GO-Solar: Grid Optimization of Solar

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Topic 2: 2030 Target

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### Project Team

<table>
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<tr>
<th>Name</th>
<th>Org.</th>
<th>Role</th>
<th>Main Responsibilities</th>
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</table>
| 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 Kadowoto      | HECO HECO Contributor |                       | • Utility system model and data gathering                                               |

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

- **Hawaiian Electric
  - Maui Electric
  - Hawaiʻi 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

- 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

- **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

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

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

- 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

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

- **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

- 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

- 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)

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)
   - Scenario Layers
     - DER locations
     - Weather data
     - etc
   - Test System Data

DiTTo Convert & Manipulate:
- N→1→N
- Merge/Modify
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<th>Task</th>
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<td>Initial Data Collection</td>
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<td>M1.1.1 Utility transmission and initial distribution models obtained</td>
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<td>M1.1.2 1 year of historic load and generation data for T&amp;D obtained</td>
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<td>Technology Development</td>
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<td>M1.2.1 Finish developing PSE and testing on existing test systems</td>
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<td>M1.2.2 Finish developing OMOO and testing on existing test systems</td>
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<td>M2.2.1 Test initial version of linked PSE-OMOO on reduced T&amp;D model</td>
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<td>M3.2.1 Develop beta stand-alone GO-Solar platform</td>
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<td>Demonstration with Hardware-in-the-Loop Testing</td>
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<td>M2.3.1 Perform CHIL validation</td>
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<td>M3.3.1 Test GO-Solar platform through hybrid CHIL/PHIL testing</td>
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<td>Validation with Large-Scale Simulation</td>
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<td>M1.4.1 Build a subset test model of T&amp;D</td>
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<td>M2.4.1 IGMS simulation of subset model of T&amp;D</td>
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<td>M2.4.2 Build a large-scale simulation model of T&amp;D</td>
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<td>M3.4.1 Validate GO-Solar platform using T&amp;D simulations</td>
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<td>Value Analysis</td>
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<td>M2.5.1 Formulate robust value analysis framework</td>
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<td>M3.5.1 Value analysis of GO-Solar</td>
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<td>Cybersecurity and Interoperability</td>
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<td>M1.6.1 Interoperability and cybersecurity plan</td>
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<td>M2.6.1 Revised cybersecurity and interoperability plan (as needed)</td>
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<td>M3.6.1 Complete cyber-vulnerability exercise</td>
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<td>Stakeholder Engagement and Technology to Market</td>
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<td>M1.7.1 Stakeholder teams identified</td>
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<td>M2.7.1 Conduct in-person stakeholder workshop</td>
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Project Architecture

GO-Solar

Predictive State Estimation

Online Multi-Objective Optimization Based Set-Point Dispatch

EMS / DMS

Broadcast in Existing Communication System

Key Innovations

Estimate and Forecast Using Scarce Measurements

Online Control of Limited Number of Devices

Both Transmission and Distribution Systems

Minimum Additional Communication Burden

Advanced Devices & Legacy Devices

Grid Monitoring

DER Monitoring

Legacy Devices

Inverters

Local Device & Control Layer

Enhanced System Layer

Traditional System Layer

Telecom & Data Layer
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
Interoperability

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

* Summarized in project reporting

GO-Solar Development & Testing

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
Progress so far: Algorithms (Task 1.2)

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

  ![Diagram]

  - Currently developed only to work with fast reacting devices (DERs)
  - Next steps: the algorithm will be extended to control legacy devices such as 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 magnitude forecast error <5%; Voltage angle forecast 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 platform can manage > 100% DGPV (Capacity) in sub-transmission and distribution settings through fast acting, near-optimal, reliable controls.
Thank you!

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