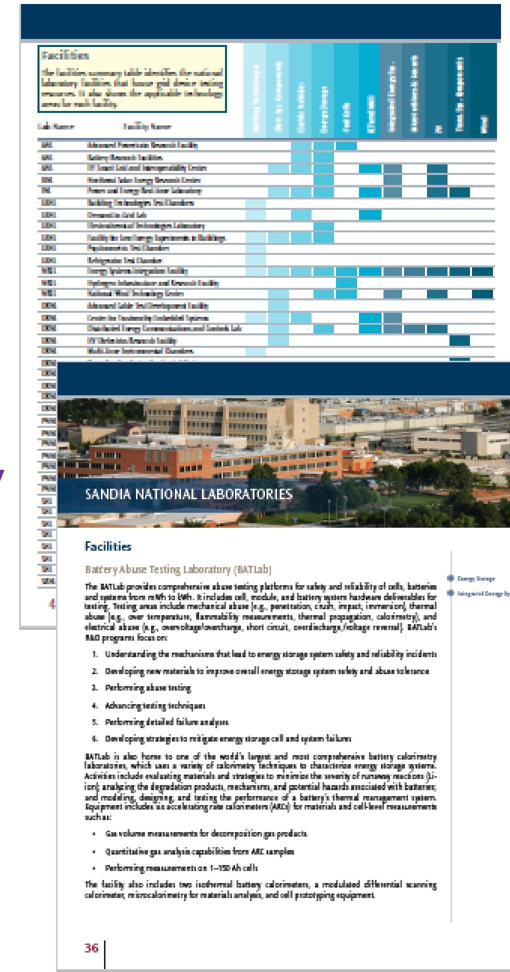
- Branding and raising awareness
- Industry participation
- Break down barriers to working with labs

GMLC-OL Main Messages:

- Scope breadth extremely challenging
- Keeping model information up-to-date
- Commonality between TN and OL valuable

Catalog of National Laboratory Test Facilities and Capabilities

- To facilitate better understanding of laboratory capabilities
- 10 National Labs, 39 distinct facilities
- 168 capability/application technology pairs
  - e.g., hardware in the loop testing of dist. sys. components
- Matrices; but also paragraphs describing facilities and capabilities
- Catalog delivered to DOE, public release forthcoming
- Searchable online version soon; periodic updates



Test Facility

- Energy Systems Integration Facility (NREL)
- Distributed Energy Technologies Laboratory (Sandia)
- …

Test Capability

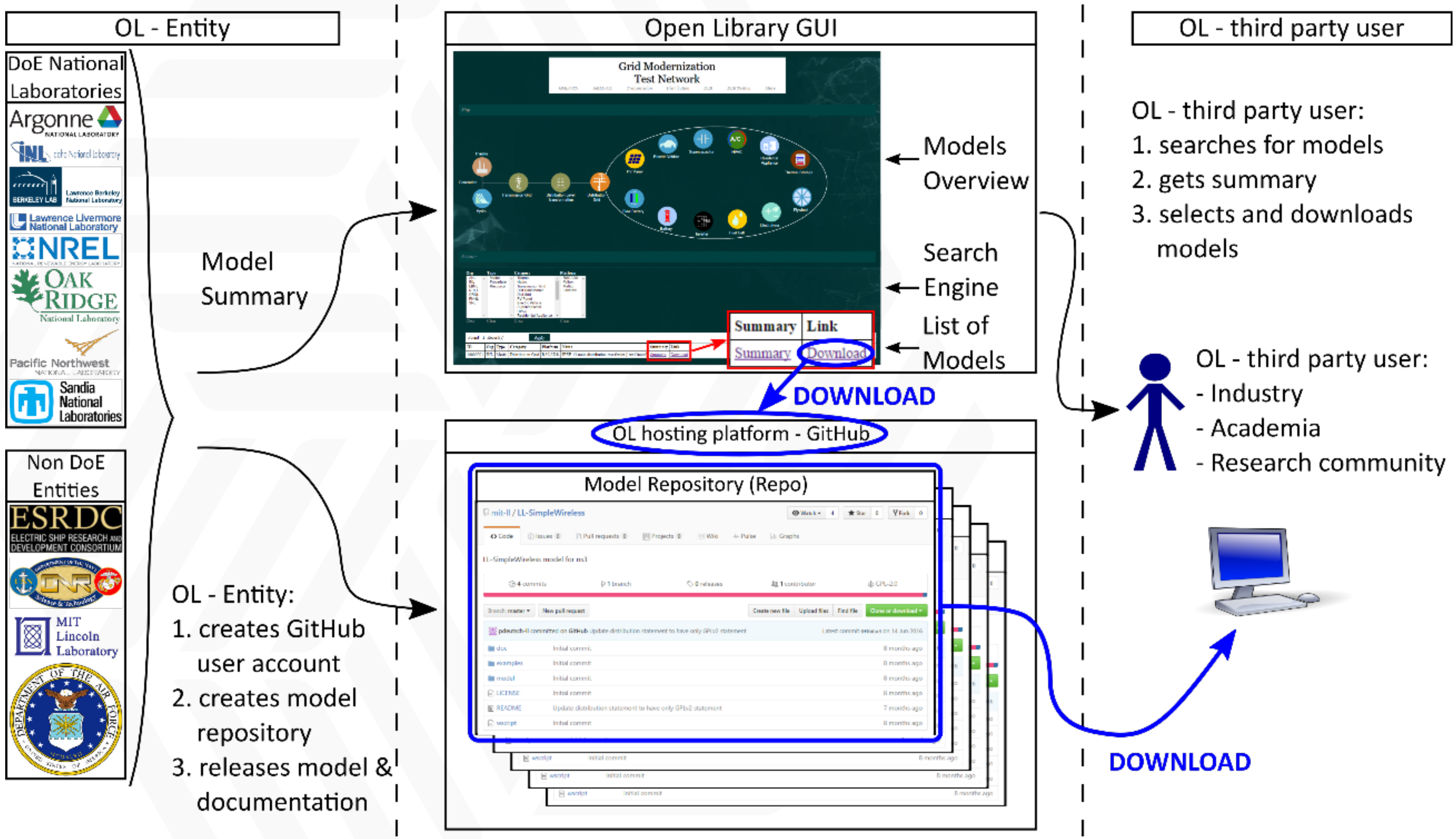
- Communications Interoperability
- Cybersecurity
- Hardware in the Loop
- Grid Compatibility and Interconnection
- Reliability / Safety / Failure Analysis
- Systems Integration and Control

Application Technology

- Building Technologies
- Dist. Sys. Components
- Electric Vehicles
- Energy Storage
- Fuel Cells
- ICT and AMI
- Integrated Energy Systems
- Microturbines and Gensets
- PV
- Trans. Sys. Components
- Wind

1.2.3 Testing Network and Open Library
Accomplishments to Date

Open Library Platform



1.2.3 Testing Network and Open Library

Response to December 2016 Program Review

Recommendation	Response
How will the labs work with industry using this new model? It's not clear to date. Please be ready to discuss at the Annual Peer Review.	• Industry core users of TN and OL • Publicizing to and soliciting feedback from industry • TN can help make it easier to partner with Natl. Labs • Industry test facilities can join TN
Please also be ready to discuss more explicitly what kind of models will be stored in the Open Library and determine the governance model for using the library.	• Challenge is too many models – only including devices and controllers connected to grid • Have a taxonomy for OL • Initial goal is models from other GMLC projects • Later, expansion to models beyond Natl Labs • Using lessons learned from other model collections

Please coordinate with the awardees of ARPA-E's GRID DATA to ensure we don't develop multiple libraries with the same or similar information.	• ARPA-E's GRID DATA:
	    • NREL (distribution)
	    • PNNL (transmission)
	• We have had discussions about using the OL as a way to make GRID DATA models public

1.2.3 Testing Network and Open Library

Response to December 2016 Program Review

GRID MODERNIZATION INITIATIVE
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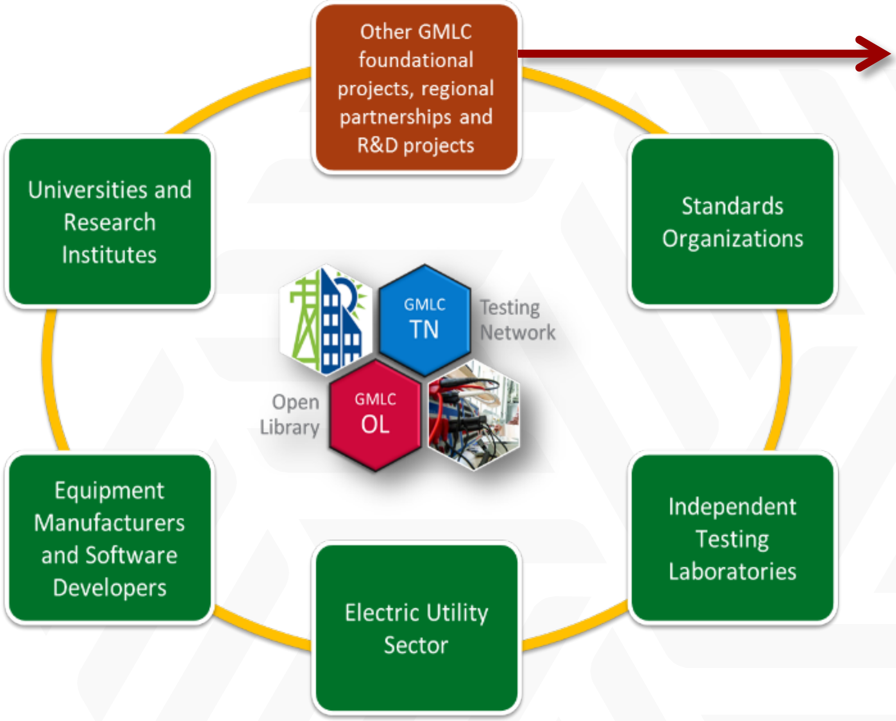
Recommendation	Response

Please look at how this complements the survey done of smart grid test beds.	• Looked in detail at survey efforts by SGIP and DERLab
	  • Cover a broad set of labs in "overview" detail
	  • Our capabilities self-assessment catalog covers only National Laboratories, but in a high detail
	• Also referenced previous DOE surveys
	• We are partnering with SGIP as we expand our catalog to facilities beyond the National Laboratories in PY2

Please be ready to discuss how this aligns with the work at MIT Lincoln Laboratory.	• Partnering with MIT/LL to understand how to best setup partnerships involving non-lab users with proprietary information, share models, etc. • We are reviewing other libraries and testing networks, including MIT/LL, to incorporate best practices and content into the OL and TN
Please send the report from the workshop.	• Provided to DOE technical monitors • Public release in progress

1.2.3 Testing Network and Open Library

Project Integration and Collaboration



GMLC Project Stakeholders	
GMLC Foundational	1.2.2 – Interoperability
	1.4.1 – Standards and Test Procedures
	1.4.2 – Grid Device Testing for Grid Services
GMLC Regional Demos	1.3.1 – Southeast Regional Consortium
	1.3.4 – Industrial Microgrid for Security & Resiliency
	1.3.5 – California DER Siting and Optimization Tool
	1.3.9 – Idaho Falls Distrib. Network Reconfiguration
	1.3.11 – NOLA Grid Analysis and Design for Resiliency
	1.3.21 – Alaska Microgrid Partnership
	1.3.22 – Technical Support to NY State REV Initiative
	1.3.29 – Hawaii Grid Frequency Support from Inverters
	1.3.33 – Midwest Interconnection Seams Study
Program Specific	TRAC, ES, ADMS, TR, VTO, SETO, AGM, FCTO

This work has been presented at:

- GMLC 1.2.3 Stakeholder Workshop
  - concurrent w/1.4.2 and 1.4.1 Workshops
- Coordination Teleconference with DERLab
- HICSS paper on testbeds (Jan. 2017)
- Coordination meetings with SGIP
- US-UK Grid Modernization Workshop (Feb. 2017)
- Session at IEEE ISGT (Apr. 2017)
- Factsheets/PowerPoint slides distributed to team to facilitate outreach

1.2.3 Testing Network and Open Library

Next Steps and Future Plans

GMLC Project 1.2.3 is creating an Testing Network and Open Library

- Enduring resource that supports grid modernization by enhancing collaboration among relevant stakeholders

Short Term Plans:

- GMLC Testing Network and Open Library website
  - Searchable version of facilities/capabilities catalog
  - Open Library with descriptions of models
- Collect additional models and testing procedures for Open Library
- Outreach to coordinate with other GMLC projects
- Governance Structure for Testing Network
  - Agreement-based entity
  - MOU to facilitate cooperation amongst the National Laboratories and streamline partnership
  - General Assembly meeting in summer 2017

Long Term/Ongoing:

- Additional stakeholder outreach
- Expand facilities/capabilities catalog beyond National Labs
  - Coordination with SGIP
- Expand Open Library
- Develop sustainable model for Testing Network and Open Library
- Efforts to federate testing facilities
- Actively participating as a team in efforts such as RT-Superlab to learn about gaps

1.2.3 Testing Network and Open Library

Next Steps and Future Plans

After 1 year…

- Overall PY1 goal to establish foundations for TN and OL accomplished
- Validated the opportunity space
  - Industry looking to National Labs for leadership
  - Difficult to find information on National Laboratory Capabilities
  - Models and tools from GMLC, National Lab, and beyond not well organized
- PY1 product: self-assessment catalog
  - Something new and valuable
  - Requires periodic updates
- OL taxonomy established
  - Challenge will be to deal with the large scope of grid devices and systems models

BACKUP SLIDES

Website with Testing Facilities and Capabilities

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HOME · CAPABILITIES · FACILITIES · LABORATORIES · CONTACT US

› CAPABILITIES

	Building Technologies	Distributed Sys. Components	Electric Vehicles	Energy Storage	Fuel Cells	ICT & AMI	Integrated Energy Sys.	Microturbines & Gensets	PV	Trans. Sys. Components	Wind
Communications Interoperability											
		x	x	x		x	x				
	x					x	x				
	x	x					x		x		x
	x	x	x	x		x	x	x	x		
		x		x		x			x		
Cybersecurity											
										x	
		x		x		x	x		x	x	
	x	x	x			x	x		x	x	x
	x	x								x	
		x		x		x	x		x	x	x

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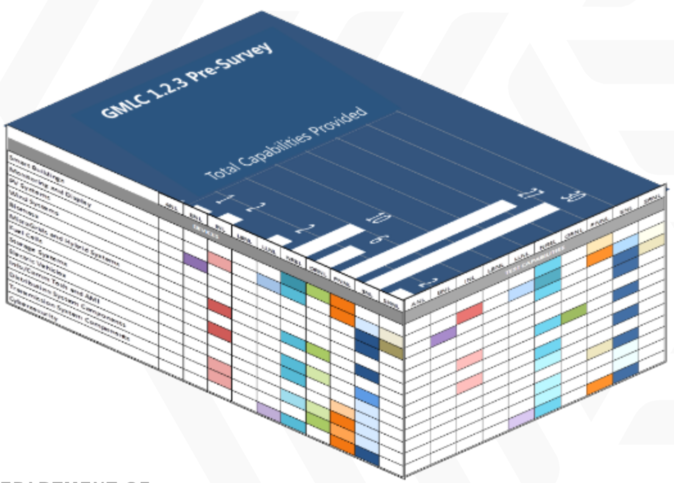
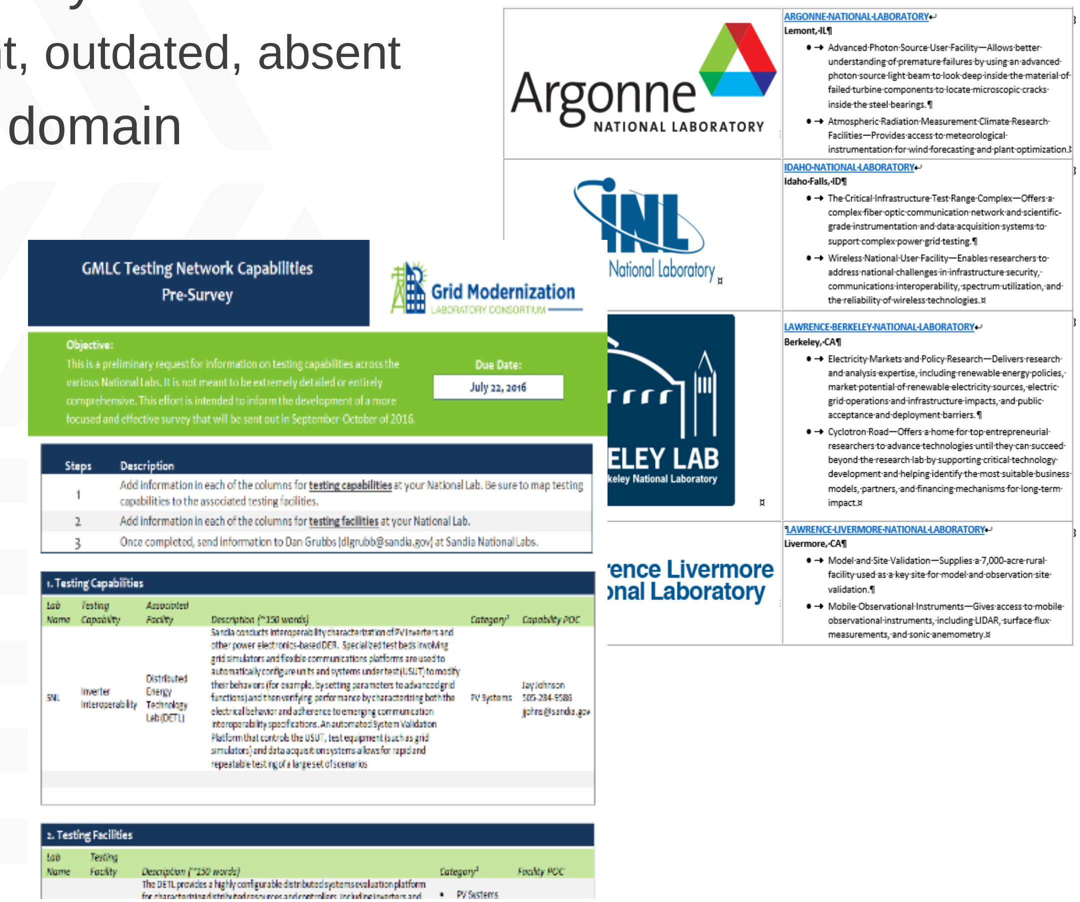
Pre-survey of Lab-based Facilities and Capabilities

- Established baseline for publically-available information
  - Data is scattered, inconsistent, outdated, absent
- Identified relevant information domain
  - Testing facilities
  - Capability categories
  - Technology application areas





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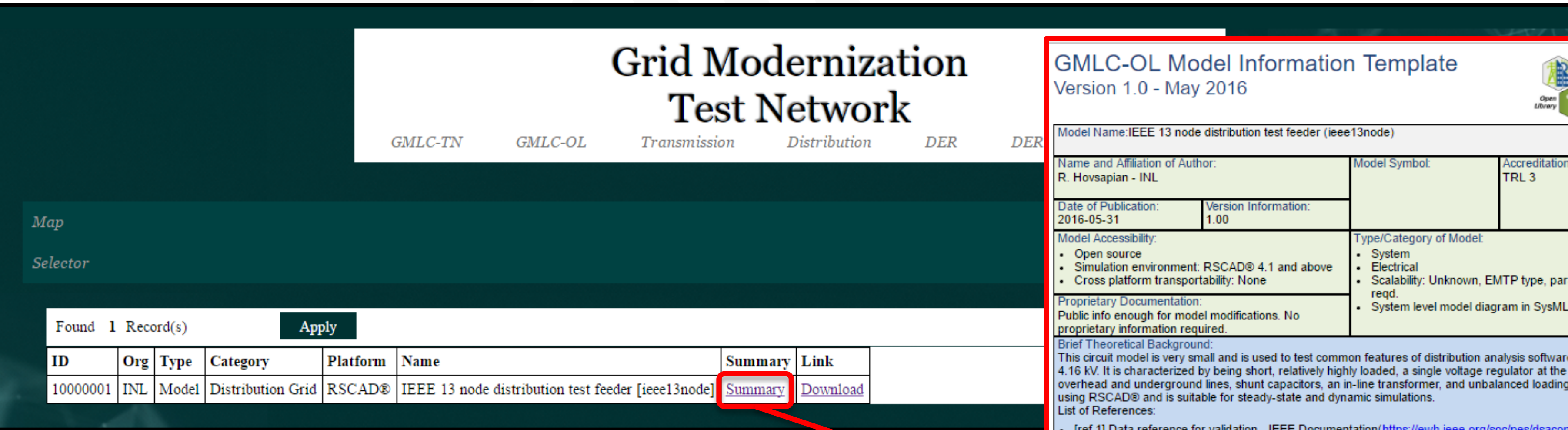
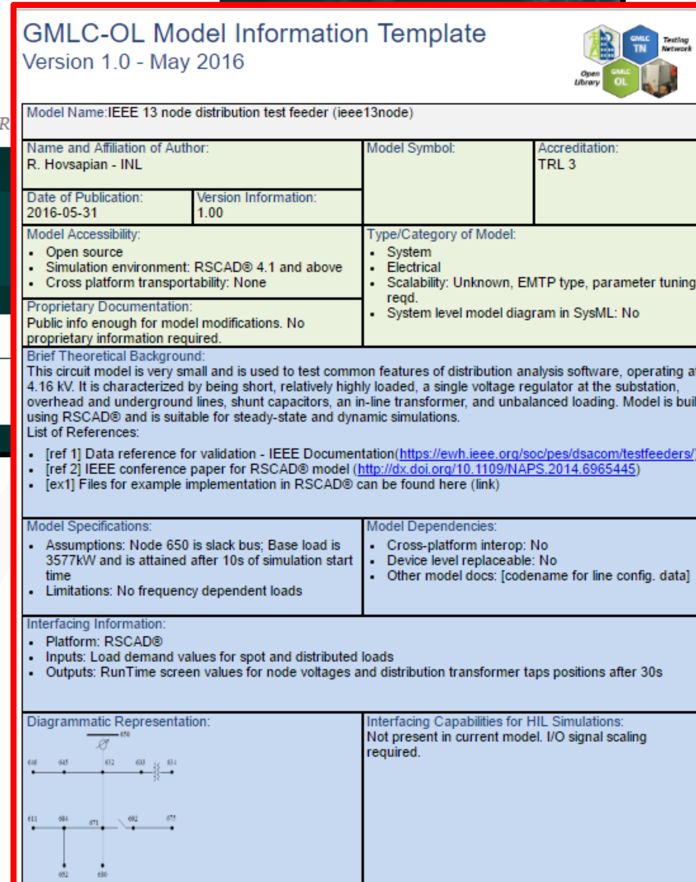
Open Library GUI - Summary





GMLC-OL Model Information Template

Version 1.0 - May 2016

Testing Network
Open Library

Model Name:IEEE 13 node distribution test feeder (ieee13node)

Name and Affiliation of Author:
R. Hovsapian - INL

Model Symbol:

Accreditation:
TRL 3

Date of Publication:
2016-05-31

Version Information:
1.00

Model Accessibility:
- Open source
- Simulation environment: RSCAD® 4.1 and above
- Cross platform transportability: None

Type/Category of Model:
- System
- Electrical
- Scalability: Unknown, EMTP type, parameter tuning reqd.
- System level model diagram in SysML: No

Proprietary Documentation:
Public info enough for model modifications. No proprietary information required.

Brief Theoretical Background:
This circuit model is very small and is used to test common features of distribution analysis software, operating at 4.16 kV. It is characterized by being short, relatively highly loaded, a single voltage regulator at the substation, overhead and underground lines, shunt capacitors, an in-line transformer, and unbalanced loading. Model is built using RSCAD® and is suitable for steady-state and dynamic simulations.
List of References:
- [ref 1] Data reference for validation - IEEE Documentation(https://ewh.ieee.org/soc/pes/dsacom/testfeeders/)
- [ref 2] IEEE conference paper for RSCAD® model (http://dx.doi.org/10.1109/NAPS.2014.6965445)
- [ex1] Files for example implementation in RSCAD® can be found here (link)

Model Specifications:
- Assumptions: Node 650 is slack bus; Base load is 3577kW and is attained after 10s of simulation start time
- Limitations: No frequency dependent loads

Model Dependencies:
- Cross-platform interop: No
- Device level replaceable: No
- Other model docs: [codename for line config. data]

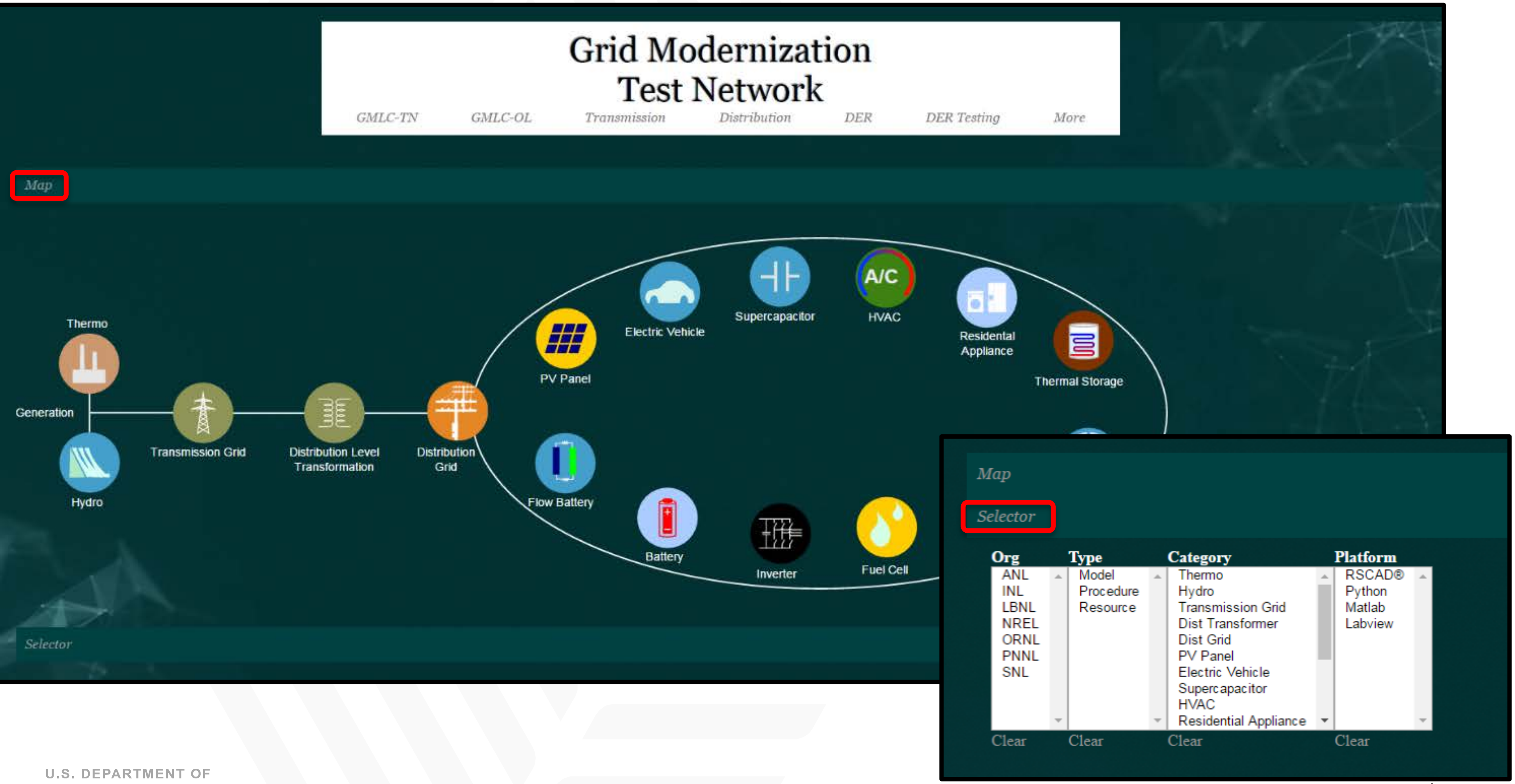
Interfacing Information:
- Platform: RSCAD®
- Inputs: Load demand values for spot and distributed loads
- Outputs: RunTime screen values for node voltages and distribution transformer taps positions after 30s

Diagrammatic Representation:

Interfacing Capabilities for HIL Simulations:
Not present in current model. I/O signal scaling required.

Common Framework describes a model and is located on the Open Library webpage assigned to that model.

Open Library Organization



GRID MODERNIZATION INITIATIVE PEER REVIEW

GMLC 1.3.29 – Grid Frequency Support from Distributed Inverter-based Resources in Hawaii

ANDY HOKE, NREL

April 18-20, 2017
Sheraton Pentagon City – Arlington, VA

Grid Frequency Support from Distributed Inverter-based Resources in Hawaii (1.3.29)
High Level Summary

Project Description

Work with the Hawaiian Electric Companies (HECO) to investigate, develop, and validate ways that distributed PV and storage can support grid frequency stability on the fastest time scale (starting within a few line cycles of a frequency event).

Value Proposition

- ✓ Can DERs reliably and autonomously support grid frequency in very high renewable penetration scenarios, and what are the challenges involved?
- ✓ In a SunShot future with low levels of synchronous generation, conventional methods of stabilizing grid frequency may no longer be adequate

Project Objectives

- ✓ Enable distributed PV and storage inverters to support grid frequency starting a few AC line cycles after the appearance of a frequency event.
- ✓ Characterize frequency support capabilities of existing inverters.
- ✓ Validate DER frequency support via conventional simulation (PSSE), hybrid T&D simulation, and power hardware-in-the-loop testing.
- ✓ Recommend DER frequency control strategies to HECO.
- ✓ Develop new models and modeling methods for DER frequency support functions.

Project Participants and Roles

NREL – Overall lead; hardware testing including PHIL; controls; hybrid T&D simulation; field deployment

SNL – Bulk power system simulation

HECO – Support modeling and simulation; field deployment

Enphase Energy and **Fronius USA** – Supply test and field hardware and technical support

FIGII and **Energy Excelerator** – Advisory

PROJECT FUNDING			
Lab	FY16 $	FY17$	Lab Total
NREL	$510k	$180k	$690k
SNL	$300k	-	$300k
Total	$810k	$180k	$990k

1.3.29 – DER Frequency Support for Hawaii

Relationship to Grid Modernization MYPP

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Directly aligns with 3 of 4 activities in the DIST area:

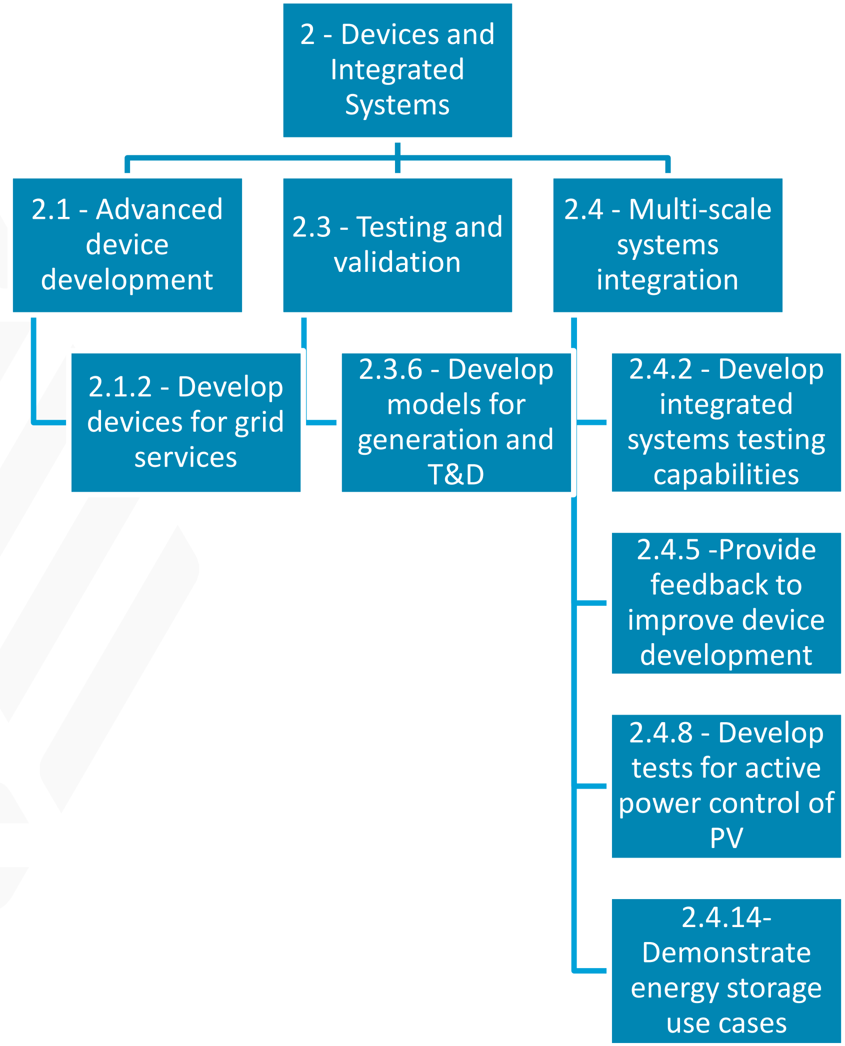
- 2.1 - Develop advanced power electronics, ESSs
- 2.3 - Build capabilities, test and validate devices
- 2.4 - Conduct multi-scale systems integration

Indirectly impacts the 4th DIST activity:

- 2.2 - Develop standards and test procedures

Also aligns with several activities in other areas:

- 4.2 - Develop coordinated system controls
- 5.2 - Develop tools for improving reliability
- 7.1 - Provide technical assistance to states



1.3.29 – DER Frequency Support for Hawaii
Approach

Task	Subtask
1 - Bulk system modeling and simulation	a) PSSE model development b) Parametric study of bulk system c) Power balancing and reserve requirement modeling
2 - Time domain modeling, simulation, and controls development	a) Hybrid time-domain system model development b) Inverter model development/validation c) Inverter controls development d) Simulate and compare control methods e) Implement/upgrade controls in vendor firmware f) Real-time PHIL model development
3 - Hardware testing including PHIL	a) Open loop inverter hardware testing b) PHIL validation of frequency supportive hardware c) PHIL validation of side-effect mitigation
4 - Field testing and demonstration	a) Field test bed planning and installation b) Field hardware demonstration c) Compare field results to lab tests and simulations
5 - TRC and reporting	a) Establish TRC and obtain TRC feedback b) Final summary report

1.3.29 – DER Frequency Support for Hawaii

Key Project Milestones

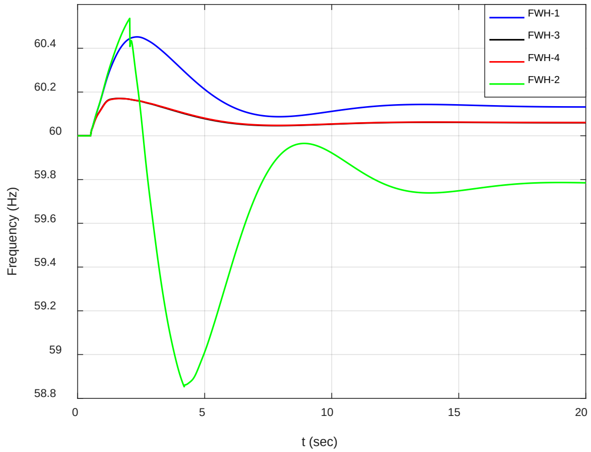
Milestone (FY16-FY17)*	Status	Due Date
1.4 - Simulations contrasting Oahu grid response to various control methods (homogeneous control implementation scenarios) complete	Complete	March 31, 2017
2.4 - Prototype inverter controls for improved DER frequency support developed	Complete	March 31, 2017
3.4 - Initial results from PHIL testing of second inverter agree with pure simulation	Complete	March 31, 2017
4.4 - Field installation of all inverters at HECO site complete	In progress. Delayed due to subcontract issues.	March 31, 2017
5.4 - Progress report delivered to TRC for review	Complete	March 31, 2017

*Project includes 30 milestones (5 per quarter). Only FY17 Q2 milestones are shown here due to space/time constraints.

Technical finding:

- As inverter-coupled generation displaces synchronous generation, **generator inertia must be replaced with other *very fast* frequency support services**
- Exact response time varies by system; Oahu needs sub-second response
- Experiments and simulations confirm PV and storage inverters can provide sufficiently fast support
- Speed of response is faster than currently envisioned for mainland U.S. – concerns about unintended interactions with sync gen (e.g. SSTI, inter-area oscillations)
- Based on input from this project, Draft IEEE Standard P1547 modified to allow sub-second frequency droop.

2019 Oahu overfreq event with varying f-W response times. (Green = 1 s response)



Excerpt from IEEE P1547 (to ballot May 2017)

P1547/D6.7, March 2017
IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces

Table 25—Parameters of frequency-droop (frequency/power) operation for DER of Category I, Category II, and Category III

Parameter	Ranges of adjustability [c]			Default settings [a]		
	Category I	Category II	Category III	Category I	Category II	Category III
db_{OF}, db_{UF} (Hz)	0.017 [b] – 1.0	0.017[b] – 1.0	0.017[b] – 1.0	0.036	0.036	0.036
k_{OF}, k_{UF}	0.03 – 0.05	0.03 – 0.05	0.02 – 0.05	0.05	0.05	0.05
$T_{response}$ (small-signal) (s)	1 – 10	1 – 10	0.2 – 10	5	5	5

Allows responses as fast as 0.2 seconds

Publications:

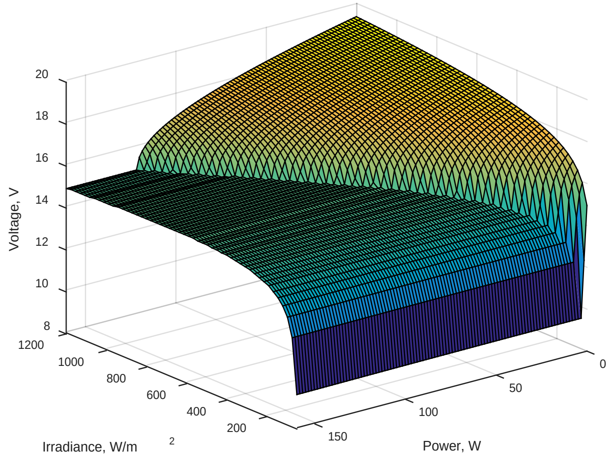
[1] A. Hoke, M. Shirazi, S. Chakraborty, E. Muljadi, D. Maksimovic, "Rapid Active Power Control of Photovoltaic Systems for Grid Frequency Support," *IEEE Journal of Emerging and Selected Topics in Power Electronics*, 2017

- Method for estimating the presently available power from a PV array
- Method for controlling the active power of a PV system accurately and rapidly (within 2-4 cycles)

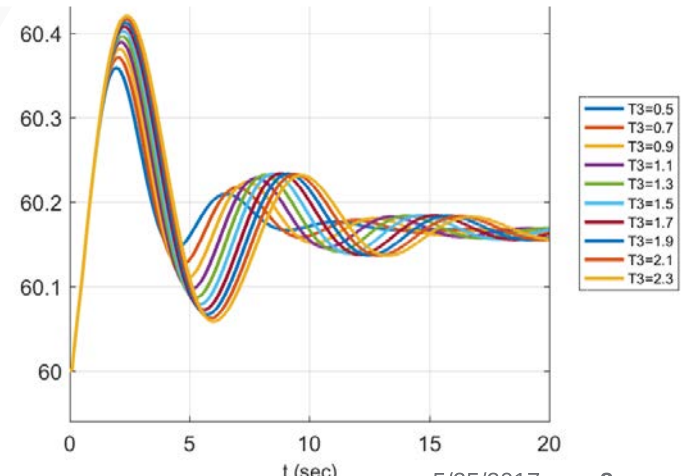
[2] M. Elkhatib, J. Neely, J. Johnson, "Evaluation of Fast-Frequency Support Functions in High Penetration Isolated Power Systems," *IEEE Photovoltaics Specialists Conference*, 2017

- Comparison of PV droop parameters using PSS/E model of future Oahu power system
- User-defined model of frequency-responsive PV

3-D lookup table for rapid APC of PV [1]



Comparing PV APC response time [2]

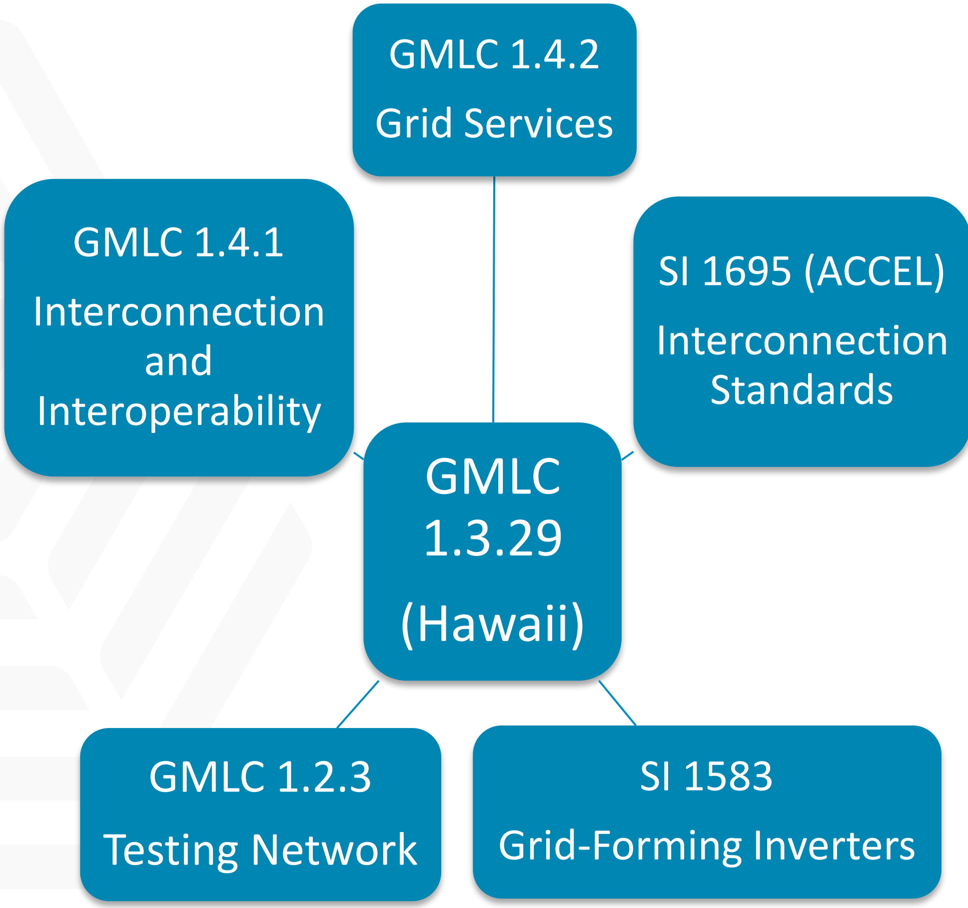


Recommendation	Response
The ability of PV systems to “ramp up” in response to a contingency needs to be investigated as part of this project and should not be a “long-term goal.”	Agreed – that has always been the plan. To clarify, *full-scale implementation* of upward response from PV is a possible long-term goal, but *experiments and simulations* of that are core tasks of this project. See publication [1] on previous page, as well as technical detail slides.
This should also include understanding the implications between the distribution and transmission systems.	Agreed. The PHIL simulation platform is specifically designed to validate the ability of real hardware inverters to respond to frequency events in an environment that emulates distribution and transmission system dynamics

- Members of the project team are coordinating with IEEE 1547's work through ACCEL to standardize DER-based grid support functions.
- Because this project aims to develop a new grid service, it requires coordination with GMLC 1.4.2 (Definitions, Standards, and Test Procedures for Grid Services), GMLC 1.4.1 (Interconnection and Interoperability), and GMLC 1.2.3 (Testing Network). Standards gaps identified will be conveyed to 1.4.1.
- Like this project, SuNLaMP project 1583 on Grid-Forming Distributed Inverter Controllers seeks to address the stability of low inertia grids. We are meeting periodically with Brian Johnson to coordinate and seek synergies.

Communications

- Presented at HECO Technical Conference. Attendees included Hawaii PUC, parties to the PUC's DER Docket, Hawaii Smart Inverter Technical Working Group, California IOUs, etc. – October 2016
- ISGT Panel Session – April 2017



Future activities and impacts:

- PSS/E investigations:
  - Effect of DER inverter response to transmission faults on frequency stability
  - Grid-forming inverter controls simulation
- Completion of PHIL tests of fast PV and storage-based frequency support (both up and down)
- Parametric comparison of DER-based frequency support using governor-only Oahu model
- *Course correction:* One manufacturer dropped most project support to focus on near-term financial goals. Incorporating new PV and storage inverters as replacements.
- Final report – September 2017
  - Summary of project findings, including limitations
  - Recommendations to HECO

Possible additions and expansions:

- Holistic study of fast frequency support including: loads (DR), EVs, bulk storage and renewables, and conventional generation in addition to DERs.
- Monitoring/visibility of DER reserve capacities for planning and operations
- Expanded investigation and development of DER controls for high-pen grids (e.g. low-SCR stability, DER fault responses)

Conclusion

Project summary

This project is developing and validating a new fast-responding DER service for stabilization of high-renewable grids through simulation, hardware testing, and field demonstration.

Impact highlights

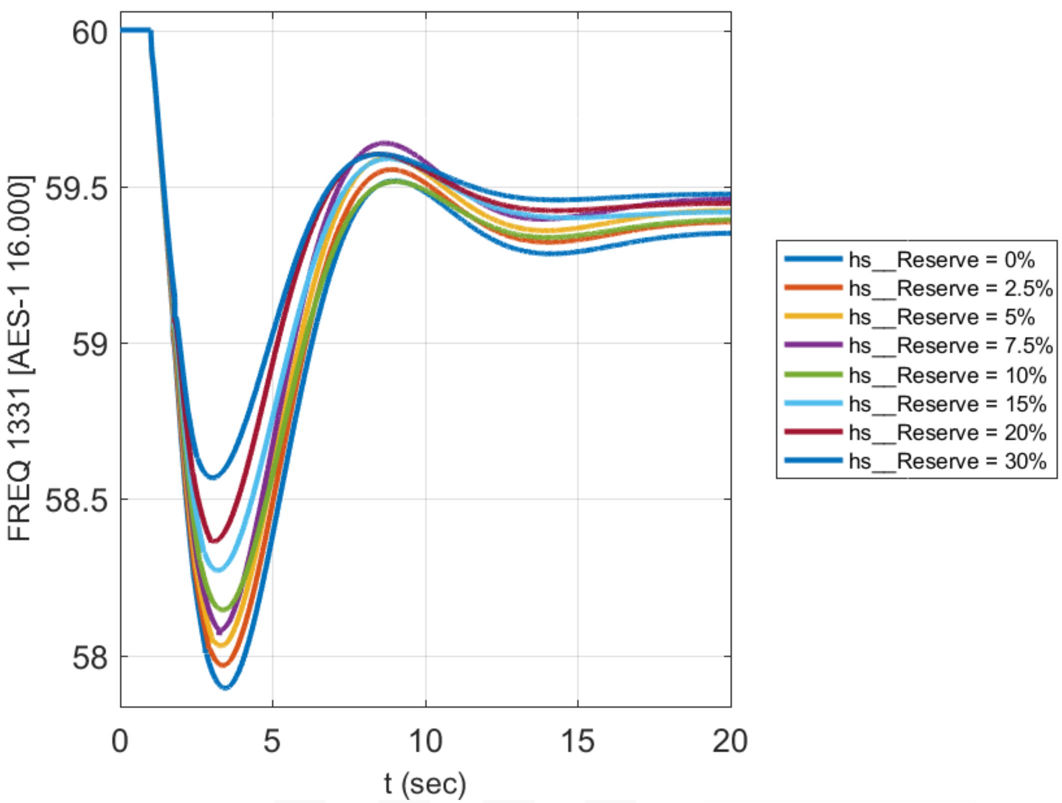
- Draft IEEE 1547 revision incorporated recommendations from this project
- Developing custom PHIL platform for combined T&D simulation
- HECO intends to modify grid operations based on the findings of this work
- Relevant in Hawaii now, and on mainland U.S. in years to come

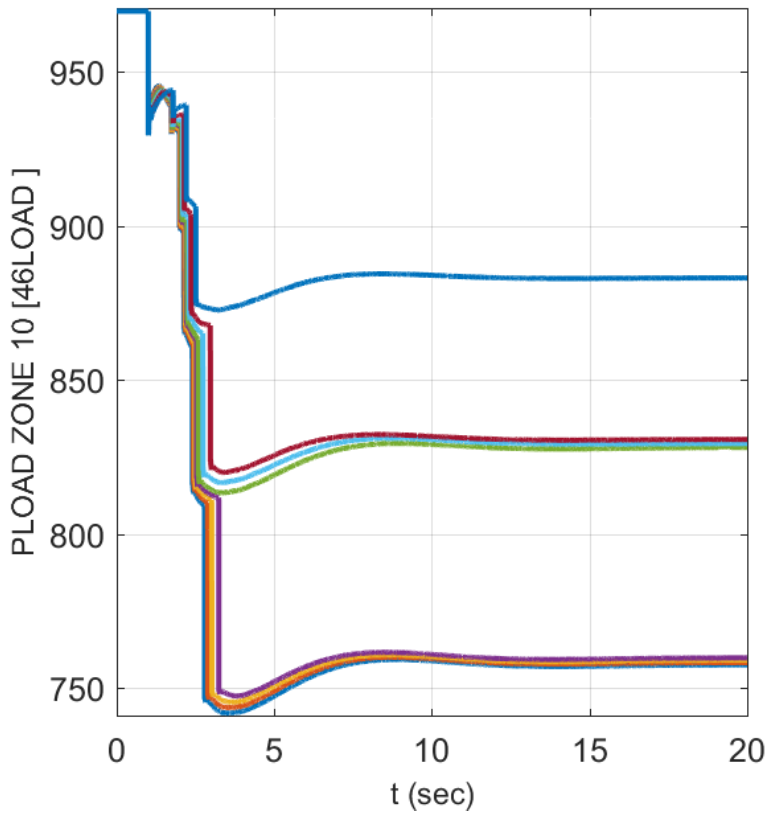
Thank you!

Questions welcome

Technical backup slides follow

PV-based up-regulation during loss-of-generation contingency: Comparison of amount of Type 3 PV held in reserve. At least 10% reserve is needed to impact load shedding





Underfrequency Event with Varying PV Reserve

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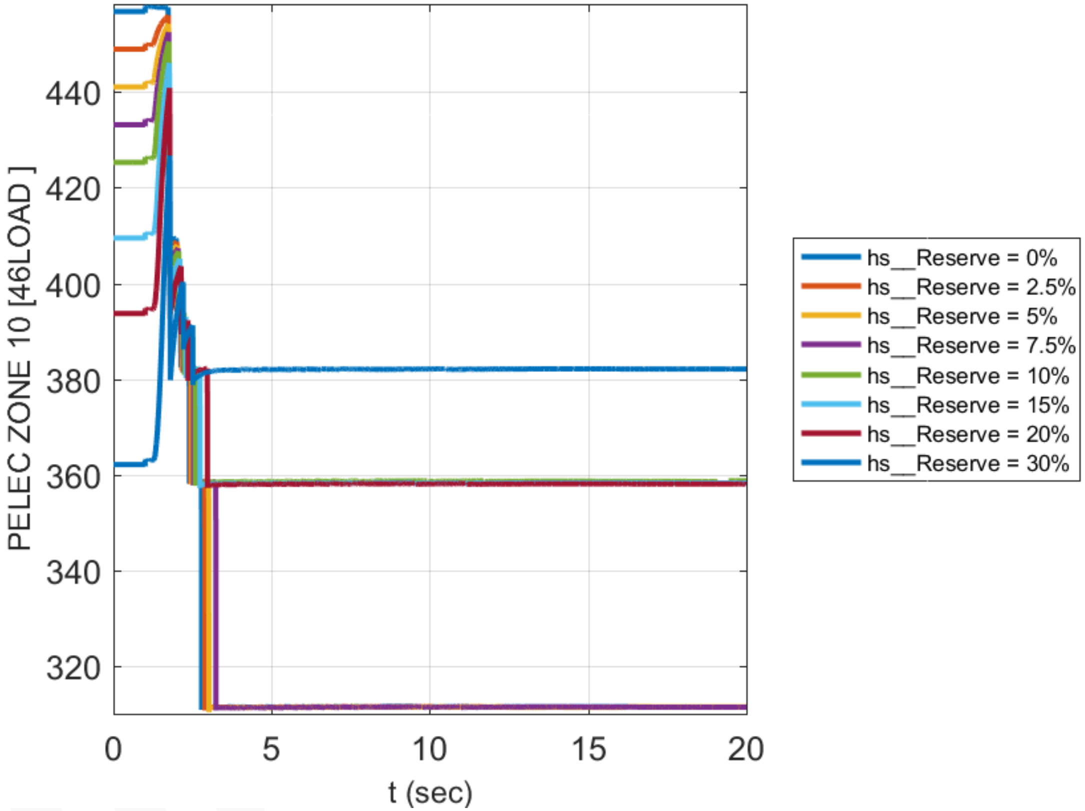
PV power during event on previous slide.

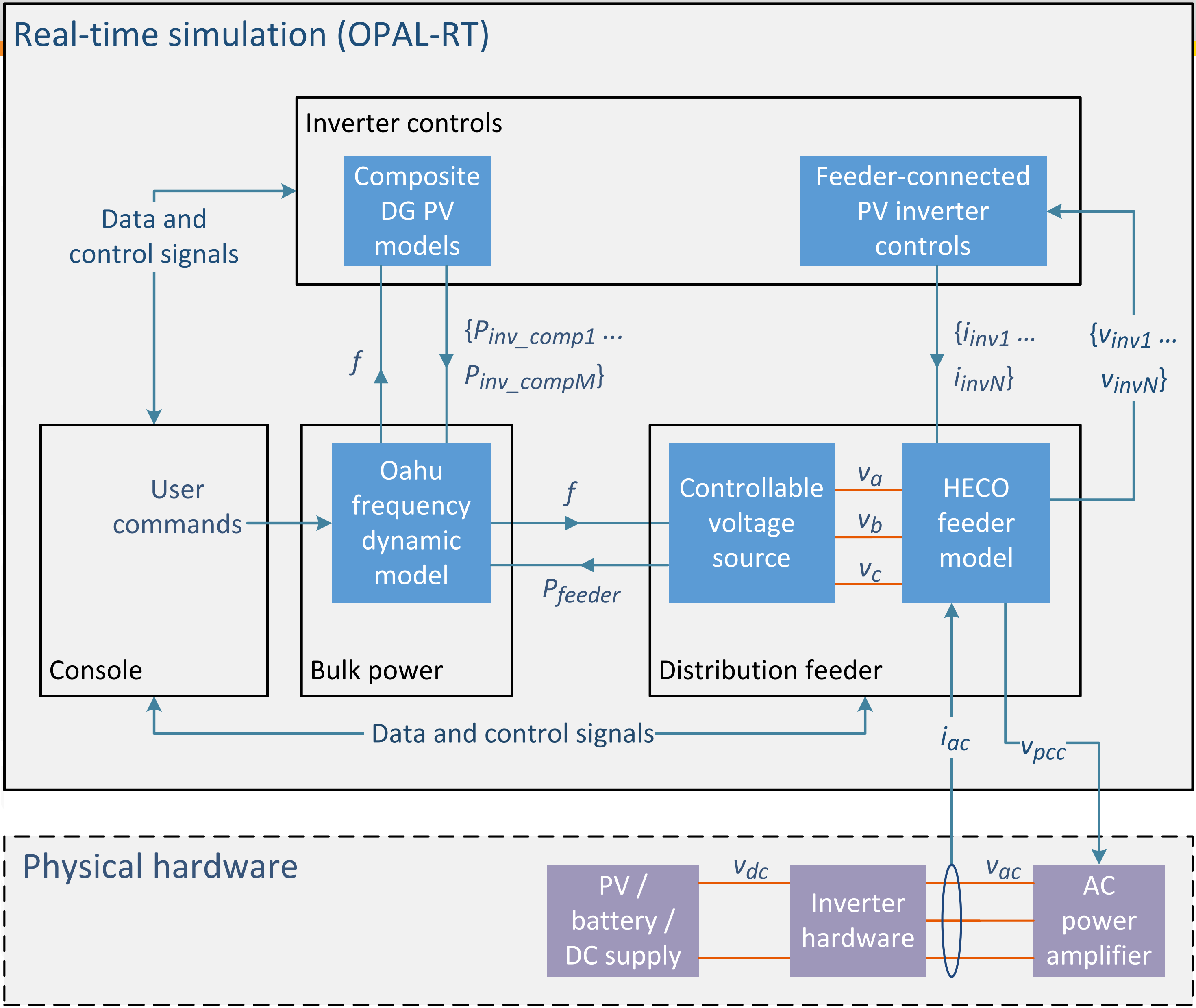
Note that current load shedding scheme largely counteracts PV response by shedding PV!



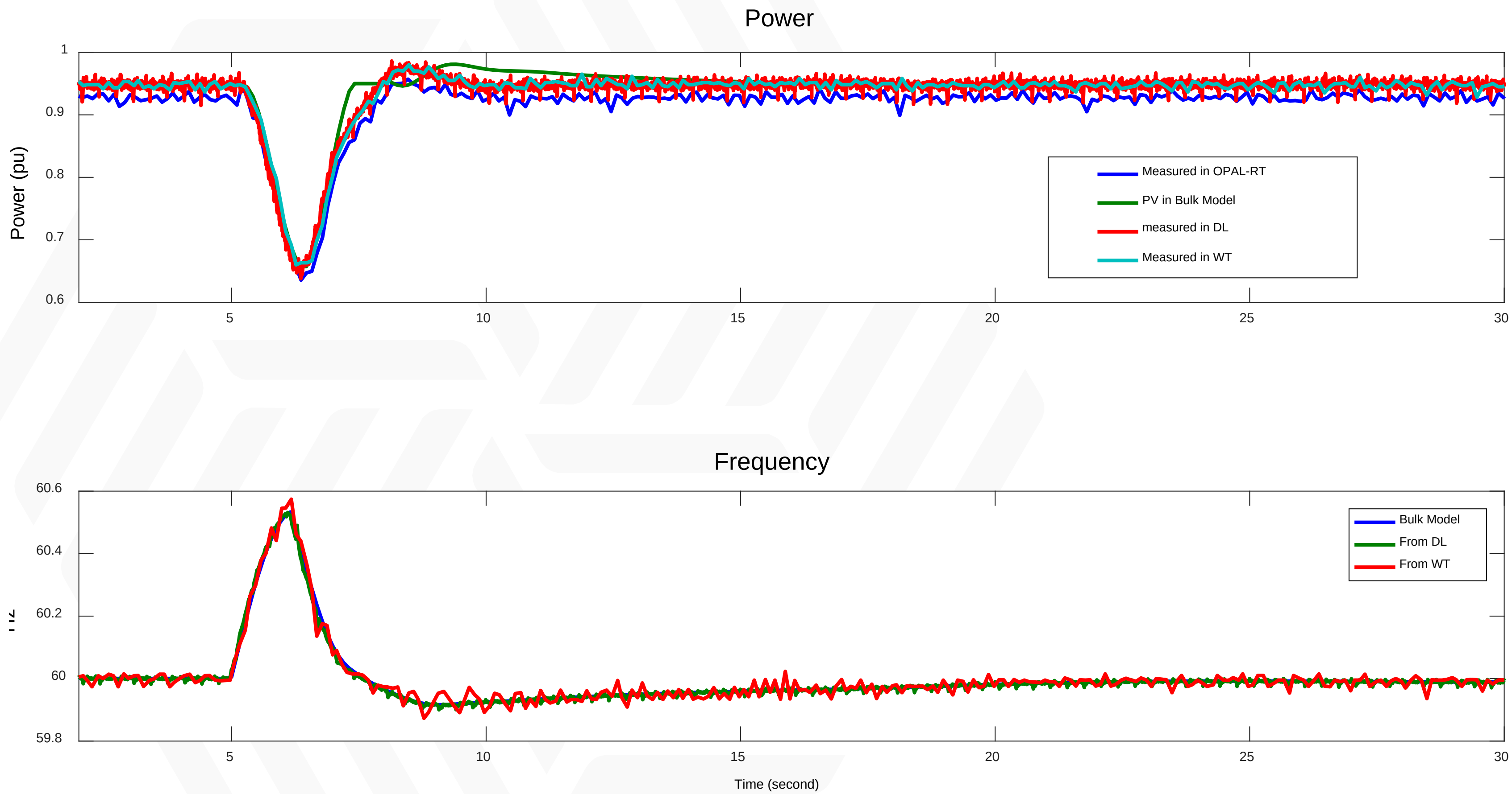
1.3.29 – DER Frequency Support for Hawaii

PHIL Model Overview

- ▶ Real-time Oahu frequency dynamic model simulates contingency events
- ▶ Frequency dynamic model drives frequency of voltage waveforms in distribution system simulation
- ▶ Hardware inverter is connected to AC supply driven by simulated PCC voltage
- ▶ Many more inverters simulated with various controls, both on distribution feeder and in bulk system model



PHIL validation of PV-based frequency support.



Standards and Test Procedures for Interconnection and Interoperability

(GMLC 1.4.1)

DAVID NARANG, NREL

April 18-20

Sheraton Pentagon City – Arlington, VA

Standards and Test Procedures for Interconnection and Interoperability (GMLC 1.4.1)
High Level Summary

Project Description

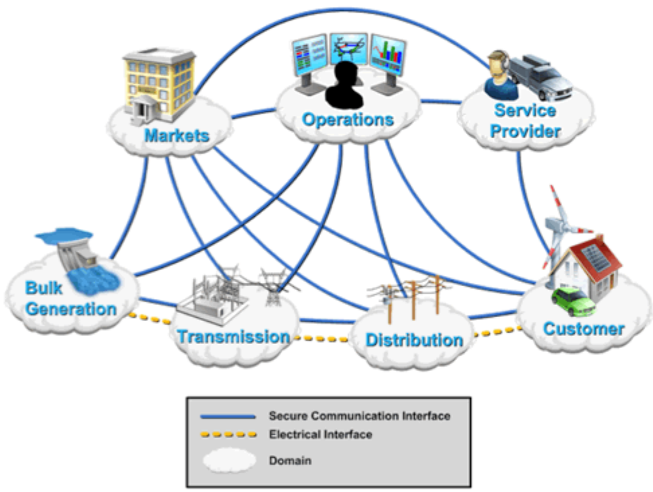
- **Accelerate the development and validation** of interconnection and interoperability standards
- Ensure **cross-technology compatibility** & harmonization of requirements

Project Objectives

- ✓ Interconnection and interoperability gap analysis & prioritization of high impact areas
- ✓ Standards coordination and harmonization for key grid services and devices
- ✓ Develop new testing procedures

Value Proposition

- **Improve coordination** of advanced generation and storage assets
- **Enable expansion** of markets for key devices
- **Eliminate barriers** that may be addressed by improved standards



Source: NIST - (Smart Grid Conceptual Model)

Project Team and Roles

NREL – Overall Lead, Inverters/PV
ANL - Automotive applications
LBNL - Responsive loads
SNL - Inverters/Energy storage
ORNL - Microgrids
PNNL - T&D automation, responsive loads

PROJECT FUNDING			
Lab	FY16 $	FY17$	FY18 $
NREL	$240,000	$240,000	$240,000
PNNL	$240,000	$240,000	$240,000
LBNL	$240,000	$240,000	$240,000
SNL	$160,000	$160,000	$160,000
ANL	$160,000	$160,000	$160,000
ORNL	$80,000	$80,000	$80,000
INL	$80,000	$80,000	$80,000
Total	$1,200,000	$1,200,000	$1,200,000

Industry Observers/Advisors/Partners

Bulk Electric System Operators
NY ISO | PJM

Utilities / Trade Groups
Duke Energy | TVA | Southern Co.
Oncor | Entergy | NRECA

Standards Development
IEEE | ASHRAE | SunSpec
SGIP | NIST

Trade Groups
EPRI | NRECA

Vendors & Manufacturers
Intel | Sunpower | Fronius
Enphase

Consulting/Academic
Enernex | MIT Lincoln Labs

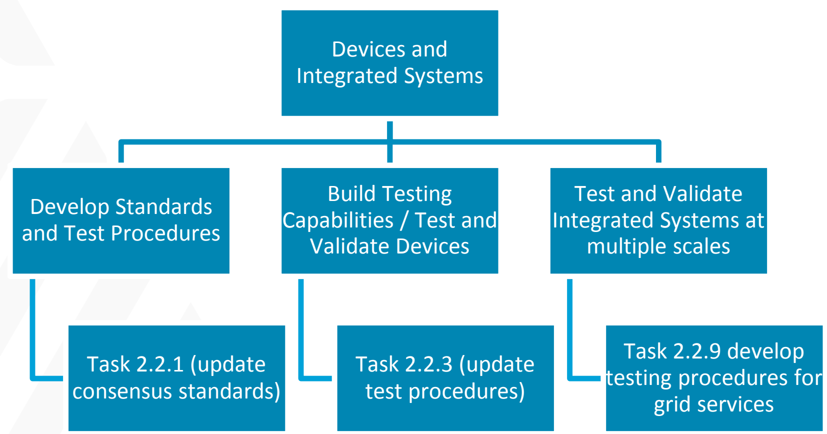
Standards and Test Procedures for Interconnection and Interoperability (GMLC 1.4.1)
Relationship to Grid Modernization MYPP

This project directly aligns with MYPP Activities

- Activity 2: Develop Standards & Test Procedures
- Activity 3: Build Testing Capabilities / Test and Validate Devices

Also aligns with:

- Activity 4: Test and Validate Integrated Systems at multiple scales
- Task 2.2.1: Update consensus interconnection standards
- Task 2.2.3: Update testing procedures for interconnection standards
- Task 2.2.9: Develop testing procedures for evaluating the ability of devices to provide grid services



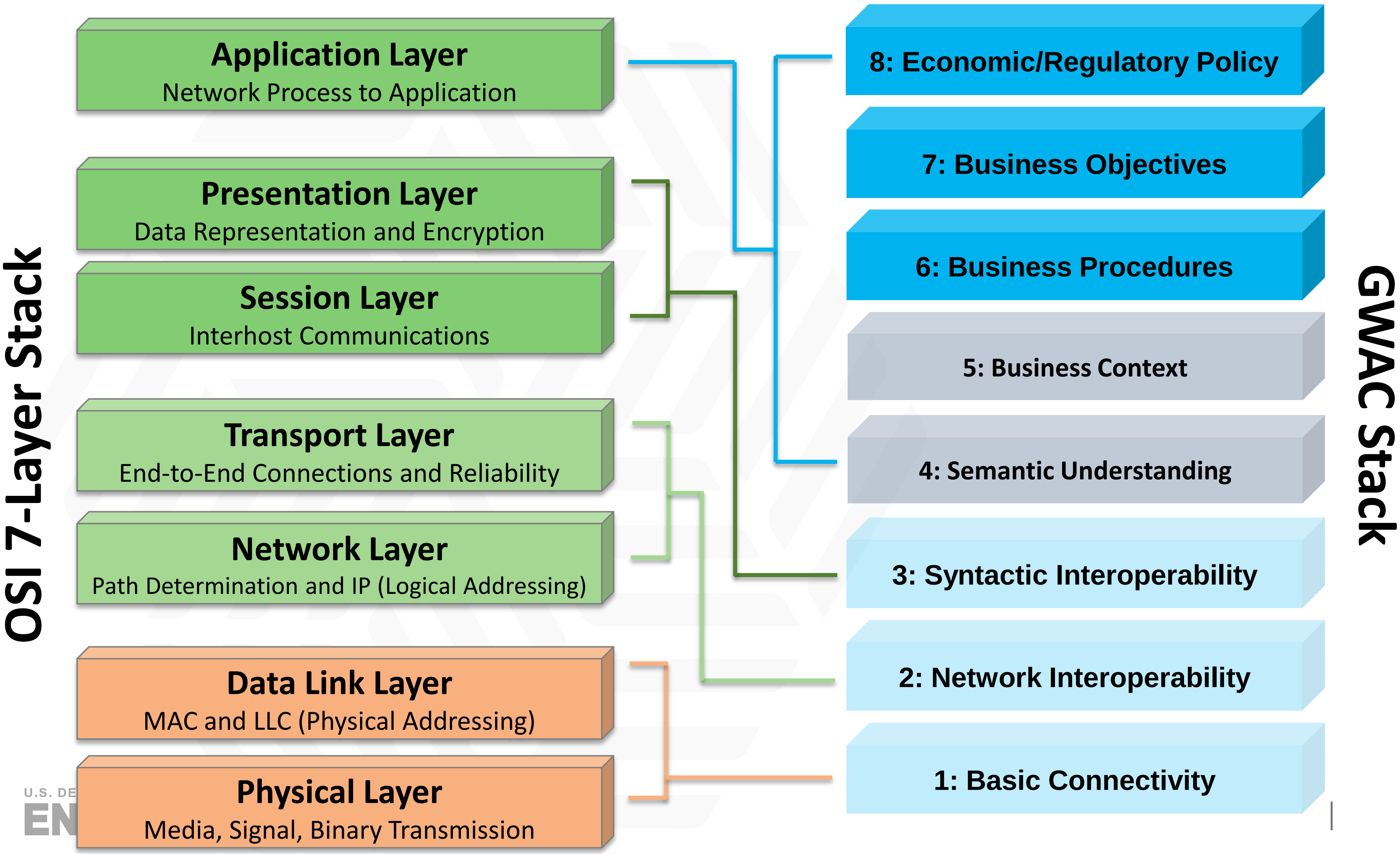
Approach

Task	Description	Key Issues
1.1	Conduct preliminary gap analysis	• Identification of relevant standards
1.2	Develop prioritization framework	• Focus on grid services (developed by GMLC 1.4.2) • Identify prioritization areas & score (market size, time to fill gap, locational urgency + resource relevance, technical difficulty
1.3	Initial standards coordination	• Identify specific standards to address

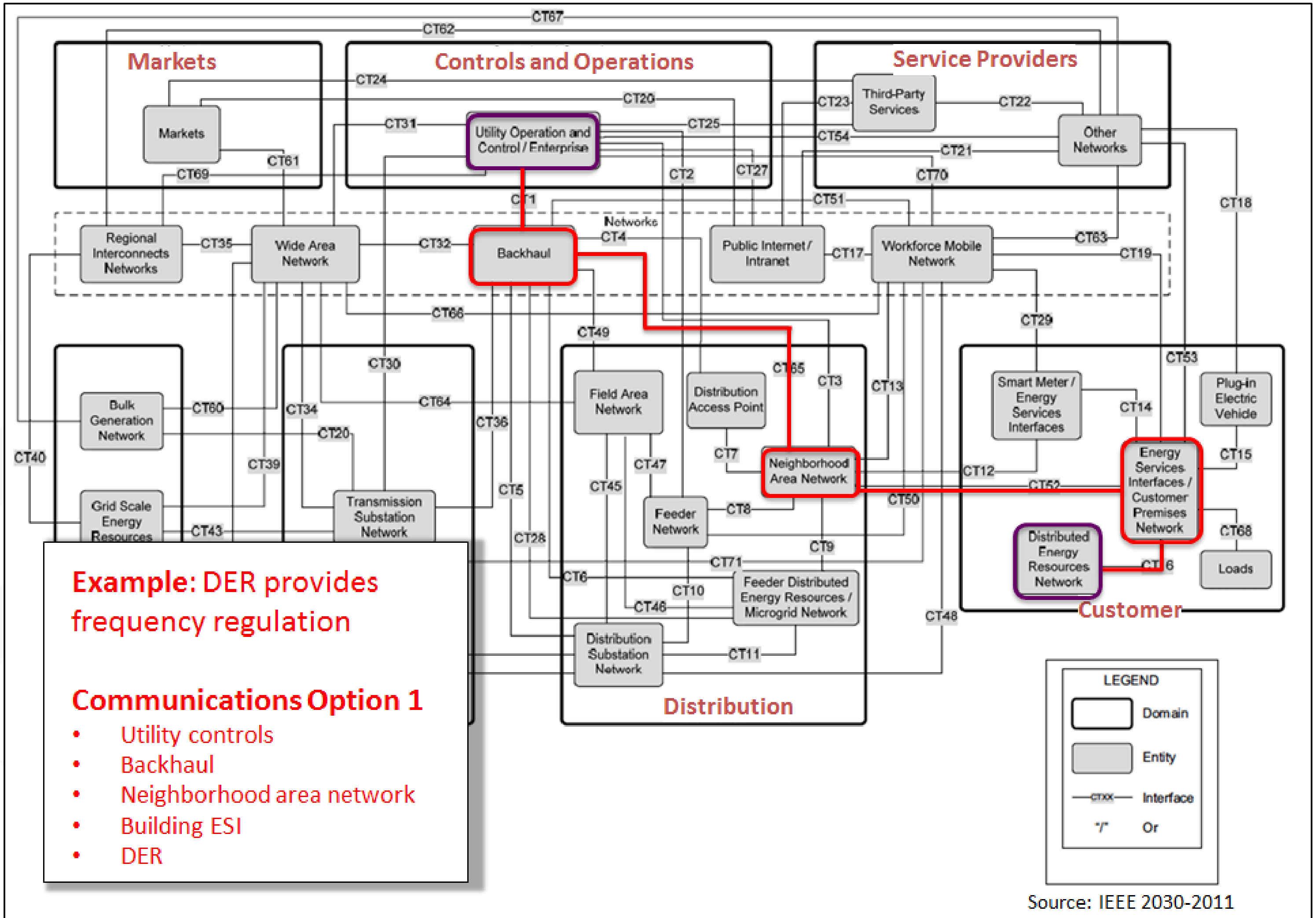
Standards and Test Procedures for Interconnection and Interoperability (GMLC 1.4.1)
Key Project Milestones

Milestone (FY16-FY18)	Status	Due Date
Preliminary gap analysis	Complete	9/30/16
Gap prioritization framework	Complete	2/28/18
Gap analysis recommendations	Complete	3/31/17
Year 1 Annual SMART Milestone Standards & codes forum	Delayed	4/1/17
Year 1 Annual SMART Milestone Annual report	In progress	4/1/17
Develop test procedures	Upcoming	Q2 2017
Validate test procedures	Upcoming	Q3 2017
Standards coordination	In progress	3/31/17 + throughout

Connecting Communications to Interoperability



Example of communicating grid service need from utility operations to customer-sited DER



Example: DER provides frequency regulation

Communications Option 1

- Utility controls
- Backhaul
- Neighborhood area network
- Building ESI
- DER

GWAC Stack Layer	Inverter-Based Systems (Generation and Storage)	Vehicles	Building Energy Management System (Responsive Loads, Generation)	Microgrids
6-8	• Grid service defined by policy or economic market (e.g., CA Title-24 DR requirements) • Grid service enabled as a business objective • Entity provides signal requesting grid service • DER/Building/Microgrid are able to respond to request for grid service • Device controls are defined for providing grid service			
5	• Data modeling relevant for providing a specific grid service			
4	• SunSpec Alliance PV Models • SunSpec/MESA Device Models • OpenFMB	• Vehicle data models	• OpenADR 2.0	• IEEE P2030.7 • IEEE P2030.8
3	• IEEE 2030.5 (SEP 2.0) • IEC 61850-90-7 • IEC 61850-7-420 • DNP3 • IEEE 2030.2 • IEEE 1547.3 • Modbus	• SAE J2847/3 (supports SEP2.0) • SAE J2847/2 •	• OpenADR 2.0 • ASHRAE 201 (FSGIM) • ASHRAE 135 (BACnet-WS) • IEC 14908 (LONmark) • IEEE 2030.5 • OBIX • OASIS EMIX • Modbus	• Modbus • TCP/IP • DNP3 Need Harmonization
2	• TCP/IP • ZigBee • DNP3 • Canbus	• TCP/IP • UDP • FTP • HTTP	• TCP/IP • DALI • ZigBee	• TCP/IP • DNP3 • Canbus
1	• Twisted Pair • CTA-2045 • IEEE 802.3 (Ethernet) • IEEE 802.11 (Wi-Fi) • IEEE 802.15.4 (Thread)	• Twisted Pair • CTA-2045 • IEEE 802.3 (Ethernet) • IEEE 802.11 (Wi-Fi) • SAE J1772 (PLC) • SAE J2931/4 (PLC) •	• IEEE 802.3 (Ethernet) • IEEE 802.11 (Wi-Fi) • IEEE 802.15.4 (Thread)	• Twisted Pair, RJ-45, CTA-2045 • IEEE 802.3 (Ethernet) • IEEE 802.11 (Wi-Fi) • IEEE 802.15.4 (Thread)
0	• IEEE P1547 • IEEE P1547.1 • UL1741 • IEEE 2030.2	• SAE J3072 (enables conformance to IEEE 1547.1) • SAE J2894-1 (PQ)	• N/A except for generation that needs to follow IEEE 1547	• IEEE 1547.4

Standards and Test Procedures for Interconnection and Interoperability (GMLC 1.4.1)
Accomplishments to Date – Gap Prioritization Summary

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	Inverter-Based Systems (Electric Energy Storage, PV Systems)				Electric Vehicles				Responsive Loads & Generation			
Grid Services	ENERGY	REG, RESERVE, RAMP	VOLTAGE MGMT	ARTIFICIAL INERTIA	ENERGY	REG, RESERVE, RAMP	VOLTAGE MGMT	ARTIFICIAL INERTIA	ENERGY	REG, RESERVE, RAMP	VOLTAGE MGMT	ARTIFICIAL INERTIA
Market size	0.72	0.72	1.00	0.20	0.40	0.32	0.20	0.00	0.76	0.76	0.76	0.28
Time to fill gap	0.83	0.83	0.83	0.17	0.50	0.33	0.20	0.03	0.23	0.17	0.17	0.17
Locational urgency & resource relevance	0.50	0.50	0.50	0.50	0.40	0.40	0.25	0.00	0.75	0.75	0.75	0.5
Technical difficulty	0.80	0.80	0.80	0.80	0.40	0.32	0.24	0.40	0.80	0.40	0.40	0.12
Gap Priority Score	0.71	0.71	0.78	0.42	0.43	0.34	0.22	0.11	0.64	0.52	0.52	0.27

low opportunity — high opportunity

Gap Prioritization Summary

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U.S. Department of Energy

Recommendations

Inverter DER

1. Affirm updates in forthcoming revision of IEEE 1547
2. Update DNP3, IEEE 2030.5, IEC 61850, and SunSpec/MESA Modbus protocol maps

Responsive Loads

1. Update OpenADR and ASHRAE standards
2. Explore capability and requirements for IEEE 2030.5 (SEP2)
3. Continue work on transactive energy for building/controllable loads
4. Explore the requirements for standardizing the energy services interface

Electric vehicles

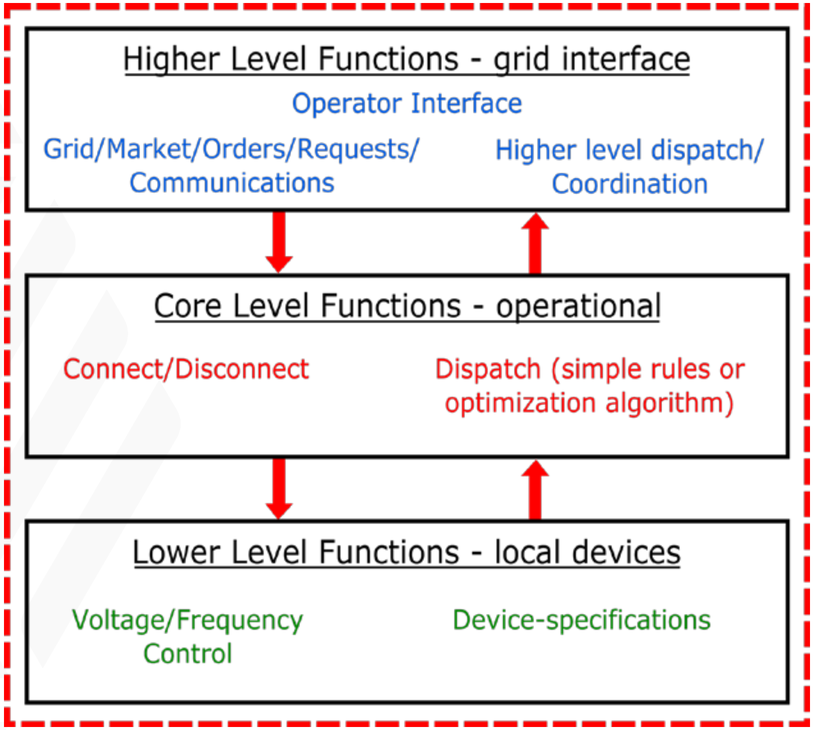
1. Update SAEJ3072

Additional Potential Gap Areas

1. Responsive equipment characterization for grid services information model
2. Cyber-physical security standard for grid-edge devices
3. Grid-responsive building standard (standardization of CA Title 24)

Standards and Test Procedures for Interconnection and Interoperability (GMLC 1.4.1) Accomplishments to Date

- Stakeholder Engagement
  - GMLC Workshop 9/2016 (Denver, CO)
  - SGIP 2016 Grid Summit 11/2016 (Washington, DC
  - GMLC workshop, 3/2017 (Atlanta, GA)
- Publications
  - Gap Analysis and Prioritization (3/2017)
- Lessons learned
  - Prioritization is important but not straight forward
  - Some key barriers are not technical
  - Some additional global gaps may need to be addressed in cases where no broad standards exist



Response to December 2016 Program Review

Recommendation	Response
Need a way to prioritize what to work on	The team has spend considerable time on developing a method to do this,. results are in.
Since IEEE 1547 is in the process of being updated, how do we engage with the IEEE process so they incorporate the cross-technology approach being used in this project?	IEEE 1547 is expected to enter balloting period in 2017, including a public comment period. This is a good opportunity to provide recommendations.
Please better define the industry observers/advisors/partners. Do not lump these all into one group. This project requires a lot of industry support.	Industry observers/advisors/partners have been better defined

Standards and Test Procedures for Interconnection and Interoperability (GMLC 1.4.1)
Project Integration and Collaboration

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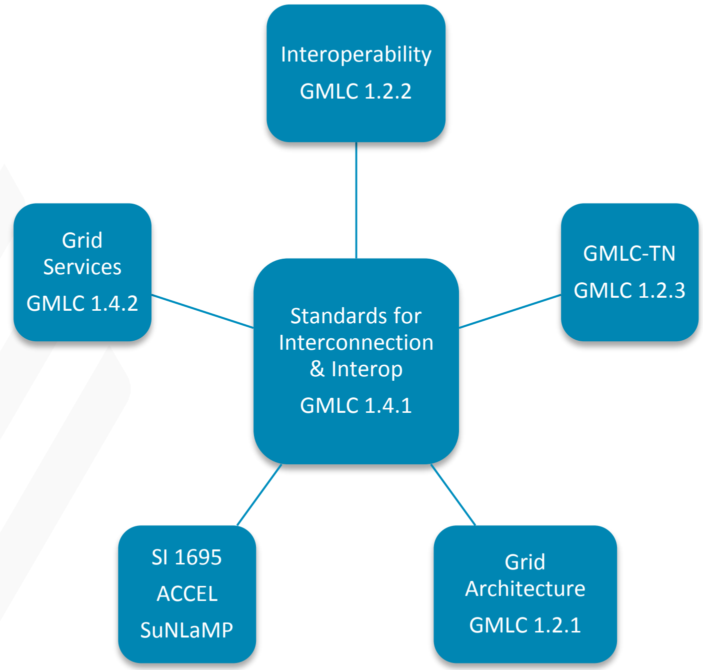
- Close coordination with GMLC 1.2.2 Interoperability Topic 1.2.2 team □overall interoperability strategic vision
- GMLC 1.4.1 team □near-term standards and test procedures
- Scenarios will be coordinated across Grid Services, and interoperability projects
- Test procedures may be housed with GMLC 1.2.3
- Will coordinate with ACCEL team to ensure efforts complement each other and do not overlap



Communications:

- GMLC Workshop 9/2016 (Denver, CO)
- SGIP 2016 Grid Summit 11/2016 (Washington, DC)
- GMLC workshop, 3/2017 (Atlanta, GA)

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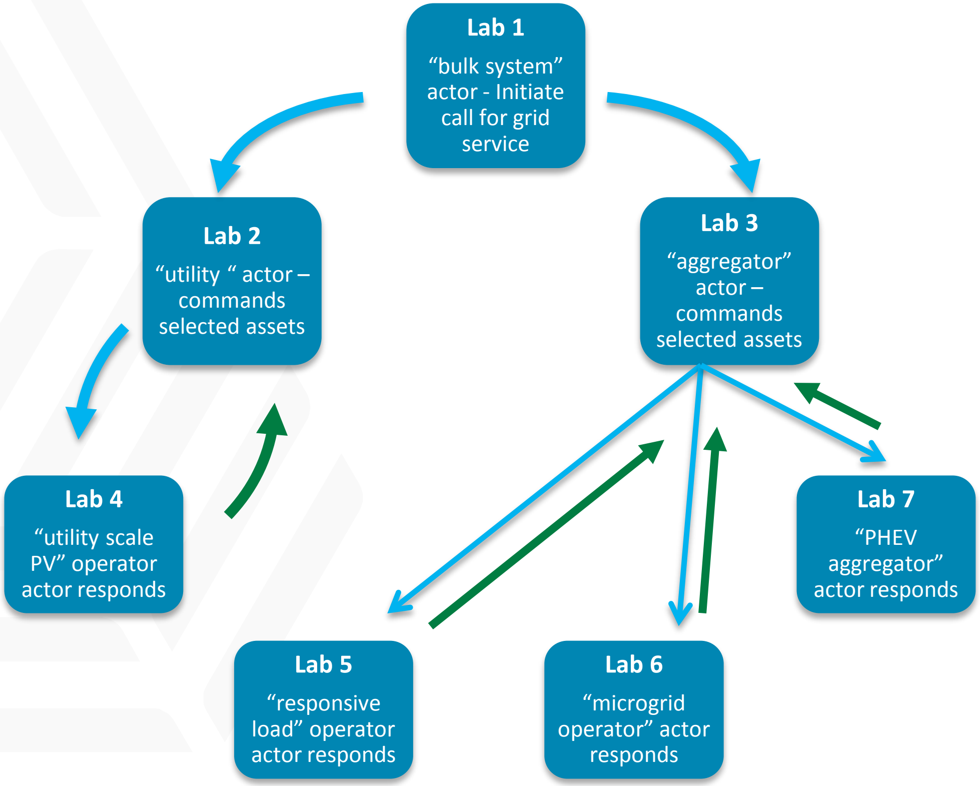
Next Steps

- Review feedback from stakeholders
- Recommendations to SDOs
- Decision on additional topic areas
- Identify focus for test procedures
- Development of demonstration to test end-to end execution of grid services by relevant grid edge devices
  - Utilizes DOE laboratory assets to show state of the art in standards and to identify gaps
  - Provides exercise of grid service concepts as well as devices



Concept of proposed demonstration of end-to-end grid service command and execution

Grid Modernization Initiative Peer Review

GMLC 1.4.2 – Definitions, Standards and Test Procedures for Grid Services from Devices

ROB PRATT

April 18-20, 2017

GMLC Peer Review Meeting
Sheraton Pentagon City – Arlington, VA

Definitions, Standards and Test Procedures for Grid Services from Devices (GMLC 1.4.2) – High Level Summary

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U.S. Department of Energy

Project Description

Develop characterization test protocol and model-based performance metrics for devices' (DERs') ability to provide a broad range of grid services, i.e., to provide the flexibility required to operate a clean, reliable power grid at reasonable cost.

Value Proposition

- ✓ ***Reward innovation,*** help manufacturers understand opportunities, enlarge the market for devices
- ✓ ***Validated performance & value for grid operator decisions*** on purchases, programs, subsidies, rebates, markets, planning, operations
- ✓ ***Independently validated information for consumers & 3rd parties*** for purchase decisions

Project Objectives

- ✓ **Simple, low-cost testing protocols** manufacturers can use to characterize equipment performance (*Recommended Practice*)
- ✓ **General, standard device model reflecting test results** for each device class
- ✓ **Proven means of estimating performance metrics** for a **standard set of grid services** from the test results
- ✓ **Protocol that can be regionalized** to reflect local markets, new services, weather, loads, etc.

Definitions, Standards and Test Procedures for Grid Services from Devices (GMLC 1.4.2) – Project Team

Project Participants and Roles			Project Funding			
Laboratory	**Device Class**	**Grid Services**	**FY16**	**FY17**	**FY18**	**Total**
Pacific Northwest National Laboratory	1. Thermal storage	A. Peak load management B. Artificial inertia/fast frequency response	$351K	$440K	$401K	$1,191K
National Renewable Energy Laboratory	3. Water heaters 4. Refrigerators 5. PV/inverters	C. Distribution voltage management / PV impact mitigation	$226K	$481K	$409K	$1,116K
Sandia National Laboratory	6. Batteries/ inverters		$106K	$323K	$274K	$703K
Argonne National Laboratory	7. Electric vehicles (DR, V2G)	D. ISO capacity market (e.g., PJM's)	$141K	$288K	$246K	$675K
Oak Ridge National Laboratory	8. Res. & Com. HVAC 9. Com. refrigeration		$146K	$588K	$481K	$1,215K
Lawrence Berkeley National Laboratory	10. Commercial lighting	E. Regulation F. Spinning reserve G. Ramping	$211K	$263K	$226K	$700K
Idaho National Laboratory	11. Fuel cells 12. Electrolyzers		$146K	$313K	$266K	$725K
Lawrence Livermore National Laboratory		H. Wholesale energy market/production cost	$94K	$35K	$48K	$177K
Totals			$1,420K	$2,731K	$2,350K	$6,500K

Definitions, Standards and Test Procedures for Grid Services from Devices (GMLC 1.4.2) – Relationship to Grid Modernization MYPP

GRID MODERNIZATION INITIATIVE
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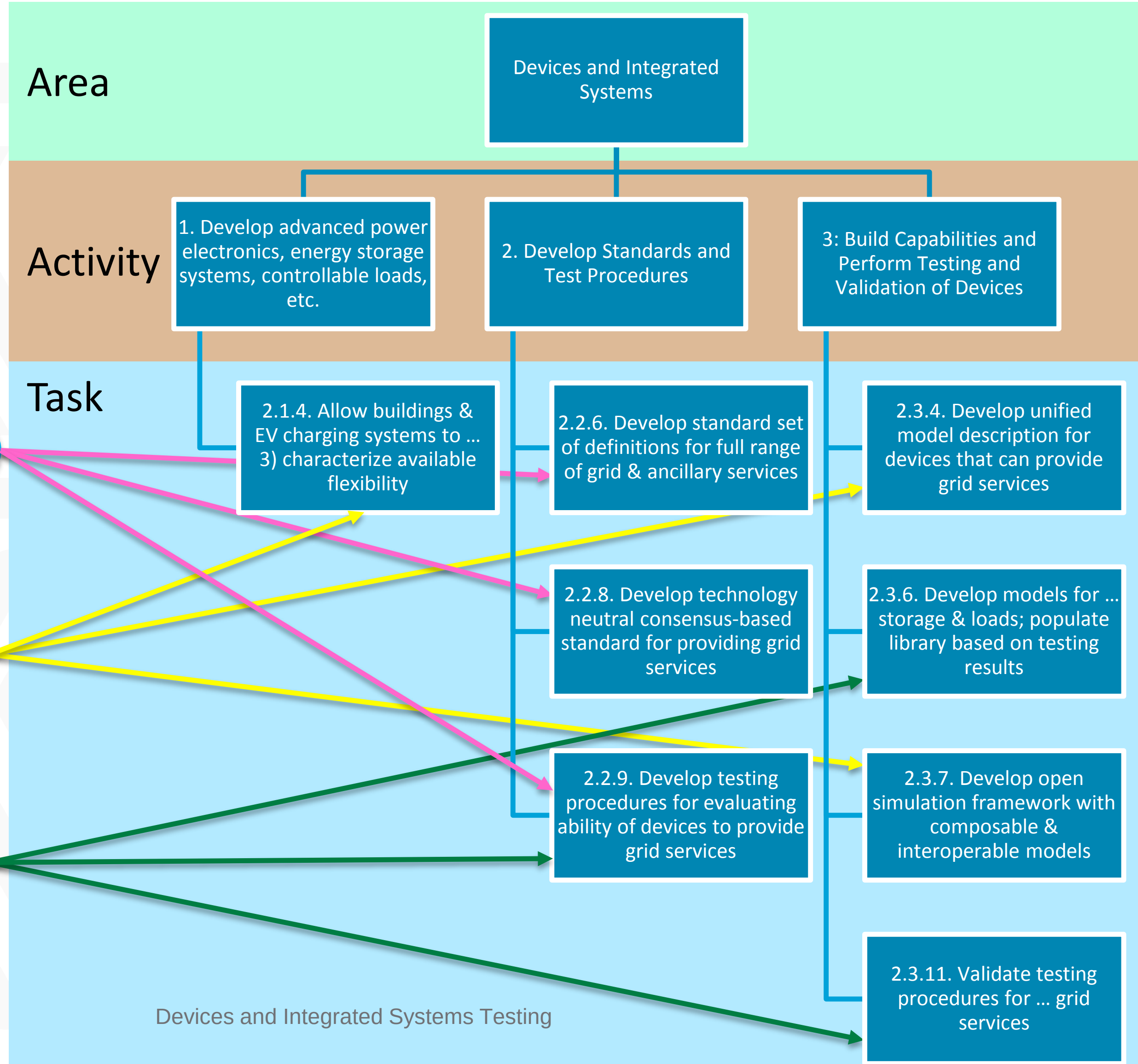
✓ *Project is **central to a number of tasks in the Devices and Integrated Systems MYPP: grid services, unified models, testing procedures** and contributes to many more.*

Definition of grid services & representative drive cycles

Battery equivalent model defines flexibility, unifies DR & DER models

Device models & validation test results contribute to testing library



Definitions, Standards and Test Procedures for Grid Services from Devices (GMLC 1.4.2) – Approach

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Characterization Protocol

- Measure device fleet parameters describing ability to provide grid services
- Simple, short (<24-hr, inexpensive) procedure, complementing existing test protocols:
  How much, how fast, how long, time lags, etc.

Model Device Fleet

- Time series model of device fleet performance
- Based on measured parameters
- Base case end-use load that must be served
- User and device limitations and requirements
- Express as battery equivalent parameters to grid services model
- Measures of consumer and device impacts

Define Grid Service

- Definition and purpose
- Requirements of providing devices
- Representative time-series "drive-cycle" of the service

Grid Service Dispatch Model

- Scale fleet of identical devices to service based on nominal power of devices and peak power required by service
- Simple, direct control of battery-equivalent fleet of identical devices

Performance Metrics

- Grid service performance metrics
- Consumer impacts (energy, comfort, amenity)
- Device impacts (cycles/yr, etc.)

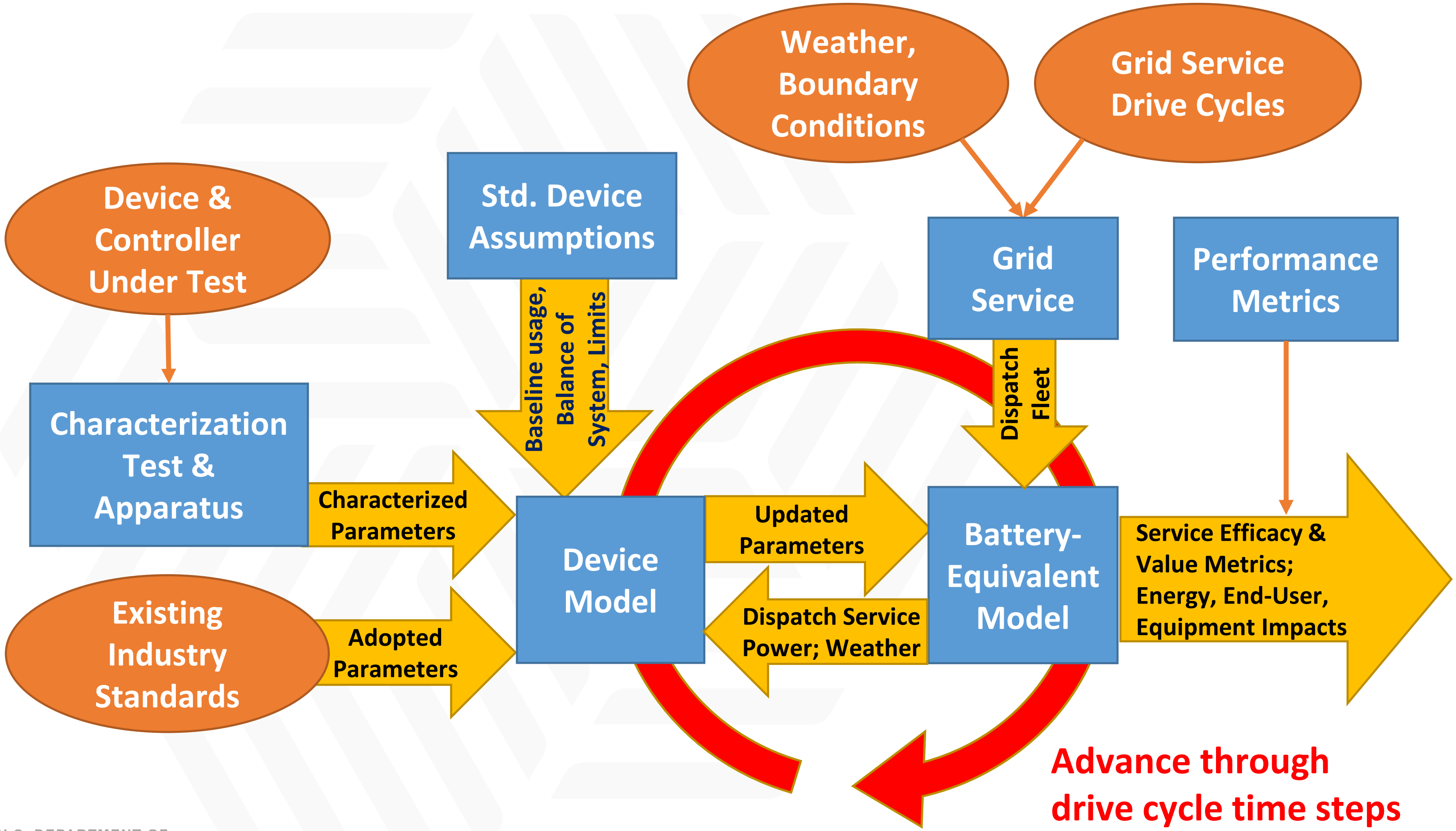
Key Challenges: 1) General battery equivalent model for all devices/services, 2) Modular design & assumptions allow regionalization

Definitions, Standards and Test Procedures for Grid Services from Devices (GMLC 1.4.2) – Key Project Milestones

Milestones* (FY16-FY18)	Status	Due Date
1. **Standard definitions & drive cycles for grid services** (draft for industry review) 2. **General device model** (draft for industry review)	**1. Complete** **2. Complete**	**October 1, 2016**
3. **Extrapolation procedure for performance of grid services**	**3. Complete**	**April 1, 2017**
4. **Draft *Recommended Practice*** (vetted with industry)	**4. Underway**	**October 1, 2017**
5. **Trials of device characterization protocols** (for each device class) 6. **Manufacturers review of characterization protocol & test results**		April 1, 2018
7. **Proof-of-concept testing validates extrapolation procedure**		October 1, 2018
8. **Stakeholder group consensus that *Recommended Practice* is useful & accurate**		April 1, 2019

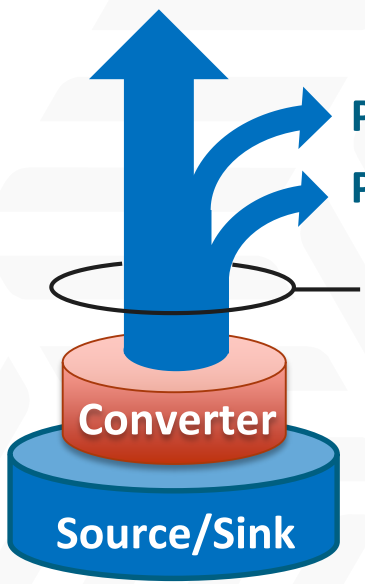
Definitions, Standards and Test Procedures for Grid Services from Devices (GMLC 1.4.2) – Accomplishments

General Framework and Approach



Define Generic Devices: Power Flows & Services

Power injected into grid (P_{Grid})



Power to end use (P_{EndUse}) +

Parasitic power ($P_{Parasitic}$)

Power from source/sink:
- Power output from generator (P_{Output}) +
- Power discharged from storage ($P_{Discharge}$)

Power Balance:

$$P_{Grid}(t) = P_{Output}(t) + P_{Discharge}(t) - P_{Enduse}(t) - P_{Parastic}(t)$$

Power for Grid Service:

$$P_{Service}(t) = P_{Grid}(t) - P_{GridBase}(t)$$; where *Base* indicates base case

$$P_{Service}(t) = \Delta P_{Discharge}(t) + \Delta P_{Output}(t) - \Delta P_{Enduse}(t) - \Delta P_{Parasitic}$$

; where Δ is the difference between the service case & base case

Definitions, Standards and Test Procedures for Grid Services from Devices (GMLC 1.4.2) – Response to Dec. 2016 Program Review

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Recommendation	Response
This project needs a lot more support from industry. The meeting in March 2017 is critical.	**Organized series of webinars & briefings** to raise awareness leading up to 2nd Industry Workshop: • GridWise Alliance pre-workshop webinar (n = 35*) • Commercial lighting webinar (n = 27*) • PV/batteries/inverters webinar (n= 321*) • HVAC & appliances webinar (n=21*) • Thermal energy storage briefings (n = 2*) • Electric vehicle industry meeting presentation (n = 13*) • More webinars to come in April (fuel cells/electrolyzers) **Partnered with the GridWise Alliance to host 2nd Industry workshop** with sponsors GE & Intel @ GE's GridIQ Center in Atlanta GA March 21-22, 2017 (n = 36*) * Count excludes DOE and national laboratory participants

✓ **Project has raised industry awareness of the project dramatically in Q1&2 FY17**

Definitions, Standards and Test Procedures for Grid Services from Devices (GMLC 1.4.2) – Project Integration and Collaboration

GRID MODERNIZATION INITIATIVE
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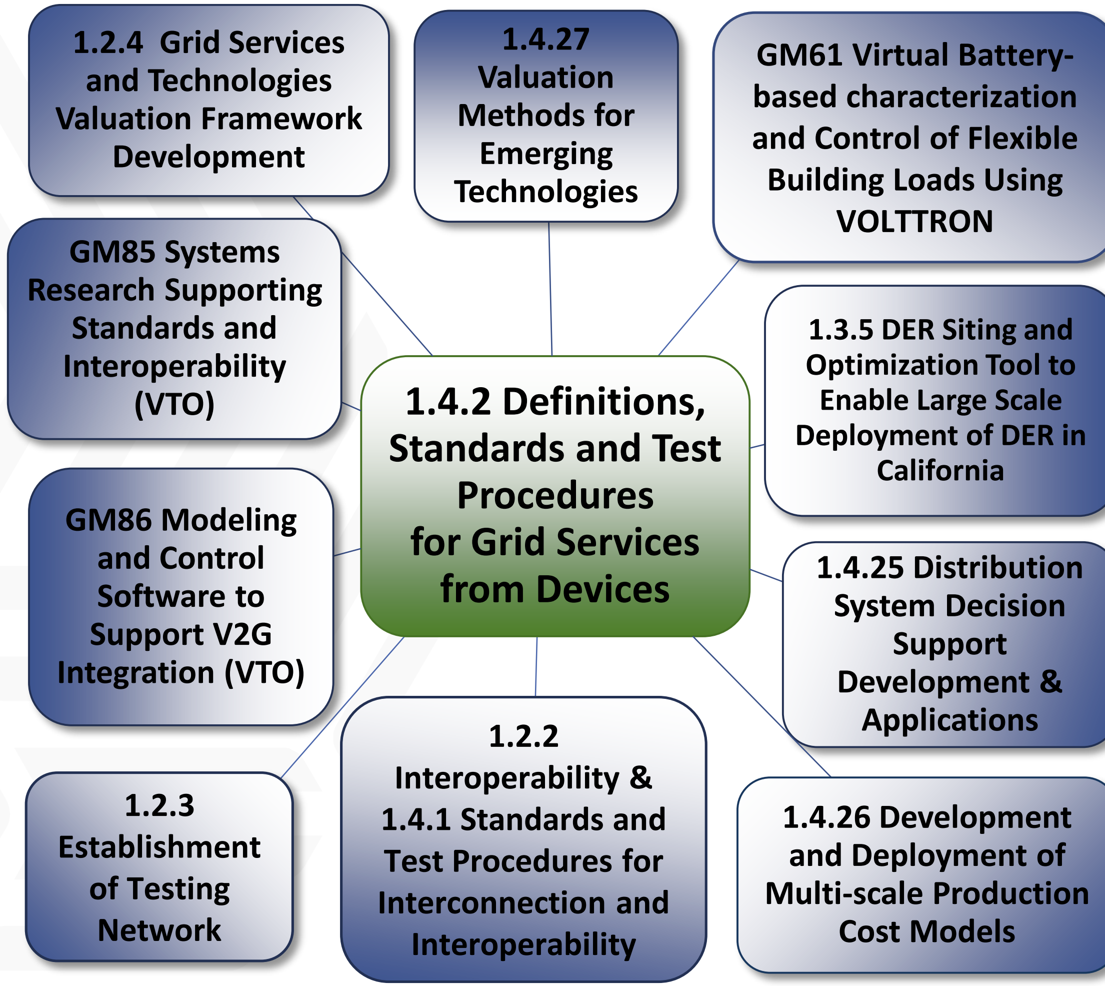
Relationship to Other GMLC Projects

- ✓ Defining grid services, & metrics for grid services are value based (1.2.4 & 1.4.27)
- ✓ Use virtual battery concept as common device model interface to each grid service (GM61)
- ✓ Device models & grid service performance models useful for long-term planning (1.3.5, 1.4.25 & 1.4.26)
- ✓ Interoperability & Interconnection (1.2.2 & 1.4.1)
- ✓ Test procedures, data, & device models delivered to GMLC Testing Network's test procedure repository library (1.2.3)
- ✓ Leverage testing & interoperability for electric vehicles (GM85 & GM86)

Engagements

- ► 1st Industry Workshop – 9-12-17, NREL
- ► 2nd Industry Workshop – 3-21/22-17, Atlanta
- ► 4 device-class & services webinars – Mar '17



Definitions, Standards and Test Procedures for Grid Services from Devices (GMLC 1.4.2) – Next Steps and Future Plans

This project is about

- **Enhancing**
- **Empowering**
- **Unlocking**
- **Unleashing**

the value of grid modernization devices everywhere!

Oct-'17: **Draft *Recommended Practice*, vetted by utility & device industries**

Apr-'18: **Test rigs & trials of characterization protocol, each device class**

Apr-'19: **Proof-of-concept testing of measured device performance against actual grid services**

Impact:

- ✓ Std. performance, value & impact metrics for devices providing grid services
- ✓ Reward innovation, sell more devices
- ✓ Better decision-making by consumers, utilities, 3rd parties
- ✓ Lower cost, more reliable, cleaner grid

Expansion Potential:

- ✓ Battery equivalent interface as a modeling standard
- ✓ Allows detailed, state-of-the-art device models to plug & play into planning and operation tools

Backup Slides

Definitions, Standards and Test Procedures for Grid Services from Devices (GMLC 1.4.2) – Data Flow between Device Model and Grid Service: the Battery Equivalent Model

Device Model

Inform Service of Constraints

Nameplate capacity
Energy storage capacity
Energy stored
Charging efficiency
Discharging efficiency
Maximum power for service
Minimum power for service
Ramp rate power up
Ramp rate power down
Time limit, hold
Time, restoration
Strike price
Price elasticity
Power injected into grid, basecase

Grid Service

Initiate exchange for time interval

Current time
Time interval
Weather data

Dispatch the service for time interval

Power delivered for service
Power injected into grid

Step 1 (Grid Service → Device Model): Initiate exchange for time interval

Step 2 (Device Model → Grid Service): Inform Service of Constraints

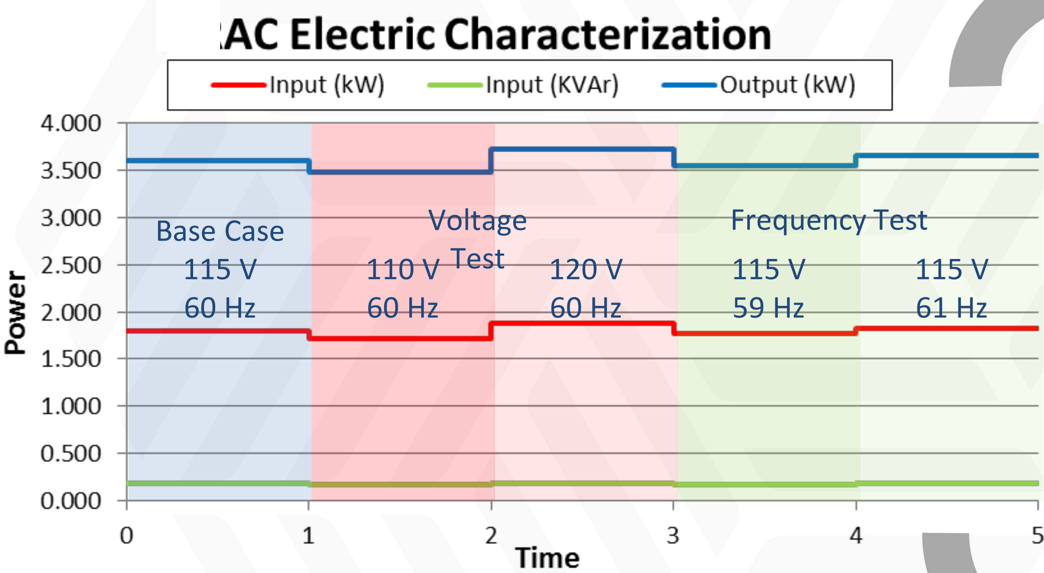
Step 3 (Grid Service → Device Model): Dispatch the service for time interval

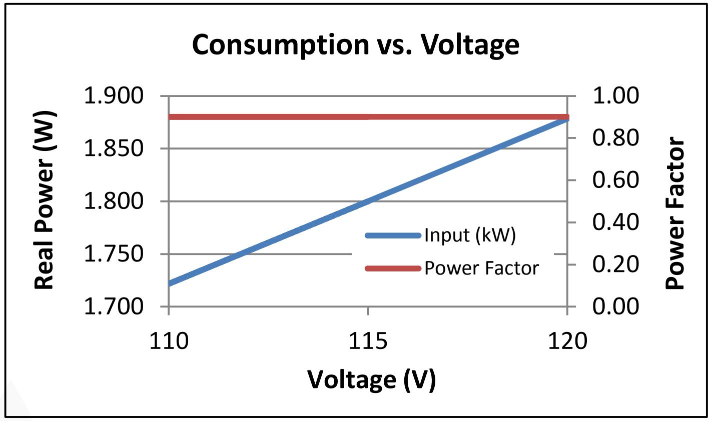
Definitions, Standards and Test Procedures for Grid Services from Devices (GMLC 1.4.2) –

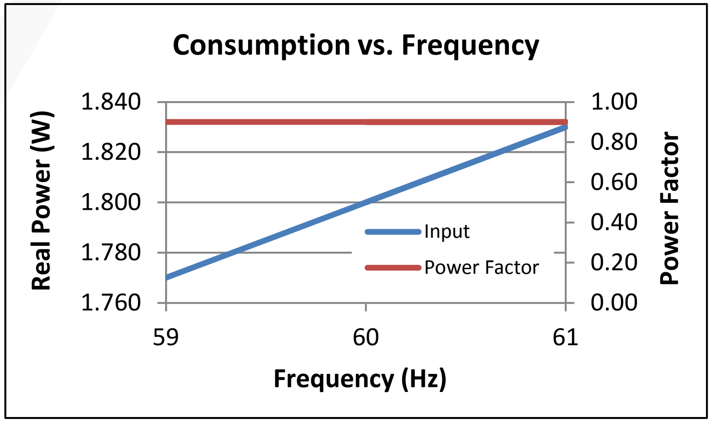
Design Principles & Functional Objectives

- Test protocol simplicity
  - Short duration, low cost
  - Leverage/complement existing standards
- Test once, rate many
  - Extrapolate test results to grid service via device model
  - Allow new services to be defined, rated
- Device performance as member of a fleet
  - Individual devices may not have fidelity required for a service
- Uniformity across device classes & grid services
  - Common dispatch & performance metrics agnostic to device type
  - Normalize performance to device nameplate capacity
- Support customized assumptions to reflect a region
  - Weather, balance of plant, baseline usage assumptions
  - Grid service “drive-cycle” patterns & values & value streams

Purpose: Determine fundamental electrical properties of device & any autonomous responses

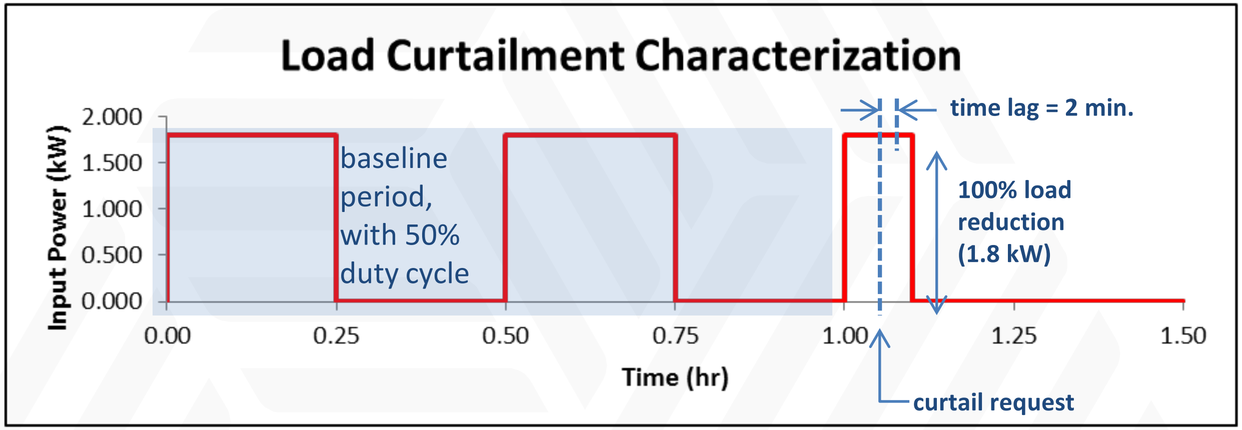






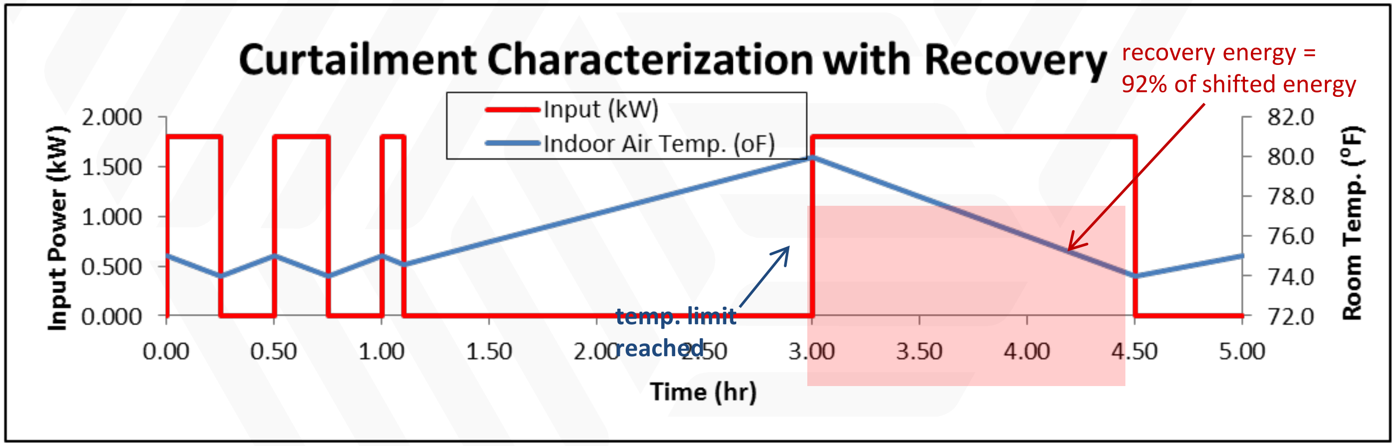
Definitions, Standards and Test Procedures for Grid Services from Devices (GMLC 1.4.2) – 2. Load-Curtailment Characterization Test for an Air Conditioner (Example)

Purpose of test: Characterize curtailment capabilities: e.g., amount of power curtailed, time lag, effect on energy consumption, etc.



Metrics

- Absolute load reduction
- % load reduction
- Time lag from request to curtailment



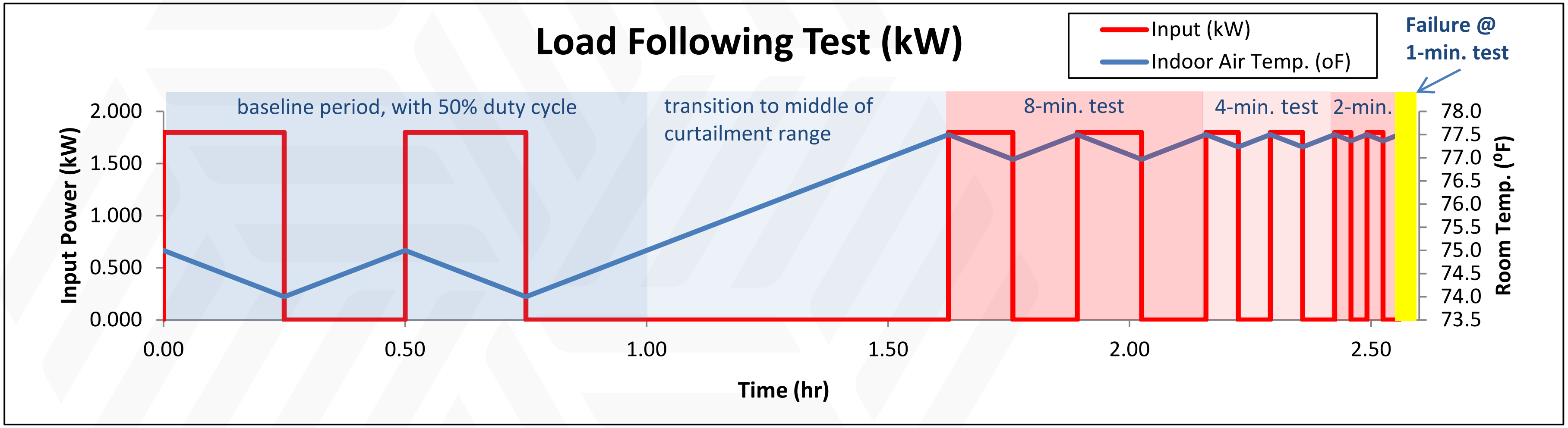
Metrics

- 92% recovery energy
- 5°F temp. rise limit
- 5-hr mode time limit (not shown)

Definitions, Standards and Test Procedures for Grid Services from Devices (GMLC 1.4.2) – 3. Load-Following Characterization Test for an Air Conditioner (Example)

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

Purpose of test: Characterize load following capabilities, i.e., ability to follow load-up/load-down signals at increasingly short intervals (for ancillary services, renewables integration, etc.)



<u>Example Metrics</u>

- **104% recovery energy (not shown)**
- **100% load following, down 2-minute intervals**
- **Time lag (2-min)**