U.S. DEPARTMENT OF ENERGY

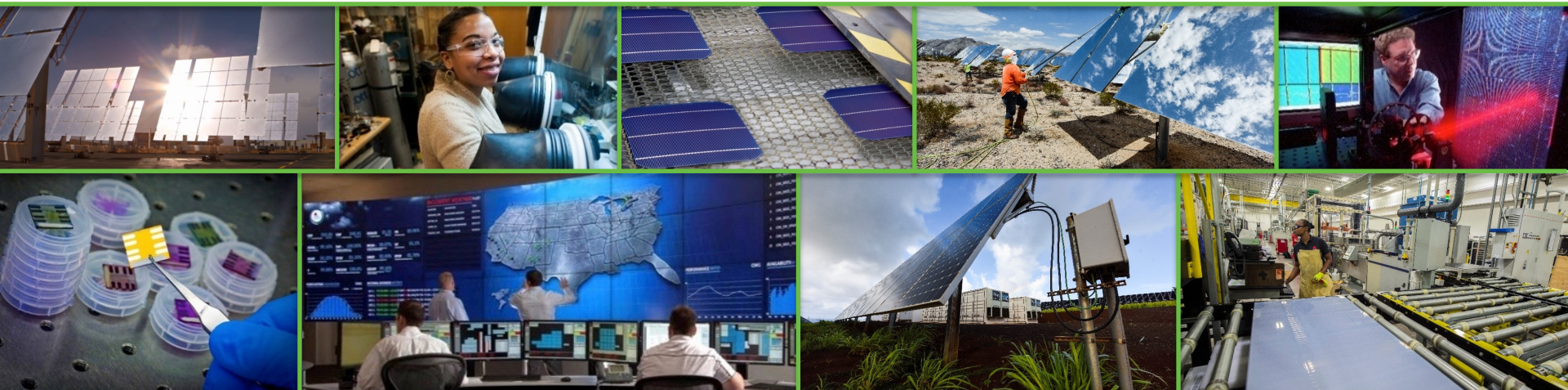
Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Overview of Solar Energy Technology Office (SETO) Funding Efforts Related to Emerging Challenges of Electromagnetic Transient (EMT) Simulation of Solar Technologies

Dr. John Seuss, Technology Manager

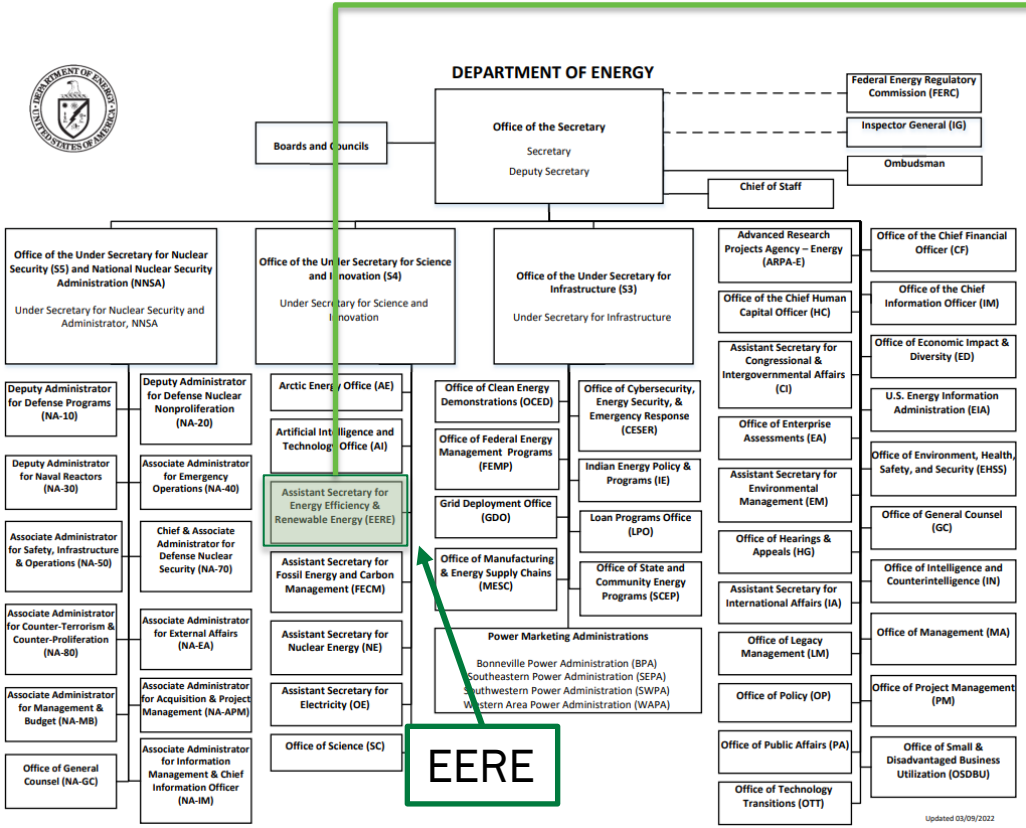
Solar Energy Technologies Office

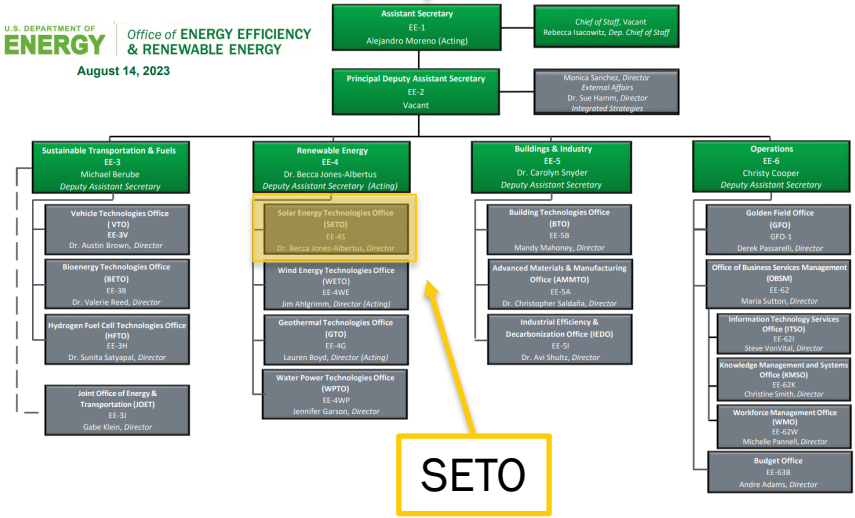
john.seuss@ee.doe.gov



Overview of Solar Energy Technologies Office

Where SETO Resides within the DOE





Solar Energy Technologies Office (SETO) Overview

MISSION

We accelerate the **advancement** and **deployment of solar technology** in support of an **equitable** transition to a **decarbonized economy no later than 2050**, starting with a decarbonized power sector by 2035.

WHAT WE DO

Drive innovation in technology and soft cost reduction to make solar **affordable** and **accessible** for all Americans

Enable solar to support the **reliability**, **resilience**, and **security** of the grid

Support **job growth**, **manufacturing**, and the **circular economy** in a wide range of applications

SETO Research Areas

PHOTOVOLTAICS

- Systems Design And Energy Yield
- Reliability And Durability
- Emerging Cell And Module Technology
- Evolutions of Existing Commercial Technology

CONCENTRATING SOLAR-THERMAL POWER

- CSP Systems - performance & reliability
- CSP high-temp components and char.
- Power cycles
- Solar collectors – low cost, autonomous heliostats
- Solar-heated industrial processes

BALANCE OF SYSTEMS/ SOFT COST REDUCTION

- Data, Analysis, and Tools
- **Permitting, Inspection, and Interconnection**
- Solar Access
- Solar Siting and the Environment
- Workforce

SYSTEMS INTEGRATION

- Power Electronics & Enabling Tech.
- PV for Resilience & Cybersecurity
- System Operation Reliability
- System Planning Models & Sim.
- Accelerate grid codes and standards development

MANUFACTURING AND COMPETITIVENESS

- Support domestic manufacturing of emerging materials
- Support & accelerate transition of new solar tech. into the market
- Support entrepreneurs and entrepreneurial ecosystem

Research Areas: Systems Integration

The goal for SETO's system integration research is to achieve high-solar grid integration by supporting the reliability of the power system, enhancing resilience and security, and increasing system flexibility to reduce grid integration costs.

Where we are now:

- Inverter-based solar and wind resources pose challenges to system reliability and stability
- Solar generation variability and uncertainties
- System operators have no visibility or control over most distributed solar

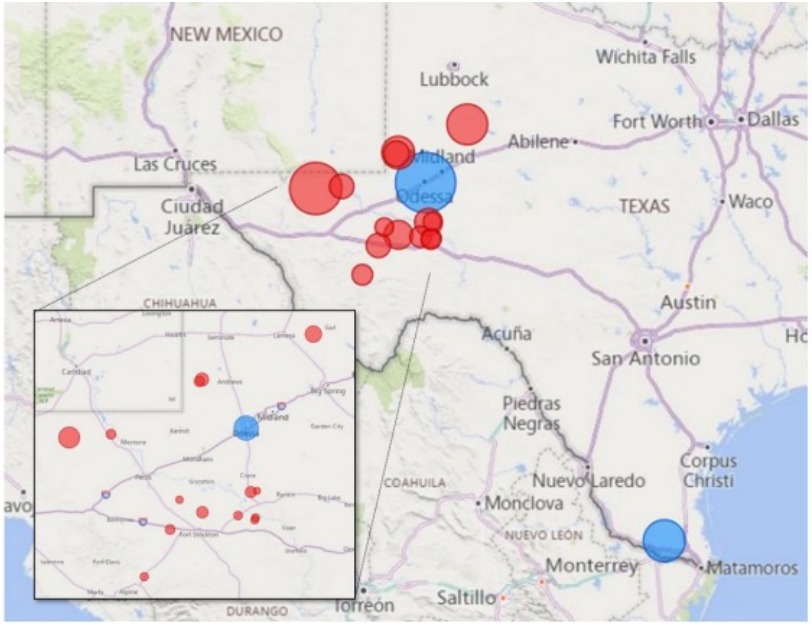
Priority R&D Topics:

- Develop long-term planning models and tools for solar integration
- Develop advanced control capabilities for power electronics
- Enhance grid services to operate high-solar grids
- Advance communications and sensing for situation awareness
- Improve solar forecasting
- Integrate storage to add flexibility
- Enhance resilience and security in system design
- Accelerate grid codes and standards development

Some Emerging Challenges Related to EMT Simulations of Solar Energy Technologies

Emerging Challenges with EMT Simulations

Recent solar disturbances may have been avoided with more thorough modeling/simulation during commissioning/interconnection, including EMT



Source: NERC, 2022 Odessa Disturbance Report, December 2022.

Table 3.1: Solar PV Tripping and Modeling Capabilities and Practices

Cause of Reduction	Can Be Accurately Modeled in Positive Sequence Simulations?	Can Be Accurately Modeled in EMT Simulations?
Inverter Instantaneous AC Overcurrent	No	Yes
Passive Anti-Islanding (Phase Jump)	Yes[a]	Yes
Inverter Instantaneous AC Overvoltage	No	Yes
Inverter DC Bus Voltage Unbalance	No	Yes
Feeder Underfrequency	No[b]	No[c]
Incorrect Ride-Through Configuration	Yes	Yes
Plant Controller Interactions	Yes[d]	Yes[e]
Momentary Cessation	Yes	Yes
Inverter Overfrequency	No[b]	Yes
PLL Loss of Synchronism	No	Yes
Feeder AC Overvoltage	Yes[f]	Yes
Inverter Underfrequency	No[b]	Yes

Challenge: More EMT simulations needed in interconnection studies could add strain to the interconnection queue and utility resources.

Emerging Challenges with EMT Simulations

DOE was provided feedback on several funding efforts related to EMT simulations:

- UNIFI external advisory board
- NREL ARIES/PEGI Workshop
- Other conferences/workshops

Challenge: Lack of standardized inverter models and reluctance of vendors to provide EMT models

- Uncertainty of operations
- Inability to validate interconnections

2023 UNIFI Consortium General Meeting

Source: UNIFI, https://sites.google.com/view/unifi-consortium/blog

Emerging Challenges with EMT Simulations

- Recent projects found that EMT-level models of IBR, as well as the power grid itself, were needed to replicate unstable IBR controller interactions
- Positive-sequence models are insufficient for studying IBR response to unbalanced faults and black start sequences

Challenge: Lack of comprehensive EMT-level power system network models and IBR plants

Challenge: Insufficient data to develop machine-learning-based protection and disturbance detection tools:

- EMT simulation may be sufficient

NREL SAPPHIRE Project – Analysis of Event on KIUC System

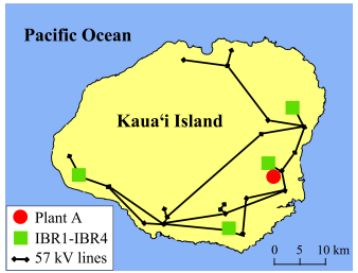
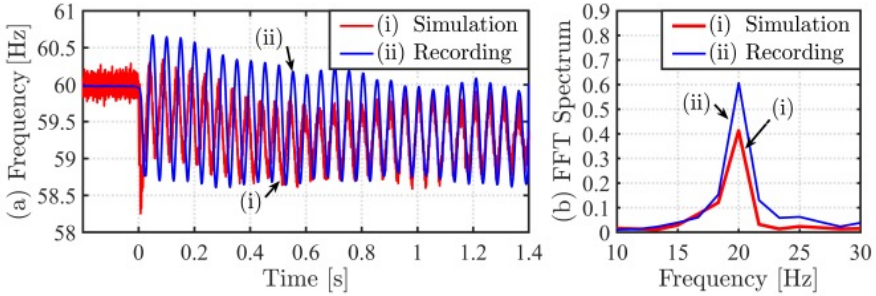


TABLE I
KIUC GENERATION MIX BEFORE AND AFTER EVENT

Time	$t = 0^-$ s	$t = 60$ s
Plant A	60.6%	0.0% ↓
IBR1	4.1%	14.0% ↑
IBR2	4.6%	21.0% ↑
IBR3	0.0%	14.0% ↑
IBR4	4.1%	23.0% ↑
Biomass	13.7%	14.0% ↑
Hydros	13.0%	13.0% –



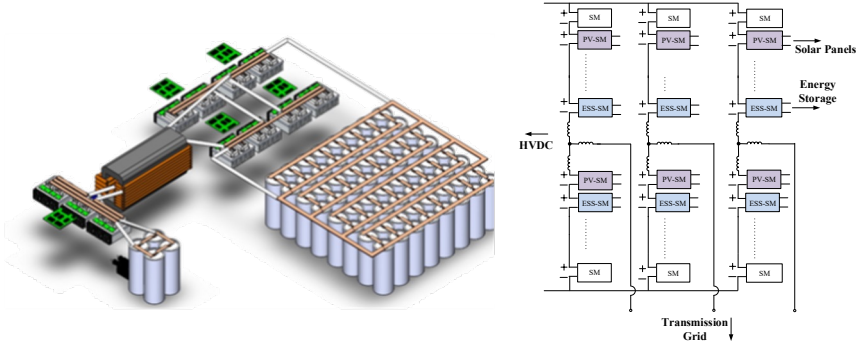
Source: S. Dong, Analysis of November 21, 2021, Kaua'i Power System 19.5 Hz Oscillation.

Emerging Challenges with EMT Simulations

Advanced power electronics applications could benefit the integration of solar energy:

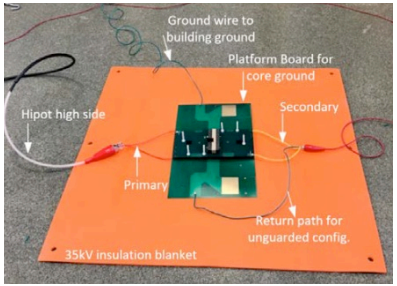
- Faster control responses through wide-bandgap devices (e.g., SiC, GaN)
- Leveraging HVDC for improved grid stability
- Ultra-fast power electronic circuit breakers
- Solid state transformers and power routers

Challenge: Various novel power electronic solutions that could benefit solar integration would require EMT simulations to validate



Source: ORNL, S. Debnath, Multi-port Autonomous Reconfigurable Solar Power Plant (MARS), Final Report

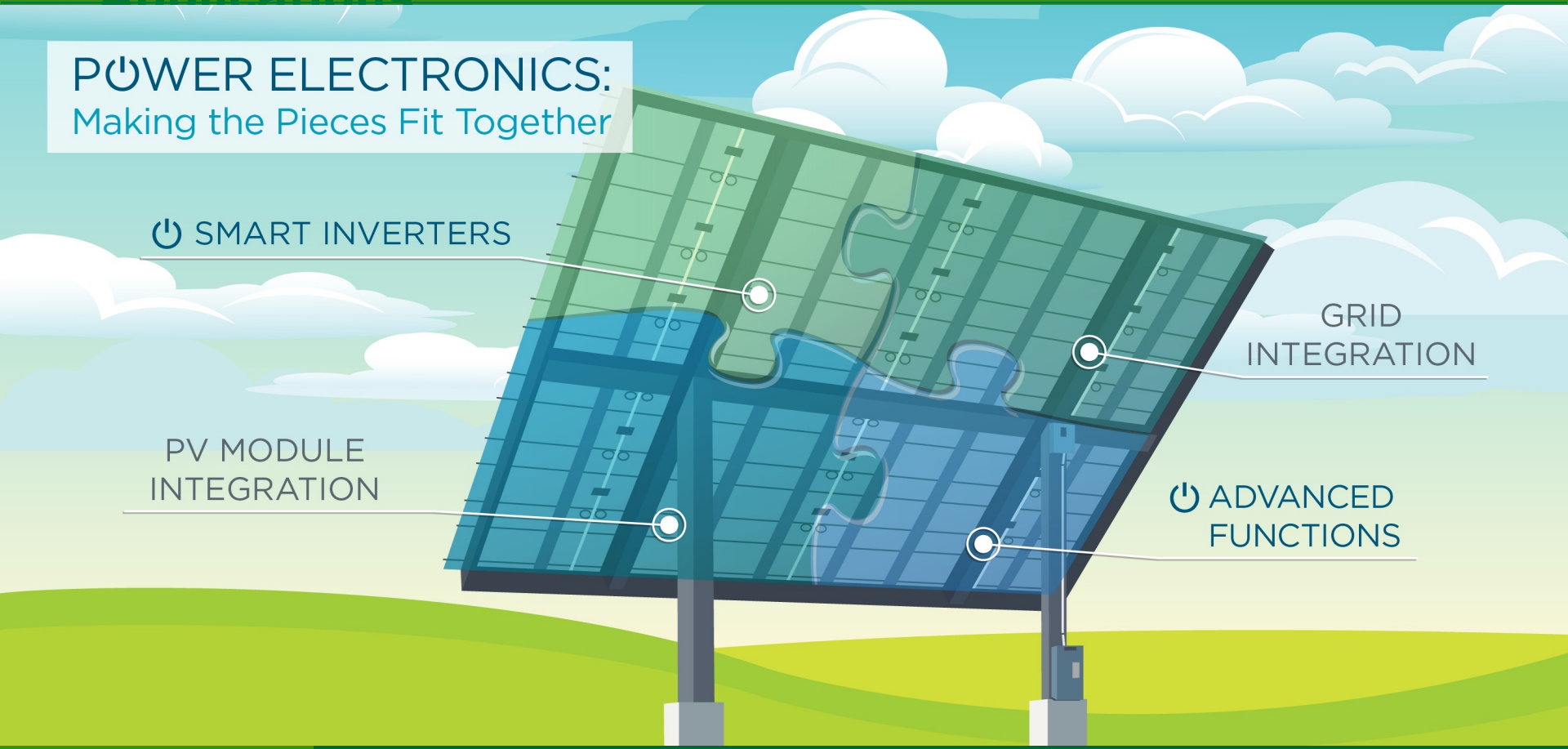
Source: UT-Austin, A. Huang, M4 Inverter: Modular, Multifunction, Multiport and Medium Voltage Utility Scale SiC PV Inverter, Final Report



Source: Univ. Washington, B. Johnson, Modular Wide-bandgap String Inverters for Low-cost Medium-voltage Transformer-less PV Systems, Final Report

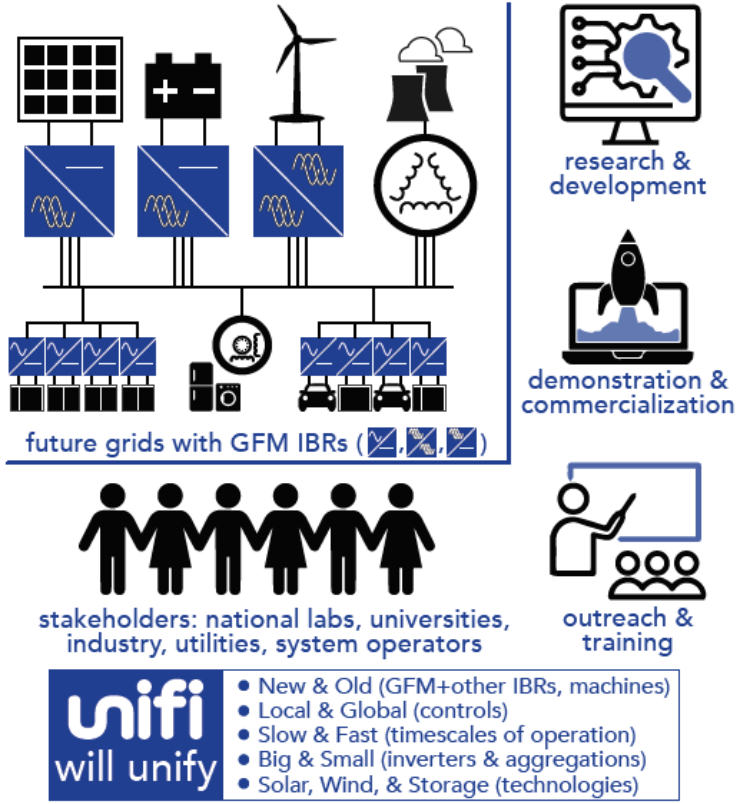
Some Recent Funding Efforts from SETO Addressing Emerging EMT Challenges

Advanced Power Electronics Design for Solar Applications



Grid-Forming Consortium: UNIFI at NREL

- **$25M over 5 years to establish a framework for continued industry collaboration**
- **Currently 14 Research/Outreach Areas**
- **Modeling and Simulation Area:**
  - Study applicability/limits of EMT vs. phasor
  - Accelerate simulation time of EMT-phasor co-simulation platforms
  - Validate black box EMT GFM models and developed reduced-order generic models
  - Develop and maintain software testbed system and GFM model library
- Register at the following link: https://sites.google.com/view/unifi-consortium/home

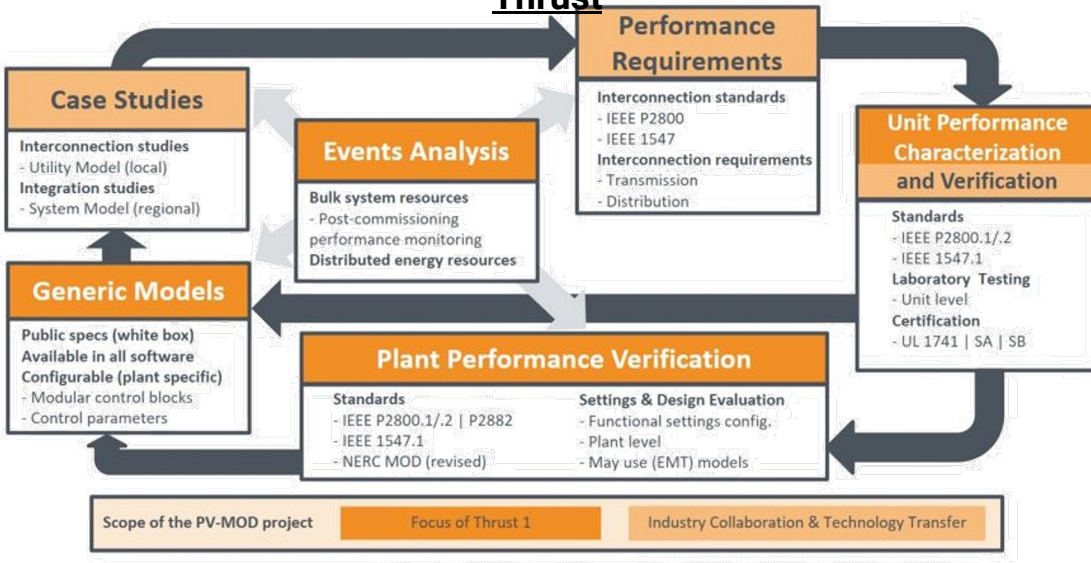


EPRI: Adaptive Protection and Validated Models to Enable Deployments of High Penetrations of Solar PV (PV-MOD)

SETO FY19 Funding Opportunity

- **Project goals (Modeling Thrust):**
  - Develop high-fidelity IBR models
  - Validate against lab tests and field measurements
  - Increase availability of generic models in commercial software
  - Transfer knowledge of using generic models to power systems engineers
- **Models and analysis include:**
  - Electromagnetic transients (EMT)
  - Power quality and harmonics
  - Short-circuit
  - Quasi-static Time Series (QSTS)
  - T&D Co-simulation

Model Development, Validation, and Commercialization Thrust



PI: Jens Boemer, EPRI

Project website: https://www.epri.com/pvmod

Recently Awarded Projects

UIC: Enabling 100% Renewable Energy Integration: Creativity-based Co-design and Demonstration of Intelligent Modeling, Protection, and Grid-Edge Control of Bulk Power Systems

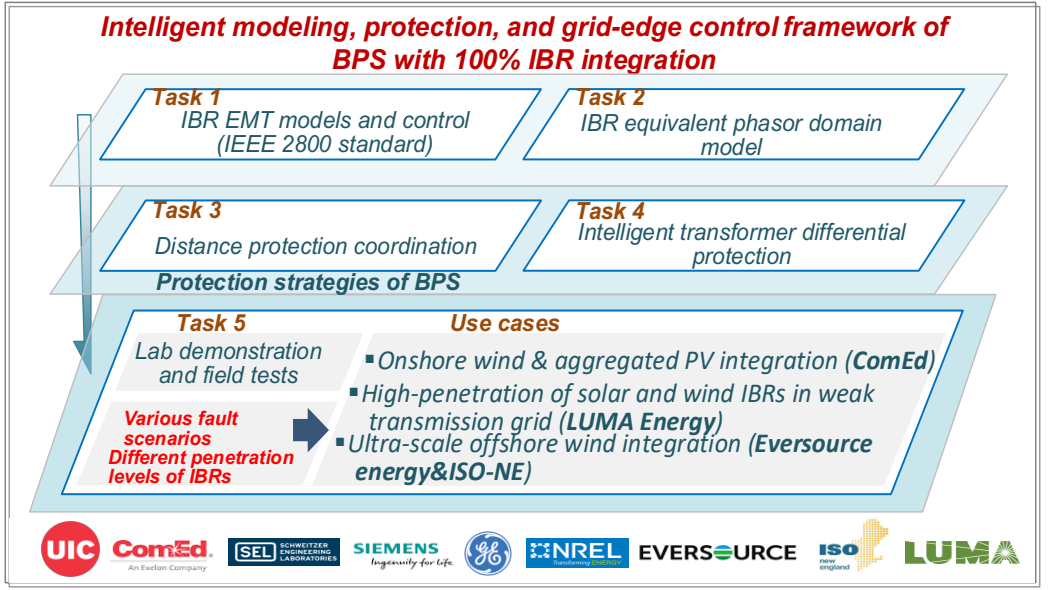
Notes of Interest

- Will provide open-source EMT models of IBR based on new IEEE 2800 standard
  - Based on vendor experimental data
  - New fault ride-through control req's
- Greatly improve simulation time with phasor-equivalent modeling
- New machine-learning based protection for power transformers against IBR-driven harmonics
- Method for coordinating existing transmission protection for any level of IBR
- Team includes 4 vendors, 3 utilities, and 1 ISO

Demonstration Sites

- Equipment installed to evaluate new protection schemes in transmission substations in Chicago, IL (ComEd) and Indiana (AES) near IBR plants

PI: Lena He, University of Illinois - Chicago



ConEd: Reliable Protection for an Inverter-Based Resources Dominant Grid: Technology Development and Field Demonstration

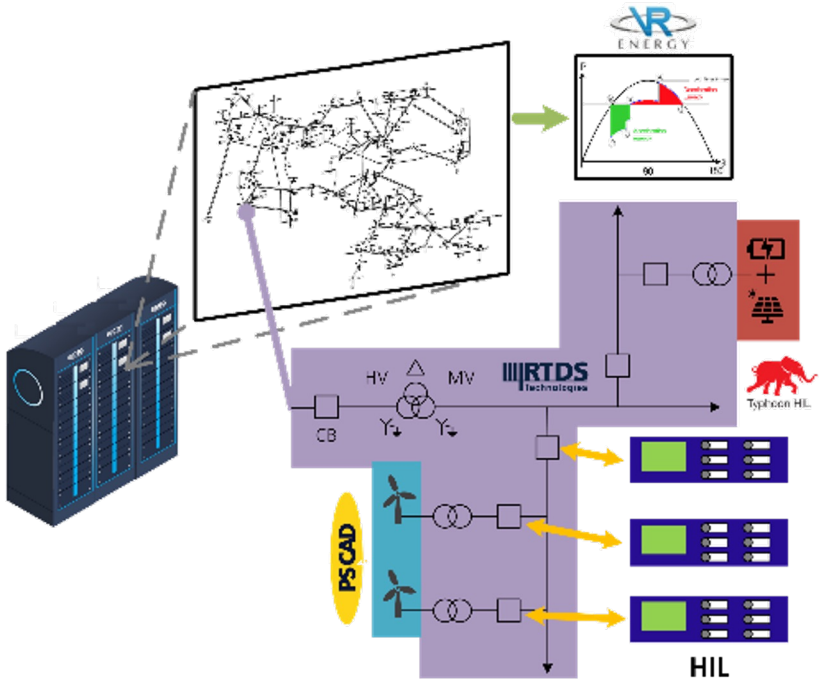
PI: William Winters, Consolidated Edison of NY

Notes of Interest

- **Develop electromagnetic transient (EMT) co-simulation framework to analyze interaction between IBR controls and transmission protection**
  - Accelerate computation time by 250%
  - Includes grid stability analysis module
  - Able to simulate up to 100% IBR
- **Will coordinate w/ commercial software vendors**
- Field tests of new synchrophasor-based transmission protection system as more sensitive (but slower) backup for existing protection
  - Source-agnostic protection scheme

Demonstration Sites

- Equipment installed to evaluate new protection schemes in transmission substations in Queens, NY (ConEd) and Virginia (Dominion)
- Hardware lab demos at SCE and SDG&E to provide both Eastern and Western interconnection examples



NREL: Protection of Inverter-dependent Transmission Systems (PROTECT-IT)

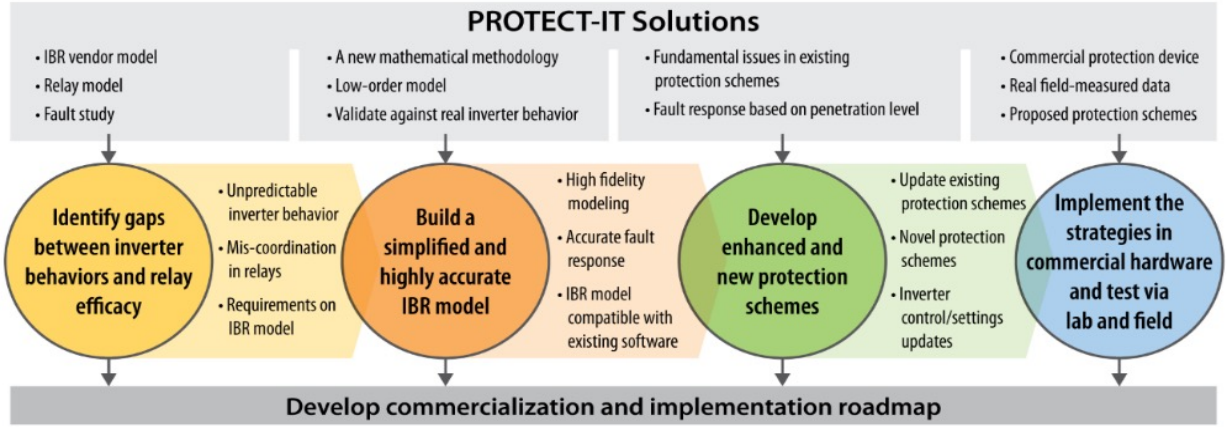
Notes of Interest

- New Machine Learning based protection scheme to adapt to changing source types
  - EMT simulations generate database of faults to train protection regardless of source mix
- New simplified rapid fault detection method based on EMT simulation of IBR
  - Will speed up analysis of protection analysis
- Framework for utility engineers to develop relay settings quickly for various IBR levels, enabling adaptive protection

PI: Jing Wang, NREL

Demonstration Sites

- Equipment installed to evaluate new protection schemes in Kauai Island, HI.
  - Demo site may operate near or at 100% IBR, including new GFM controls
- PNM to provide non-island transmission system models for HIL testing at NREL's ESIF

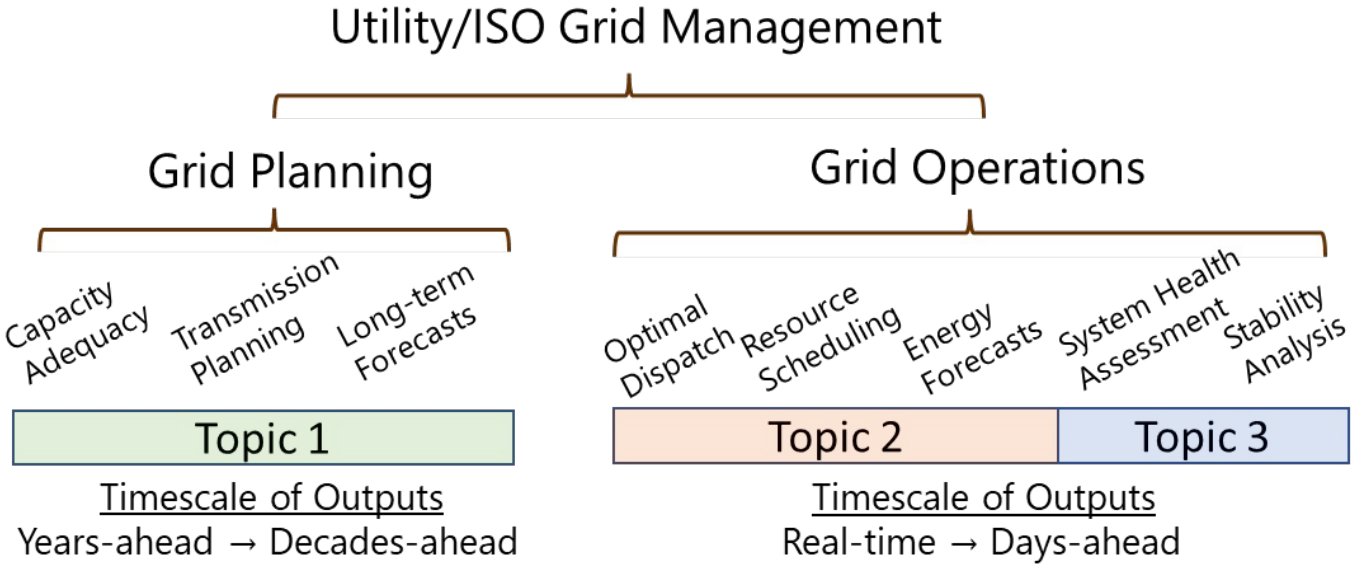


FY23 SETO Systems Integration Open Funding Opportunity

https://www.energy.gov/eere/solar/articles/funding-notice-operation-and-planning-tools-inverter-based-resource-management

Overview: OPTIMA (Operational and Planning Tools for IBR) FOA

- Expected: 9-13 awards across 3 Topic Areas, $30M federal funds total
- FOA released: 4/20/23, selections: December 2023, awards: April 2024
- **Full Applications Due 9/14/2023**

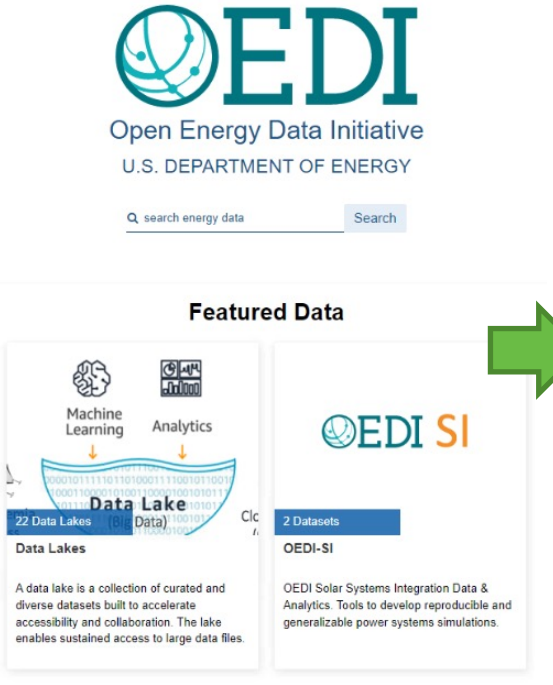


SETO.OPTIMA.FOA@ee.doe.gov

Overview Open Energy Data Initiative for Solar Systems Data Integration and Analytics (OEDI-SI)

OEDI SI Overview

- Leverage existing OEDI architecture
- SETO Core LabCall Program
- National Labs collaboration (ANL, NREL, ORNL, PNNL)
- DOE|SETO FY22-24 Lab Call: 2021 Oct. to 2024 Sept.
- Open Energy Data Initiative (OEDI) (openei.org)



What is OEDI SI?

OEDI Solar Systems Integration Data and Analytics (OEDI SI) is a collection of use-cases that provide public domain data sets, their curation and mapping into single integrated input data for power system analysis of distribution and transmission networks with high solar generation resources.

The main goals of OEDI SI are to:

- Provide access to public data, data integration and mapping into a single consistent data set in some of the widely accepted I/O formats
- Provide at least one physics and network, or data and ML based power system analysis algorithm(s)
- Enable reproducible, robust, replicable and generalizable R&D in simulations and emulation of solar system integration
- Encourage and enforce open-source algorithms and publicly available multiple data sets in standard I/O formats

Currently, OEDI SI is still being developed by a subject matter experts with collaboration of four National Laboratories: Argonne National Laboratory (ANL), National Renewable Energy Laboratory (NREL), Oak Ridge National Laboratory (ORNL), and Pacific Northwest National Laboratory (PNNL). It is being funded through a 2022 Lab Call Program by DOE/SETO Systems Integration.

OEDI SI Data

Browse OEDI SI Use-cases | View the OEDI SI Wiki | Submit OEDI SI Data

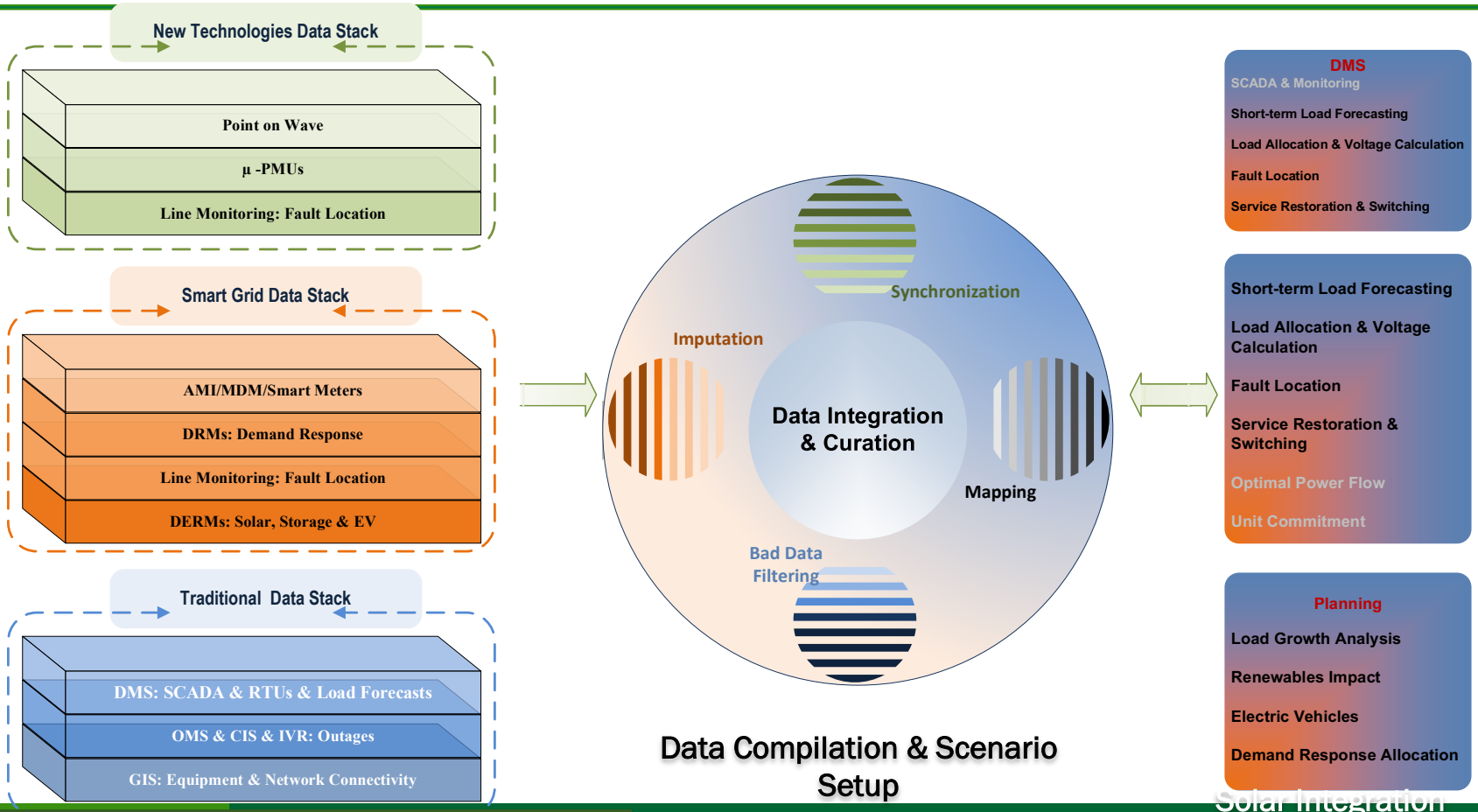
OEDI SI Program Goals

- **Make generic test data for solar generation integration to power systems analysis publicly available for testing and verification of new analytics**

- **Provide data anonymization, imputation, synchronization and bad data pre-processing to consistently map and integrate the individual data coming from different OT/IT systems**
  - Data pre-processing scripts for preparing different scenarios off from pre-canned use-cases

- **Provide open-source algorithms to enable using the integrated data for different power systems algorithms**
  - Physics-/network- & data-/ML-based solar analytics
  - Make their verified results and metrics available to researchers for comparing their algorithms

OEDI SI Overview

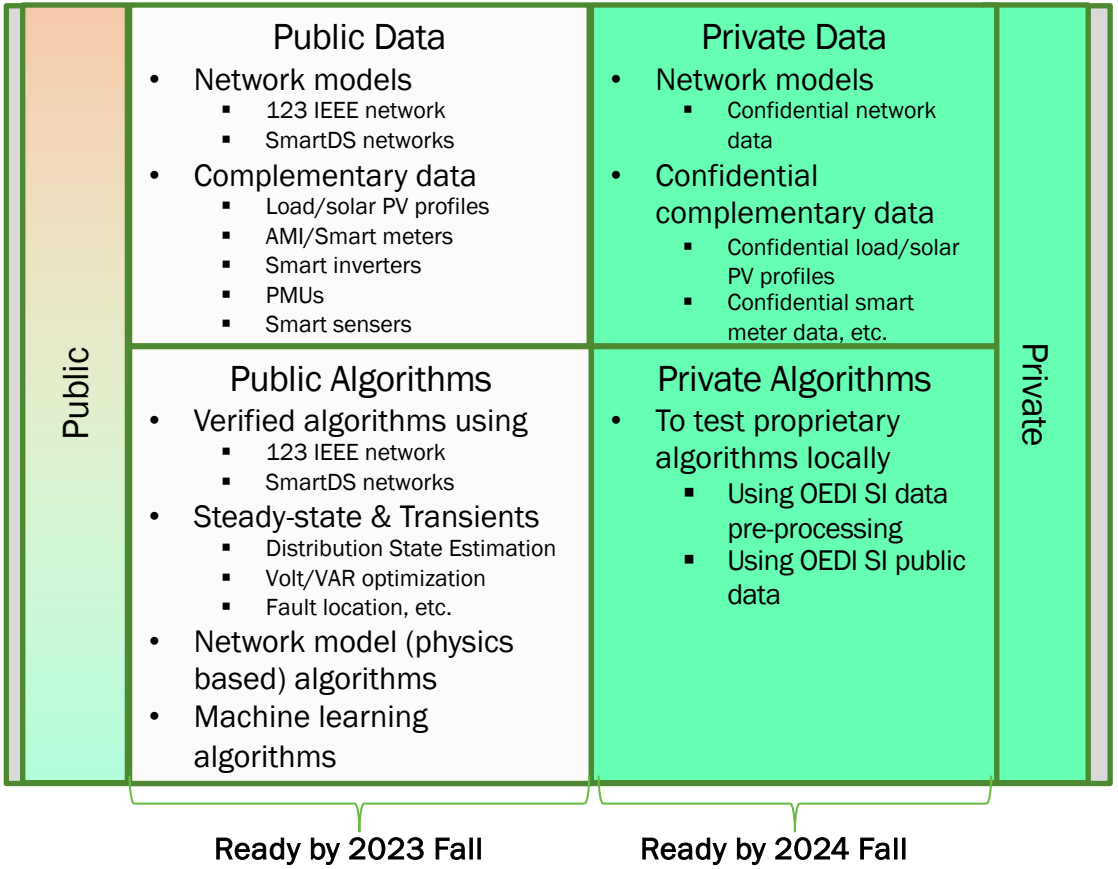


Data Compilation & Scenario Setup

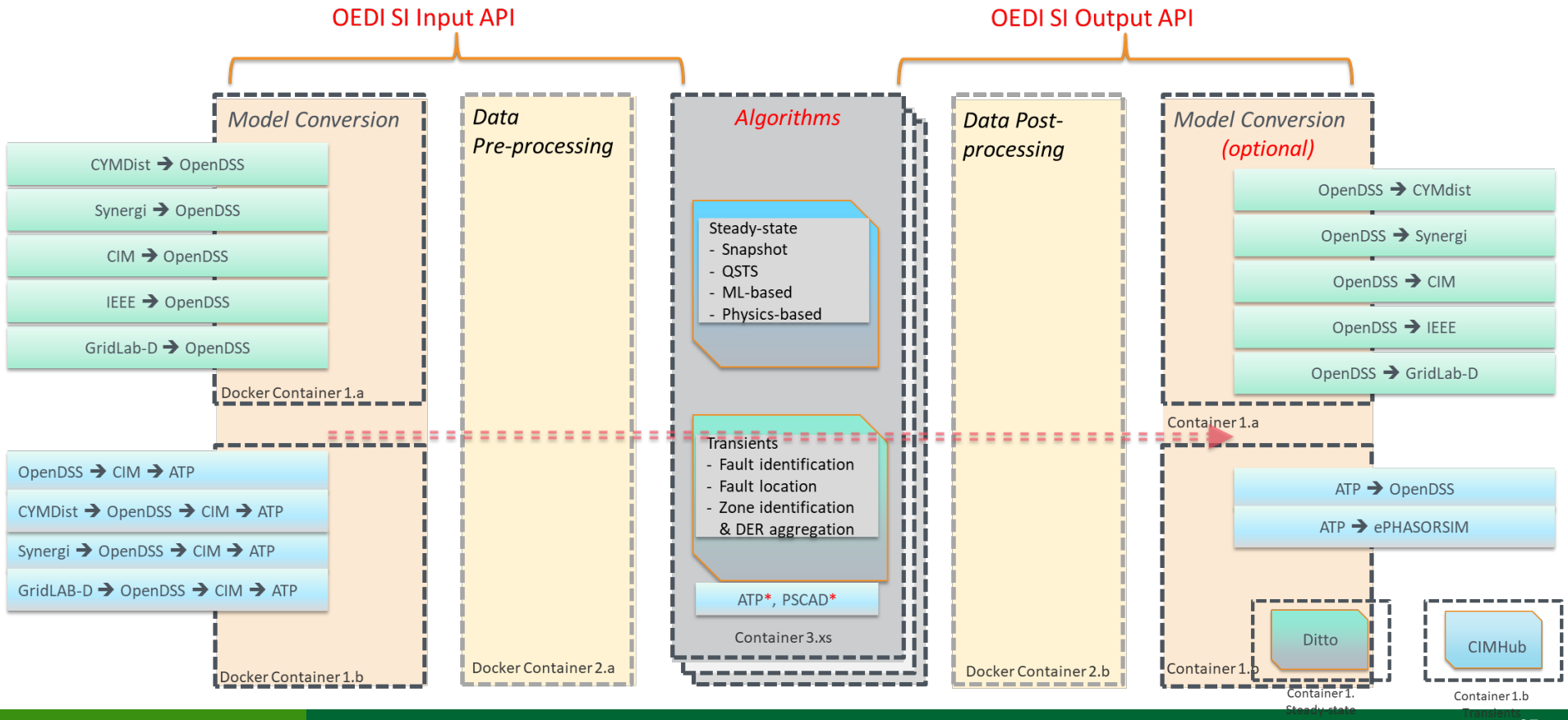
Data from Multiple OT/IT Technologies

Solar Integration Analytics

OEDI SI Overview

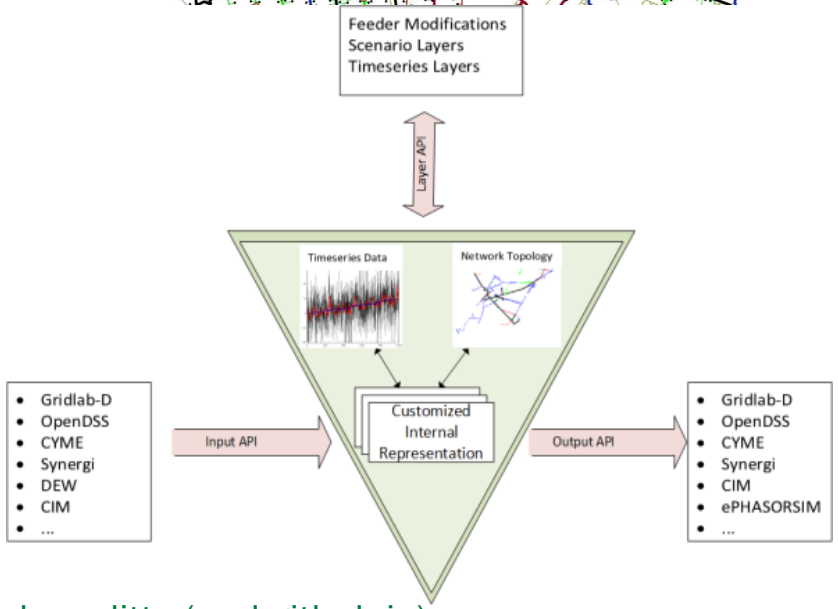


OEDI SI Functional Overview



OEDI SI Model Converters

- Feeder Conversion
- Comprehensive Feeder Metric Computations
- Graph Theory Network Analysis
- Feeder Modification:
  - Modify loads
  - Add solar
  - Set controls of components
  - Add/remove electrical components
  - And more!



DiTTo by NREL [DiTTo examples - ditto (nrel.github.io)]

Learn About Upcoming Funding Opportunities

EERE Funding Opportunity Updates

Promotes the Office of Energy Efficiency and Renewable Energy's funding programs.

SIGN UP NOW:

energy.gov/eere/funding/eere-funding-opportunities

SETO Newsletter

Highlights the key activities, events, funding opportunities, and publications that the solar program has funded.

SIGN UP NOW:

energy.gov/solar-newsletter

Email: john.seuss@ee.doe.gov