ENERGISE Program Kickoff

DOE Award #: DE-EE0008000

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

GO-Solar: Grid Optimization of Solar

Yingchen Zhang & **Bryan Palmintier**

National Renewable Energy Laboratory

Topic 2: 2030 Target

October 11, 2017
Washington, DC

Project Team

Name	Org.	Role	Main Responsibilities
Yingchen Zhang	NRE:	Co-PI	• Overall project management • Lead the technology development and HIL testing tasks
Bryan Palmintier	NREL	Co-PI	• Lead the large-scale simulation and value analysis tasks
Andrey Bernstein	NREL	Key Contributor	• Development of online multi-objective optimization
Rui Yang	NREL	Key Contributor	• Development of predictive state estimation
Maurice Martin	HECO	Key Contributor	• Lead the cybersecurity and interoperability task
Colton Ching	HECO	HECO Lead	• Stakeholder engagement
Kenneth Fong	HECO	HECO Contributor	• Implementation/integration guidance
Marc A. Asano	HECO	HECO Contributor	• Technical monitoring
Ryan Kadomoto	HECO	HECO Contributor	• Utility system model and data gathering

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

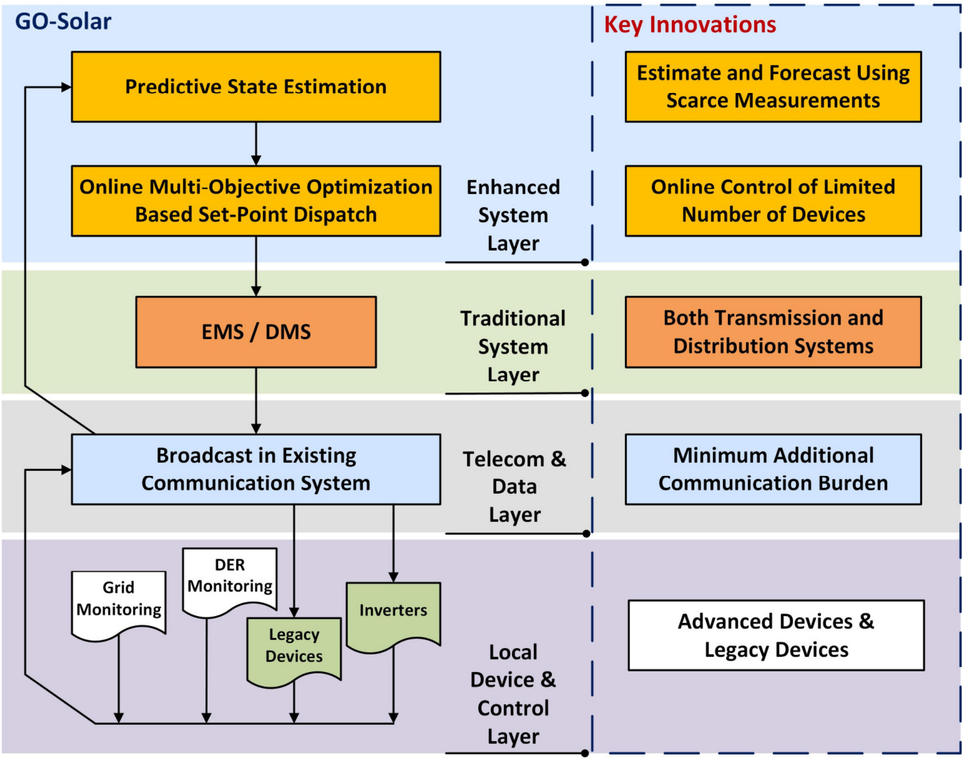
- Technology development
- Modeling and simulation
- Testing and validation
- Implementation and dissemination

Hawaiian Electric
Maui Electric
Hawai'i Electric Light

- Data and models
- Technical monitoring
- Implementation/integration guidance
- Simulation and testing review
- Evaluation

Project Goals

Proactively manage extreme penetrations of distributed solar and other DERs using only a **few measurement points** as input through **predictive state estimation (PSE)** and a **only few outputs** through carefully selected control nodes identified and dispatched through **online multi-objective optimization (OMOO)**.



The Challenge

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- Traditional operations cannot support extreme penetrations of distributed generation from solar PV (DGPV):
  - Unprecedented uncertainty
  - Supply-demand imbalance
  - Large reserve margins
  - Voltage management challenges
  - Interactions with existing equipment

- Difficult to communicate with and control millions of DERs:
  - Expensive communication infrastructure
  - Optimization Scalability
  - State-of-the-art EMS/DMS too slow for PV transients

Opportunity

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- DGPV & DER Device Revolution:
  - Fast control response
  - Explosion of measurement points
  - Local automation
- Recent Algorithmic breakthroughs:
  - Machine learning
  - Decomposable optimization
  - Tight convex relaxations
- Pervasive communication systems
- Emerging transmission-distribution mutual awareness

Opportunity & Lingering Gaps

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- DGPV & DER Device Revolution:
  - Fast control response — How to access?
  - Explosion of measurement points — Too many?
  - Local automation — System-level support?
- Recent Algorithmic breakthroughs — Power Systems Application?
  - Machine learning
  - Decomposable optimization — Scalability
  - Tight convex relaxations
- Pervasive communication systems — Diverse & Unconsolidated
- Emerging transmission-distribution mutual awareness — How to mutually benefit?

GO-Solar Approach

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

System awareness using only a few measurement points as input through *predictive state estimation* (PSE)

Near-optimal real & reactive dispatch using only a few outputs through *online multi-objective optimization (OOMO).*

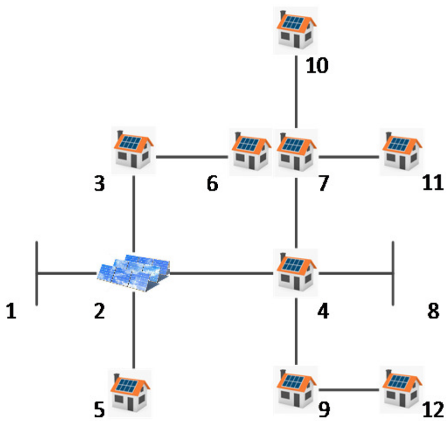
Through a software platform that empowers utilities to seamlessly dispatch **both legacy devices and DERs** and achieve system-wide performance and reliability targets

… To enable **extreme solar futures** with >> 100% capacity

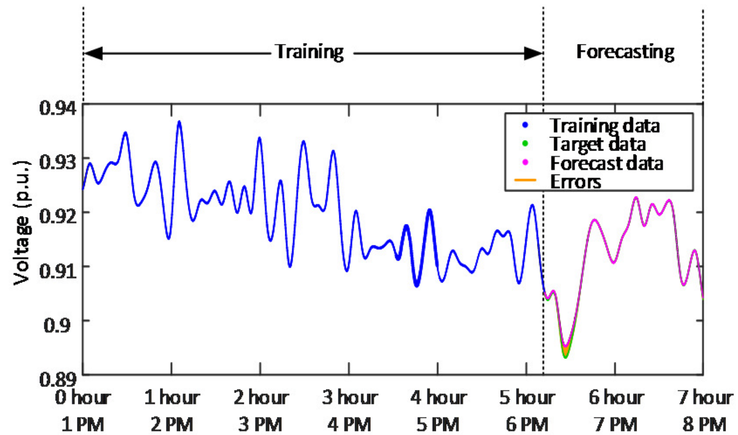
And help meet **Hawaii's 100% renewable energy** by 2045

Major Innovations: **PSE**
Predictive State Estimation

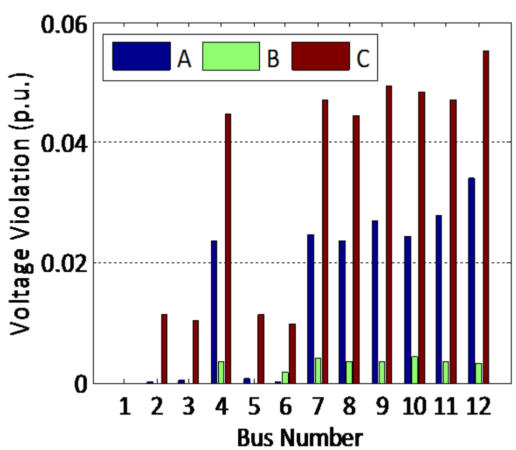
Goal: Use machine learning to forecast near-future system states



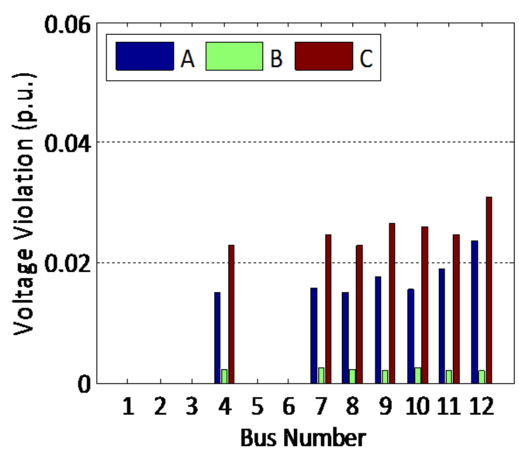
(a)



(b)



(c)



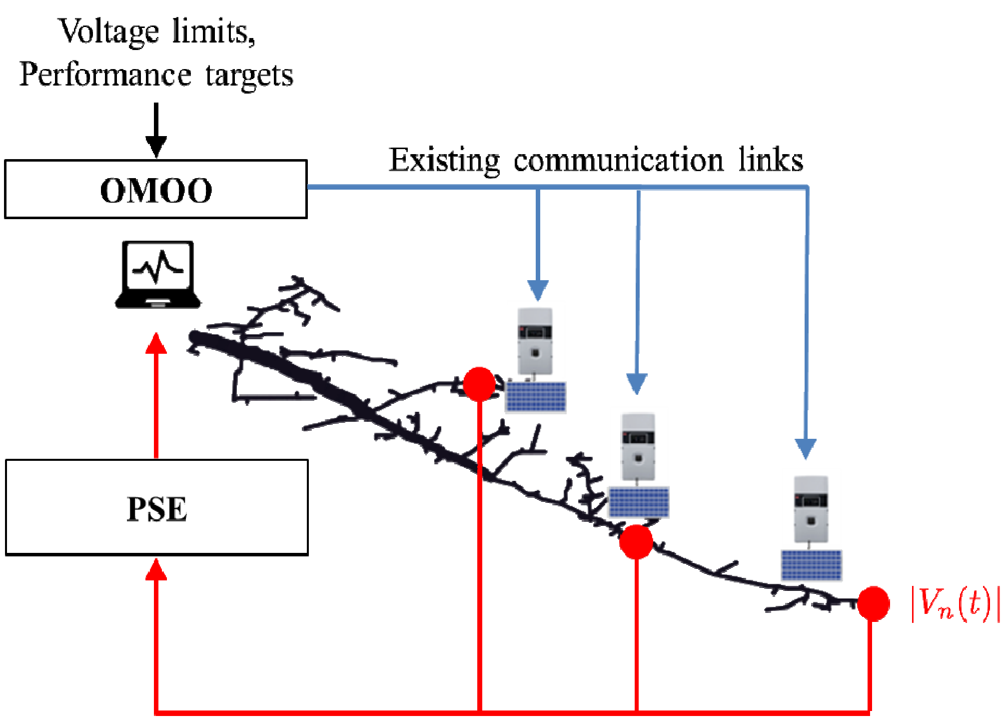
(d)

- Heterogeneous measurements
  - SCADA
  - Nonconventional
- Few measurements:
  - Incomplete observability
- Machine learning
  - Model-free
  - Deep learning
- Builds on recent NREL algorithm developments
- Enables proactive dispatch

Major Innovations: **OMOO**
On-line multi-objective optimization

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Goal: AC OPF dispatch with a small number of both legacy and fast-response devices



- Fast near-optimal AC dispatch
  - Gradient & project methods
  - System-wide
- On-line selection of subset of devices to control
  - New DER devices
  - Legacy devices
- Adaptive to grid changes
- Tunable multi-objective weighting
  - Utility
  - DERs
- Scalability
  - Parallelization
  - Decomposition

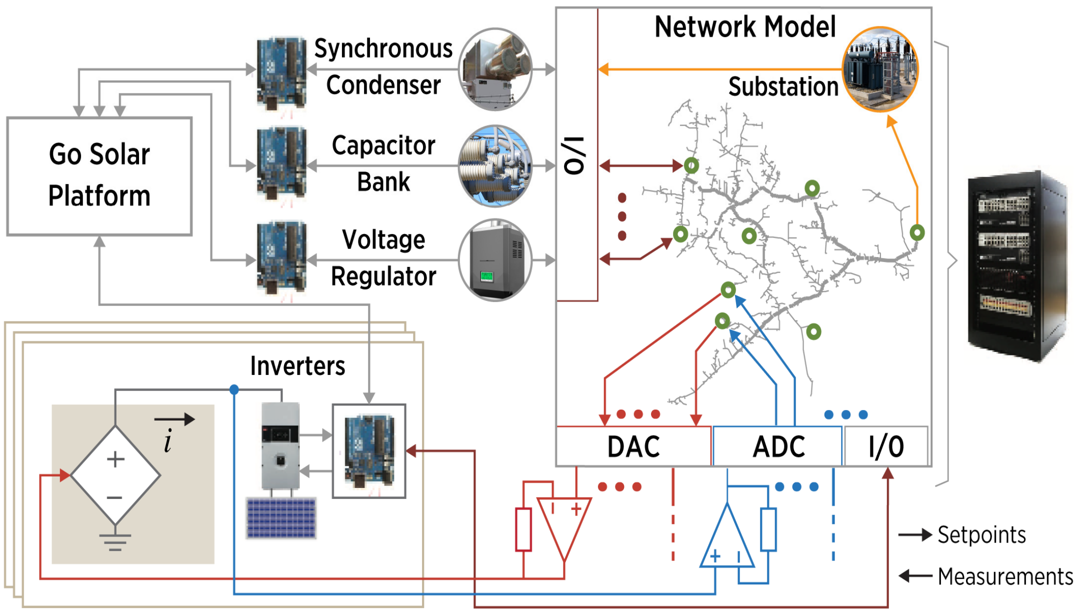
Main Project Tasks/Subtasks

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- ❖ Task 1: Initial Data Collection
  - Full T+D system data for Oahu
- ❖ Task 2: Technology Development
  - PSE + OMOO Algorithms
- ❖ Task 3: Demonstration with Hardware-in-the-Loop Testing
  - In ESIF, first CHIL, then CHIL + PHIL with 100+ devices
- ❖ Task 4: Validation with Large-Scale Simulation
  - IGMS-HELICS, ~1M node T+D+Controls QSTS simulation
- ❖ Task 5: Value Analysis
  - Cost/benefit with/without GO-Solar based on large-scale runs
- ❖ Task 6: Cybersecurity and Interoperability
- ❖ Task 7: Stakeholder Engagement and Technology to Market

Key Task: Hardware-in-the-Loop (HIL) Testing

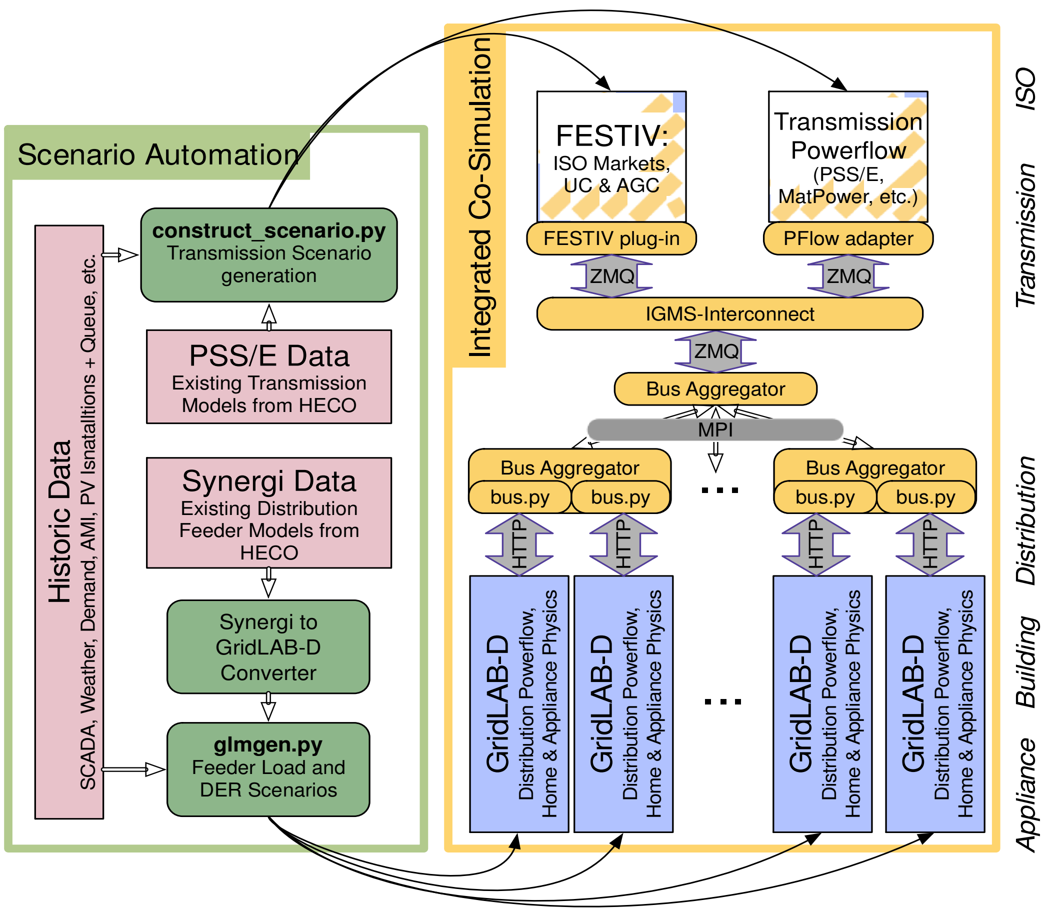
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy



- Full GO-Solar software with actual hardware devices
  - 100+ hardware devices
  - Mix of Power HIL (PHIL) and Controller HIL (CHIL)
  - Combined with larger power system simulation
- Multiple scenarios based on portions of actual HECO system
  - Routine, contingency, and futuristic operations
- Leverage existing NREL testbeds in ESIF

Key Task: Large-Scale Simulation

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

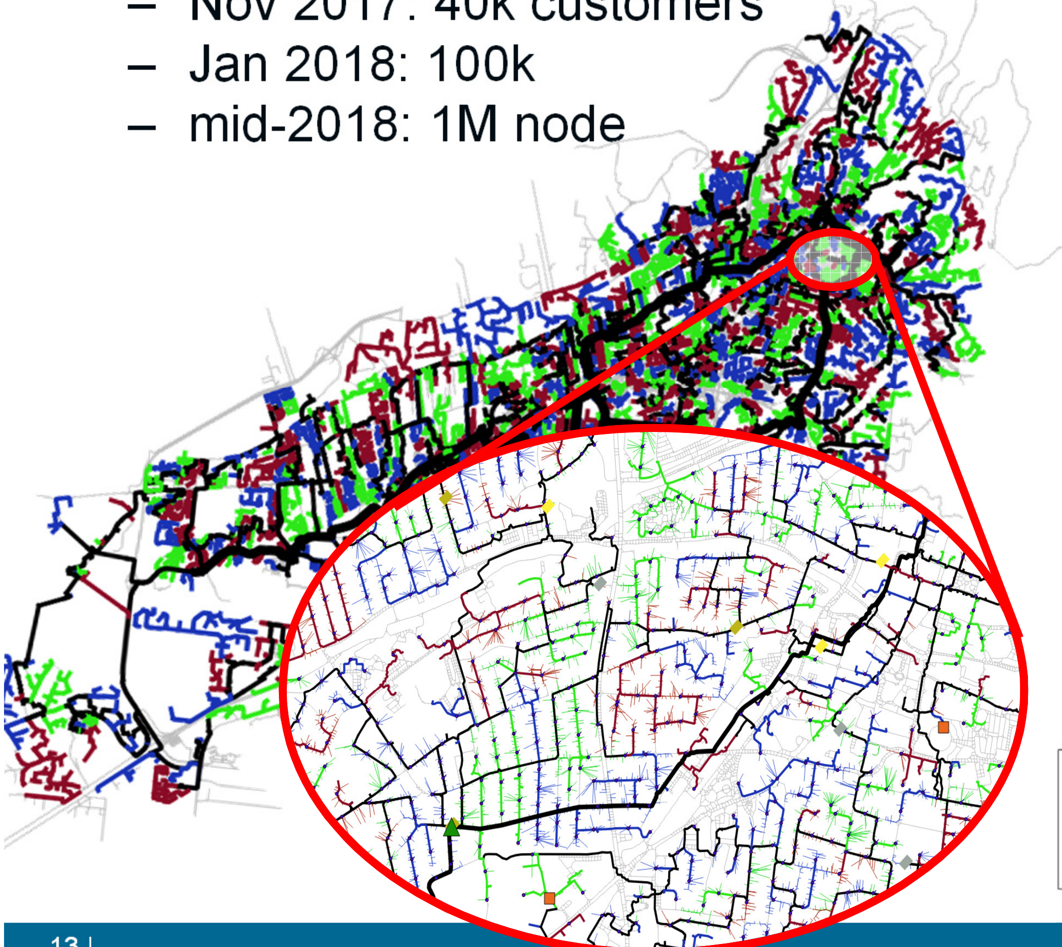


- Full-scale representation of HECO's Oahu power system
  - Integrated T&D
  - Intelligent devices
- Integrated Grid Modeling System (IGMS)
  - > 1 million nodes test systems running now
  - Upgrading to use HELICS co-simulation core (from GMLC TDC project)
- Actual HECO system model & historic EMS data
- Larger systems? Mainland?
  - Synthetic distribution models from NREL's Smart-DS project (ARPA-E GRID DATA)

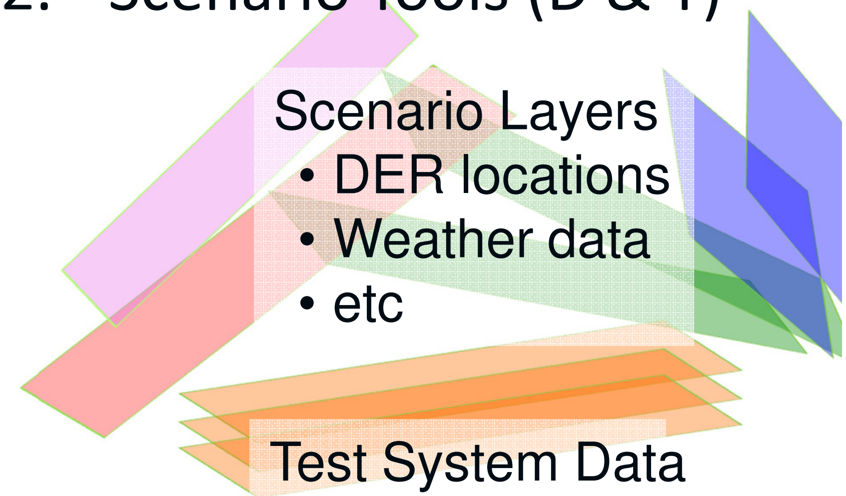
Relevant, Related Project
Smart-DS (NREL's GRID DATA)

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

1. Large-scale Fully Synthetic Distribution (RNM-US)
   - Comprehensive: Substations, Secondaries, HV, more.
   - Nov 2017: 40k customers
   - Jan 2018: 100k
   - mid-2018: 1M node

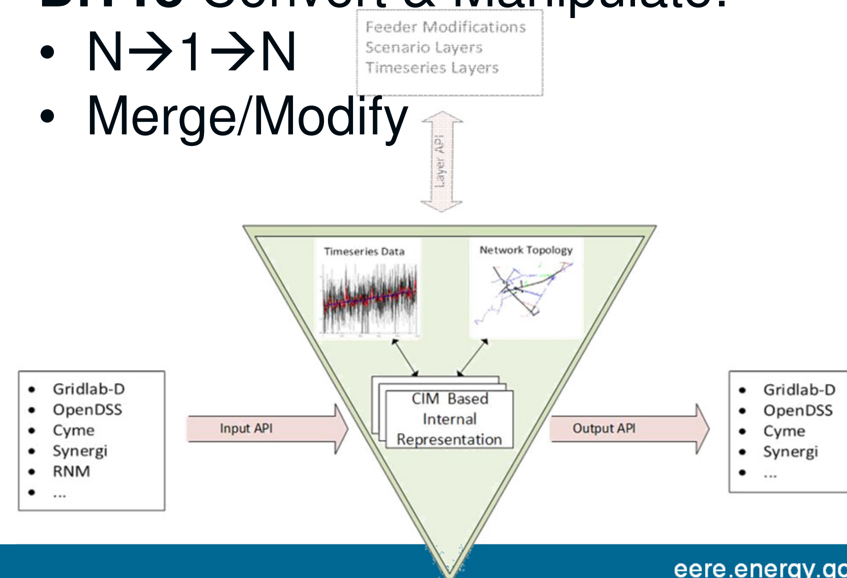


2. Scenario Tools (D & T)



DiTTo Convert & Manipulate:

- N→1→N
- Merge/Modify



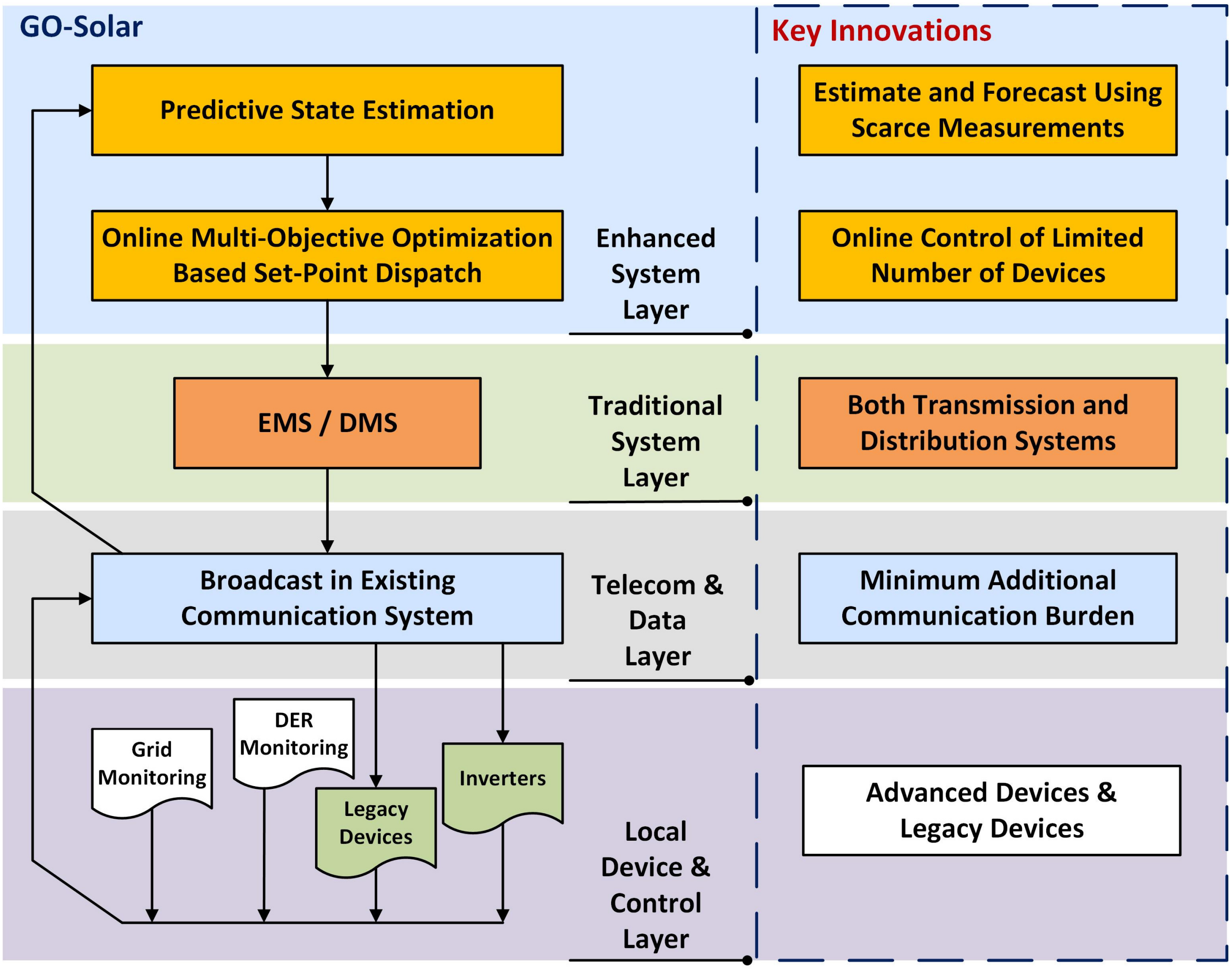
Project Milestones/Deliverables

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Task	Description	Budget Period 1				Budget Period 2				Budget Period 3			
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
1	Initial Data Collection												
M1.1.1	Utility transmission and initial distribution models obtained		*										
M1.1.2	1 year of historic load and generation data for T&D obtained			*									
2	Technology Development												
M1.2.1	Finish developing PSE and testing on existing test systems				*								
M1.2.2	Finish developing OMOO and testing on existing test systems					*							
M2.2.1	Test initial version of linked PSE-OMOO on reduced T&D model							*					
M3.2.1	Develop beta stand-alone GO-Solar platform											*	
3	Demonstration with Hardware-in-the-Loop Testing												
M2.3.1	Perform CHIL validation								*				
M3.3.1	Test GO-Solar platform through hybrid CHIL/PHIL testing												*
4	Validation with Large-Scale Simulation												
M1.4.1	Build a subset test model of T&D				*								
M2.4.1	IGMS simulation of subset model of T&D					*							
M2.4.2	Build a large-scale simulation model of T&D						*						
M3.4.1	Validate GO-Solar platform using T&D simulations											*	
5	Value Analysis												
M2.5.1	Formulate robust value analysis framework									*			
M3.5.1	Value analysis of GO-Solar												*
6	Cybersecurity and Interoperability												
M1.6.1	Interoperability and cybersecurity plan	*											
M2.6.1	Revised cybersecurity and interoperability plan (as needed)								*				
M3.6.1	Complete cyber-vulnerability exercise										*		
7	Stakeholder Engagement and Technology to Market												
M1.7.1	Stakeholder teams identified			*									
M2.7.1	Conduct in-person stakeholder workshop							*					
M3.7.1	Conduct stakeholder workshop												*

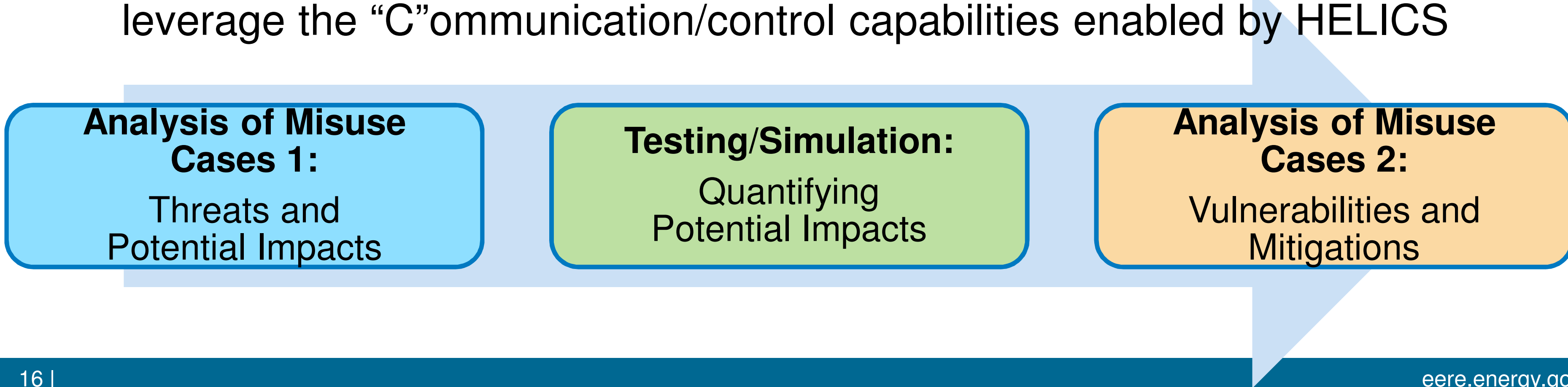
Project Architecture

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy



Cybersecurity

- Focus on understanding security risks inherent in the GO-Solar platform architecture.
- Five scenarios examined:
  1. Control signal spoofing
  2. Control node compromise
  3. Sensor data spoofing
  4. Communication Denial-of-Service (DoS) attack
  5. Communication latency (to understand acceptable cyber overhead)
- **Element #1:** Multi-disciplinary panel review—both power systems and cybersecurity—to identify vulnerabilities & ID mitigation strategies
- **Element #2:** Analyze by building on large-scale simulations. This will leverage the "C"ommunication/control capabilities enabled by HELICS



GO-Solar Development & Testing

Data Ingestion

- **Protocol Correction***
  Compensate for differences in protocol implementation
- **Data Normalization***
  Convert all data into one format
- **Data Cleansing**
  Toss out errors. Part of PSE algorithms

Data Processing & Controls

- PSE and OOMO
- **Data Volume**
  How much data needs to be processed?
- **Data Retention**
  How long must data be available to the PSE?
- **Data Retrieval**
  What types of queries will the PSE need to make?

Actuation and Data Sharing

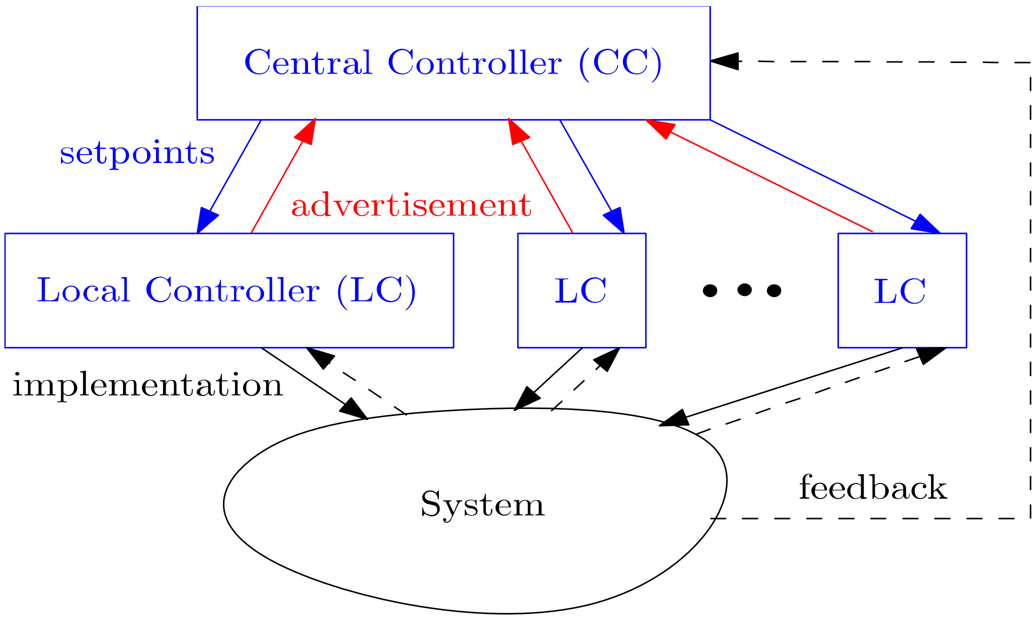
- Translating controls to physical units
- **Control protocols (HIL only)**
  Varies by device type. Etc.
- **Applications & Systems***
  With whom will GO-Solar need to share data?
- **Sharing Mechanism***
  How might data be shared?
- **Level of Effort***
  Cost (in development time) to enable sharing

* Summarized in project reporting

Progress so far: Algorithms (Task 1.2)

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

❖ Centralized framework for real-time control using OMOO [1]:



❖ Currently developed only to work with fast reacting devices (DERs)

❖ Next steps: the algorithm will be extended to control legacy devices such capacitor banks, voltage regulators, etc.

[1] Bernstein and Dall'Anese, "Bi-Level Dynamic Optimization with Feedback", in the the 5th IEEE Global Conference on Signal and Information Processing (GlobalSIP 2017)

Technology Summary

The key innovation of GO-Solar approach is to proactively manage very large DER populations using only a few measurement points as input through predictive state estimation (PSE) and a only few outputs through carefully selected control nodes identified and dispatched through online multi-objective optimization (OMOO).

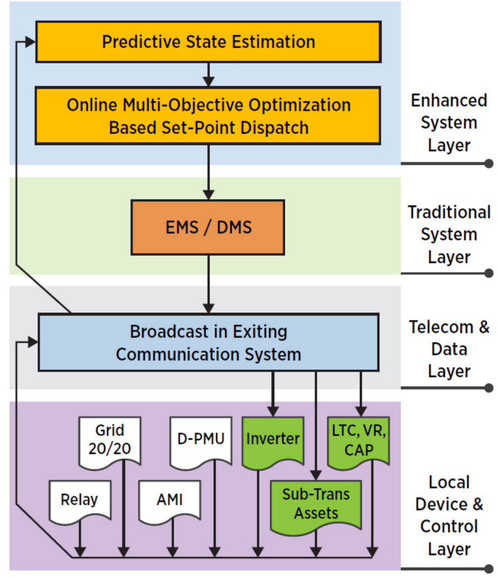
Technology Impact

Achieving more than half of the system-wide feeders at >100% (capacity) penetration of DGPV as part of Hawaii's larger renewable portfolio standard target of 40% (energy) renewables by 2030 on its way to 100% renewable energy by 2045.

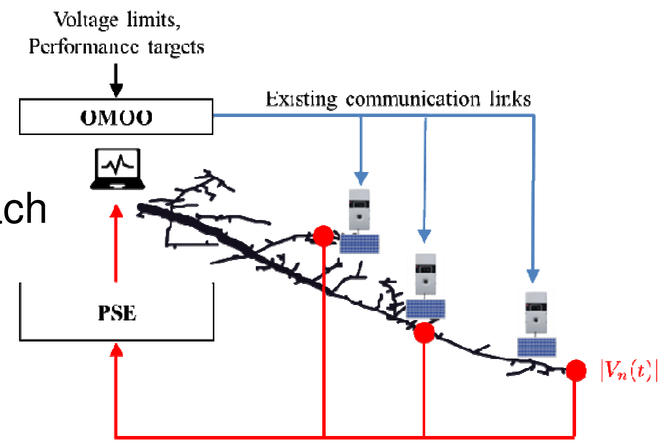
Proposed Project Goals

1. Predictive State Estimation: Voltage manitude forecast error <5%; Voltage angle forcaste error <10%
2. Online Multi-objective Optimization: Flattening the voltage profile to within 1% for no-solar baseline and maintaining ≤5% with 100%–200% (capacity) DGPV.
3. Hosting Capacity: Achieving more than half of the system-wide feeders at >100% (capacity) penetration of DGPV as part of Hawaii's larger renewable portfolio standard target of 40% (energy) renewables by 2030 on its way to 100% renewable energy by 2045.

GO-Solar Concept



Approach



GO-Solar platform can manage > 100% DGPV (Capacity) in sub-transmission and distribution settings through fast acting, near-optimal, reliable controls

Thank you!

Bryan.Palmintier@NREL.gov