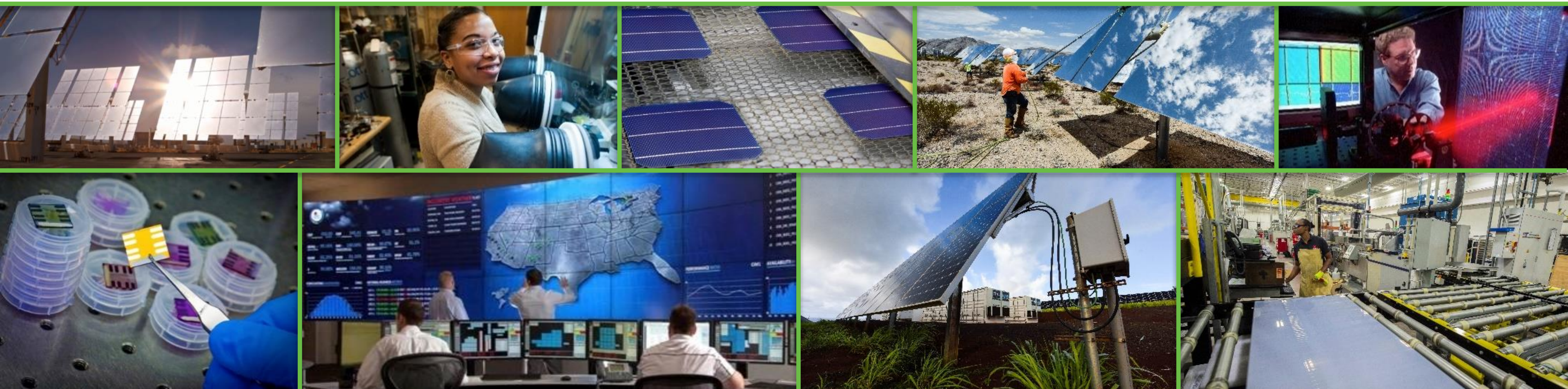
SETO Systems Integration Program Update

Guohui Yuan

Presented to ORNL EMT Workshop, August 2024



Solar Energy Technologies Office Overview

MISSION

We accelerate the advancement and deployment of solar technology in support of an equitable transition to a decarbonized energy system by 2050, starting with a decarbonized power sector by 2035

WHAT WE DO

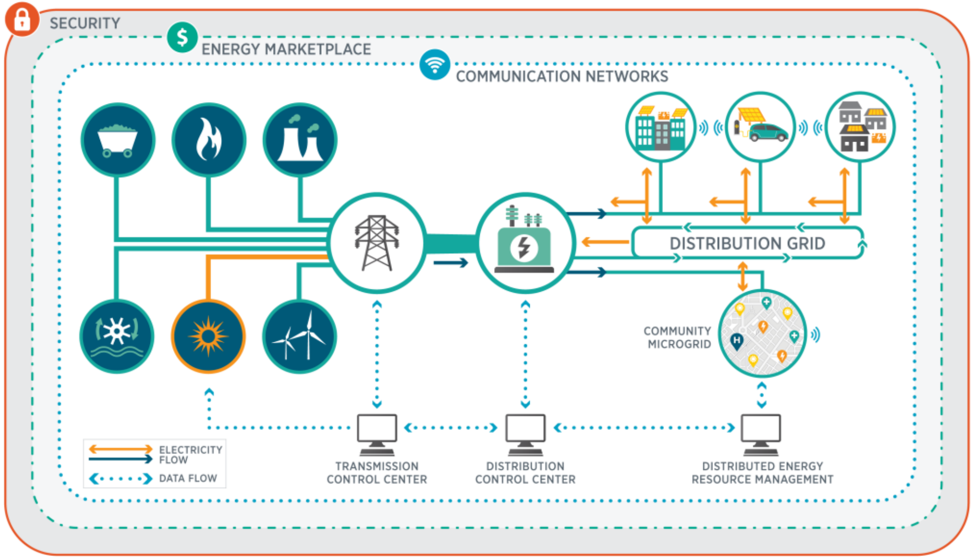
Drive innovation in technology and soft cost reduction to make solar affordable and accessible for all Americans

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 Systems Integration (SI) Program

The Systems Integration (SI) subprogram supports early-stage research, development, and demonstration (RD&D) of technologies and solutions – focusing on technical pillars **data, analytics, control, and hardware** - that advance the **reliable, resilient, secure and affordable** integration of solar energy onto the U.S. electric grid.



Achieving 100% Decarbonized Power System

SETO System Integration Key Research Areas

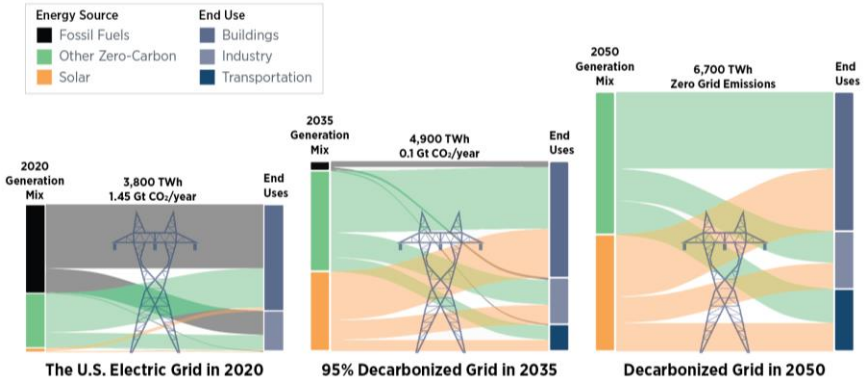
~$50-60M annual budget, ~90 active RD&D projects

System Planning	System Operation	Resilience & Cybersecurity	Enabling Technologies
• **Power system modeling** • **PV plant and inverter modeling** • Solar resource data & solar forecasting • Resource adequacy • Production cost modeling • Reliability and interconnection standards	• Real time situation awareness • State estimation and power flow • System and inverter control • System protection, stability, risk management • Grid services and system flexibility • DER integration and aggregation of PV, ESS, EV, and buildings • SW tools -EMS, ADMS, DERMS, MGMS	• Resilience planning and benchmark metrics • Resilient microgrids and DER-based solutions • Measurement & Verification, and cost/benefit analysis • Cybersecurity R&D and assessment tools for device, plant, and system • Cybersecurity standards • Stakeholder education and information sharing	• Power electronics • Energy storage • Data analytics and AI/ML • Sensing and communication • High performance computing and cloud-based tools • CHIL and PHIL testbeds

U.S. Clean Energy Transition 2020-2050

Rapid Deployment of Solar PV, Wind, and Battery Storage

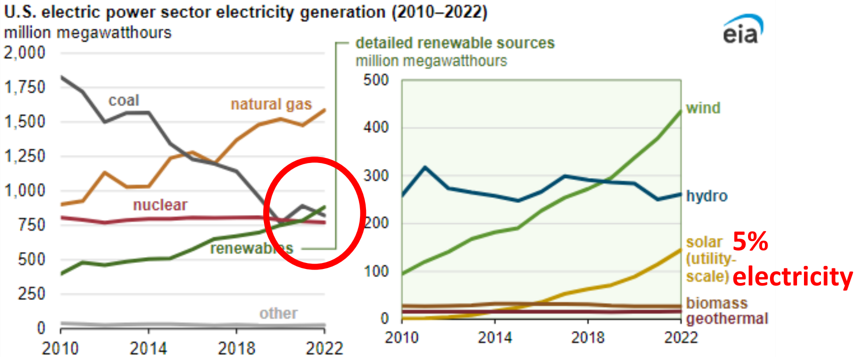
DOE solar Future Study, 2021

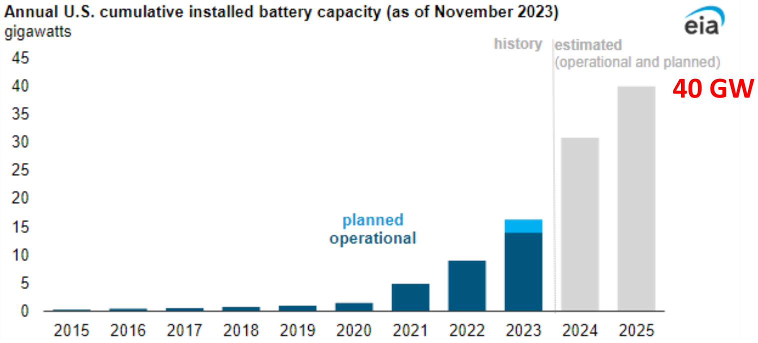


Solar: As of 2020, 3% of electricity demand, 80 gigawatts AC installed.

Solar: 40% of electricity demand, 1,000 gigawatts installed

Solar: 45% of electricity demand, 1,600 gigawatts installed 3,000 GW in decarbonized energy system





How Did We Get Here?

More solar

More affordable solar

More affordable reliable solar

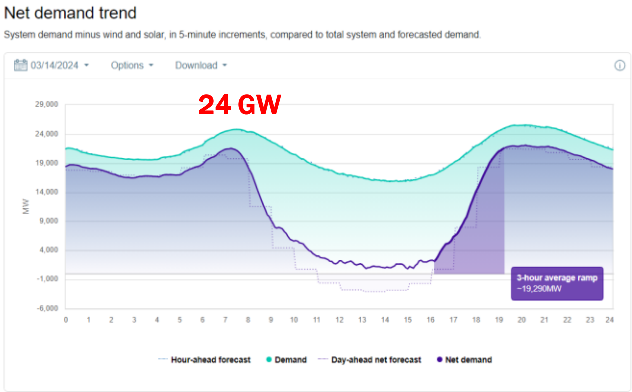
More affordable reliable resilient solar

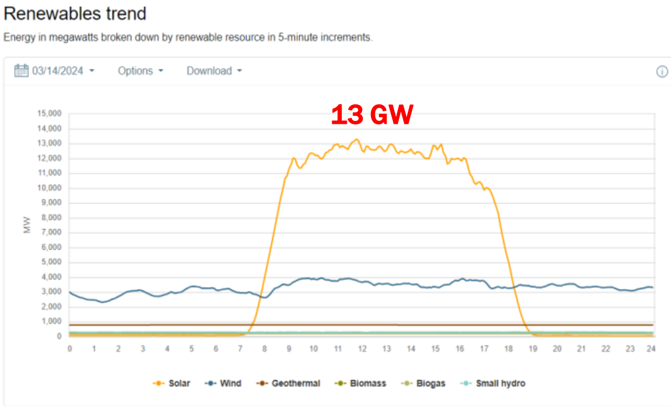
More affordable reliable resilient secure solar

Managing Solar and Wind Generation Variability and Uncertainty

Spring Light—Load Day

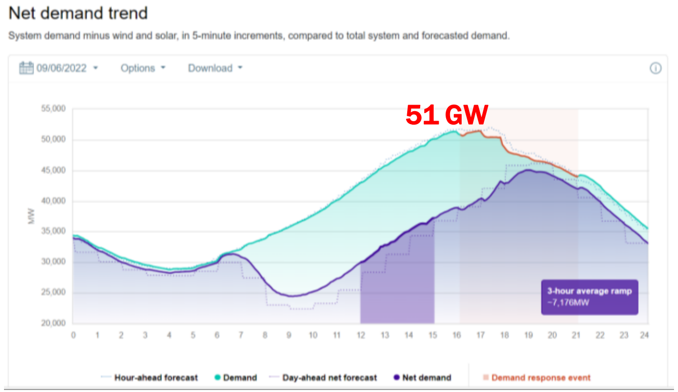
March 14, 2024
Load 16.5 GW
Solar 12.5 GW
Wind 3.5 GW
Wind + Solar ~100%

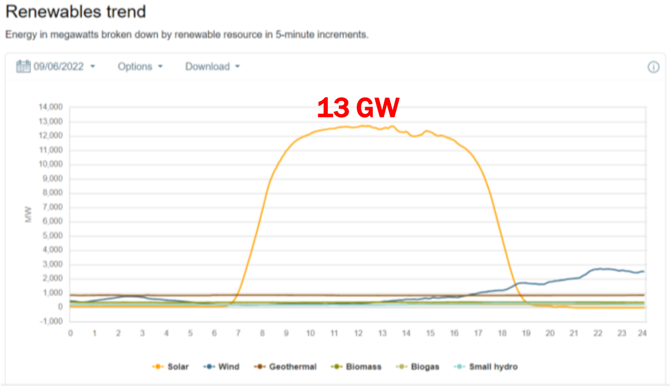




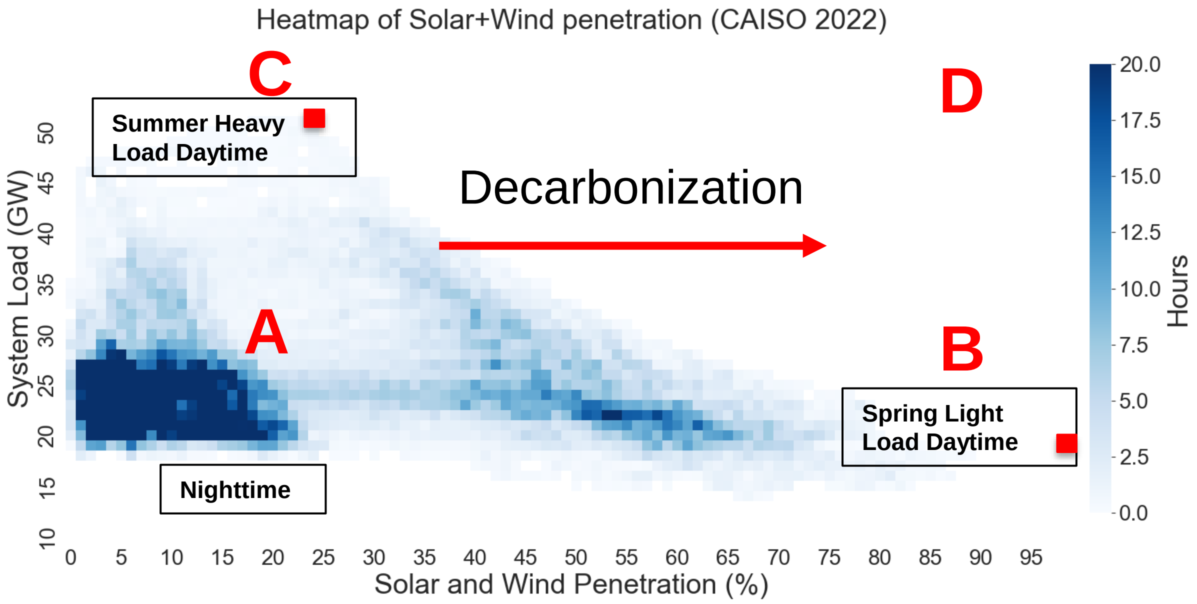
Summer Heavy-Load Day

September 5-7, 2022
Load ~51 GW
Solar~13 GW
Wind ~0.7 GW
Wind + Solar 20-30%



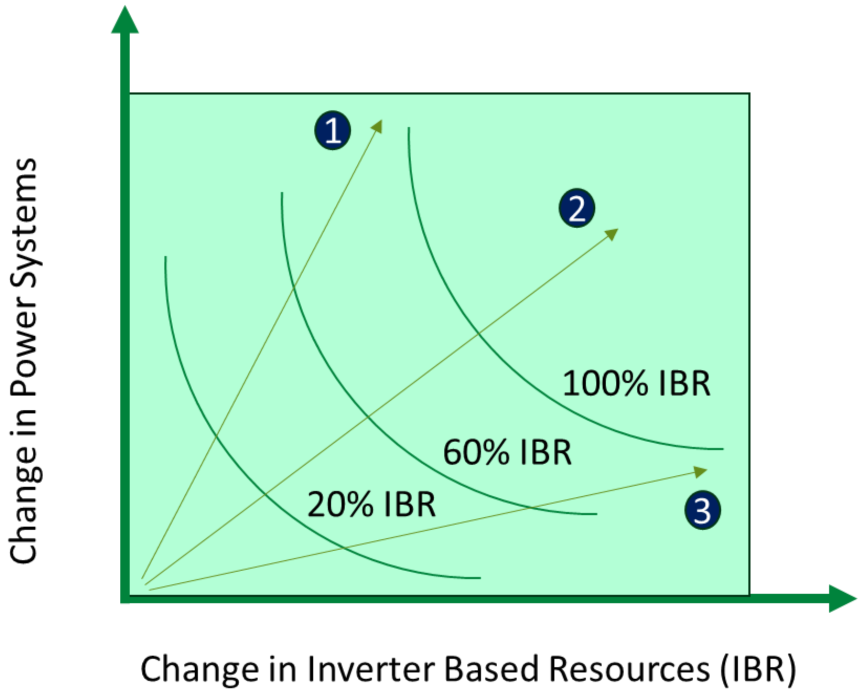


Operating a Power Grid with Extremely High IBR Contribution



The frequency of occurrence of solar and wind power contributions at different demand levels in CAISO for 2022. For a vast majority of the operation periods, solar and wind penetration is low (Area A). Occasionally solar and wind provide a high contribution to the generation supply, with high percentage at low demand times (Area B), and lower percentage at high demand times (Area C). In the future, as solar and wind reach much higher deployment, the system will operate at high demand most of the times (Area D).

Co-Evolution of Inverter Based Resources (IBR) and Power Systems



1. Small change in IBR, large change in power system
2. Optimal changes in IBR and power system
3. Large change in IBR, small change in power system

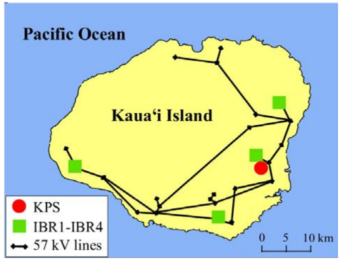
EMT Simulation for System Planning and Operation

- 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

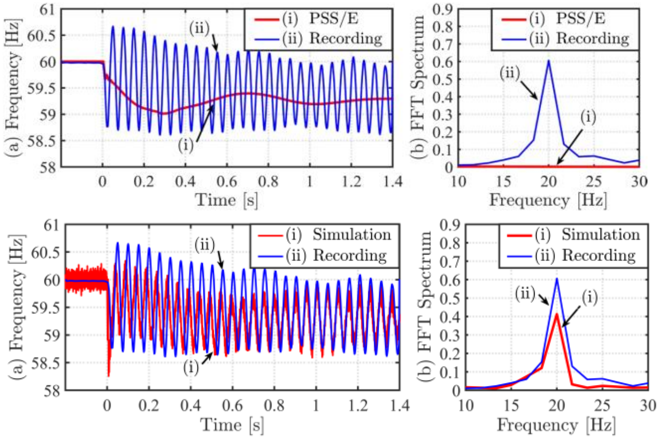
Challenge: Lack of comprehensive EMT-level power system network models and IBR plants

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

Challenge: Lack of standards



NREL SAPPHIRE Project – Analysis of 19.5 Hz Oscillation Event on KIUC System in 2021



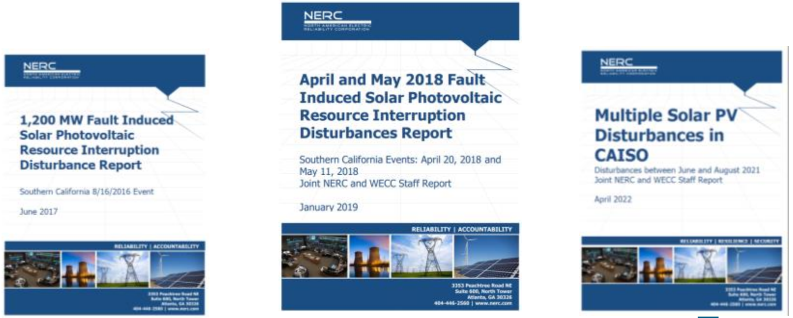
Phasor-Based

Vendor EMT w/ Tuning

Source: Jin Tan, “EMT Simulations for Hawaii Oscillation Events, ORNL-DOE-NERC EMT Workshop, August 13, 2023.

Ensuring Grid Reliability and Stability

- Major events in US, UK, and South Australia since 2016 Blue Cut Fire have shown
  - Significant "unexpected" loss of utility-scale solar PV, wind, and distributed generation (including DPV) due to transmission disturbances
  - Needs for improvements to NERC Reliability Standards, address modeling issues during interconnection studies and commissioning, and performance-based requirements for IBRs



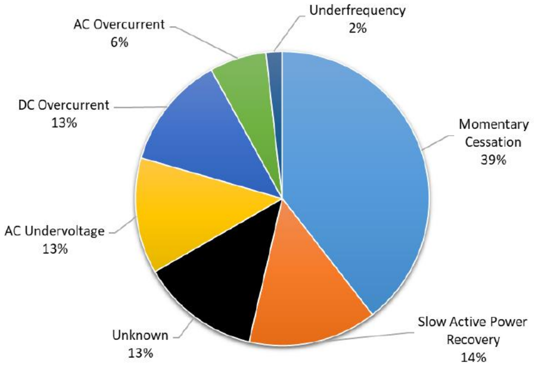


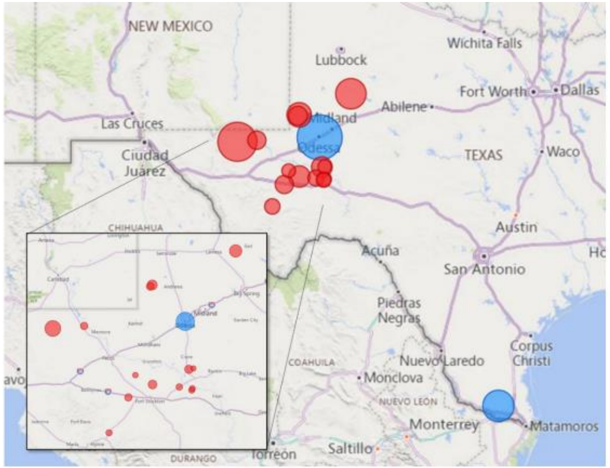
Figure 2.1: June 24 Disturbance Causes of Solar PV Reduction

Table ES.1: Overview of Disturbances

Disturbance and Name	Initiating Fault Event	Description of Resource Loss*
June 24, 2021 "Victorville"	Phase-to-Phase Fault on 500 kV Line	Loss of 765 MW of solar PV resources (27 facilities) Loss of 145 MW of DERs
July 4, 2021 "Tumbleweed"	Phase-to-Phase Fault on 500 kV Line	Loss of 605 MW of solar PV resources (33 facilities) Loss of 125 MW at natural gas facility Loss of 46 MW of DERs
July 28, 2021 "Windhub"	Single-Line-to-Ground Fault on 500 kV Circuit Breaker	Loss of 511 MW of solar PV resources (27 facilities) Loss of 46 MW of DERs
August 25, 2021 "Lytle Creek Fire"	Phase-to-Phase Fault on 500 kV Line	Loss of 583 MW of solar PV resources (30 facilities) Loss of 212 MW at natural gas facility Loss of 91 MW at a different natural gas facility

EMT for Interconnection Studies

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.

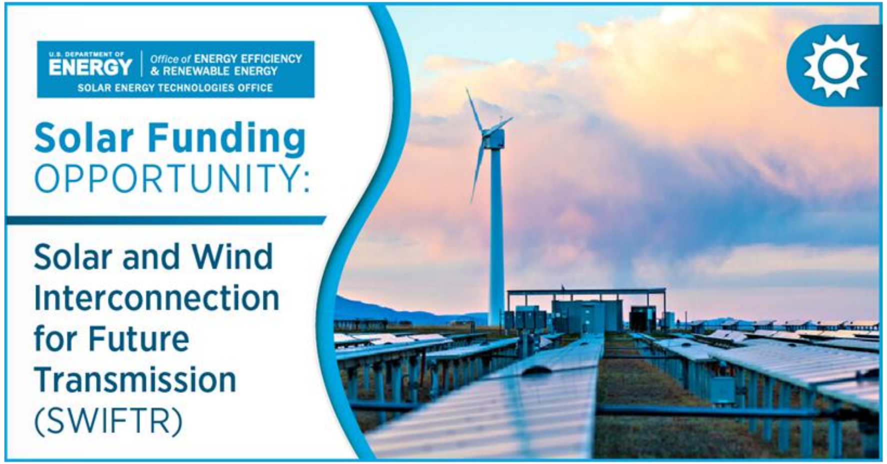
SETO Systems Integration R&D Activities

New Funding Opportunities - STRIVES

- **FOA released on 5/28/2024**
- **Concept papers due on 7/25/2024**
- $31 million to improve power systems simulation software tools and demonstrate new business models for distribution systems operations.
- Part of a collaborative effort by the DOE EERE to issue multiple FOAs totaling more than $100 million announced in April 2024 (**STRIVEs, Connected Communities 2.0, and SuperTruck Charge**)

- Topic 1: Robust Experimentation and Advanced Learning for Distribution System Operators – 8-10 projects, $2.5-3 million each
  - Projects in this topic area will design and perform field demonstrations of distribution system operator models that consider technology development and the roles of non-traditional stakeholders in potential distribution electricity services and markets.
- **Topic Area 2: Improved Simulation Tools for Large-Scale IBR Transient and Dynamic Studies – 4-5 projects, $1-2.5 million each**
  - Projects in this topic area will develop and demonstrate software tools and methodologies to improve the ability of power systems engineers to accurately and efficiently model the dynamics of power systems with large amounts of geographically dispersed IBRs.

New Funding Opportunities - SWIFTR



- FOA released on 3/19/2024
- Full applications due on 7/11/2024
- $10 million to develop new analytical tools and approaches that will accelerate the reliable interconnection of renewable energy into the electrical grid.
- **Part of DOE's i2X program and in collaboration with DOE Wind Office**

- **Topic Area 1: Improved Efficiency of Electromagnetic Transient (EMT) Simulations for Interconnection Studies of Inverter-based Resources (IBR) – 1-5 projects, $1-2 million each**
  - Projects in this topic area will create or improve software tools for EMT simulations and will determine when detailed EMT studies are needed and make these studies faster and more reliable to speed approval of interconnection requests.
- Topic Area 2: Dynamic Stability-Enhanced Network Assessment Tools – 1-5 projects, $1-2.5 million each
  - Projects in this topic area will fund grid operators to develop tools to provide interconnection stakeholders with data on transmission system characteristics such as stability, voltage, and grid strength while securing sensitive energy infrastructure information.

Other Recent Funding Programs

In May 2023, $26 million IIJA funding for 8 projects that will demonstrate **grid services and system protection** with solar, wind, and battery storage resources.

In March 2024, $34 million to fund 11 projects to develop new tools to enable **grid planners and operators to** reliably integrate solar energy and optimally utilize renewable resources.

In November 2022, $27 million for 17 projects to enable **communities** to utilize solar and solar-plus-storage for resilience planning.

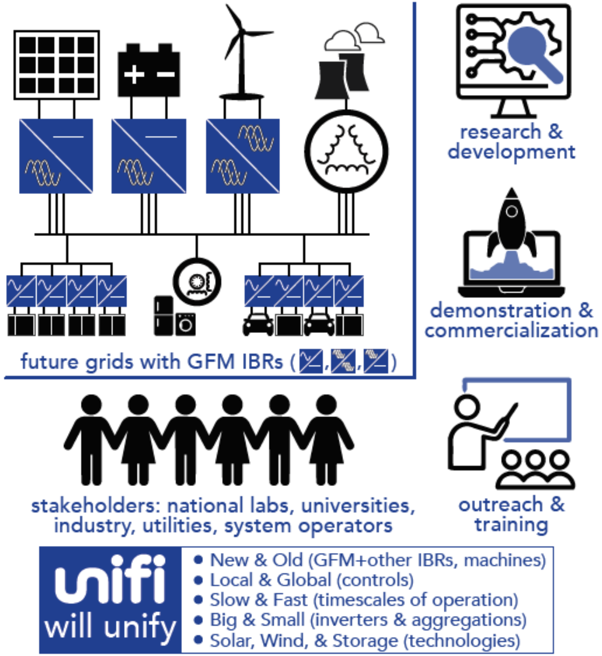
EMT Simulation for Grid-Forming Technologies (NREL)

UNIFI consortium - $25M over 5 years to establish a framework for continued industry collaboration on grid forming technologies.

PI: Ben Kroposki, NREL

Modeling and Simulation Area:

- **WECC-approved GFM models: REGFM_A1 and REGFM_B1**
- 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

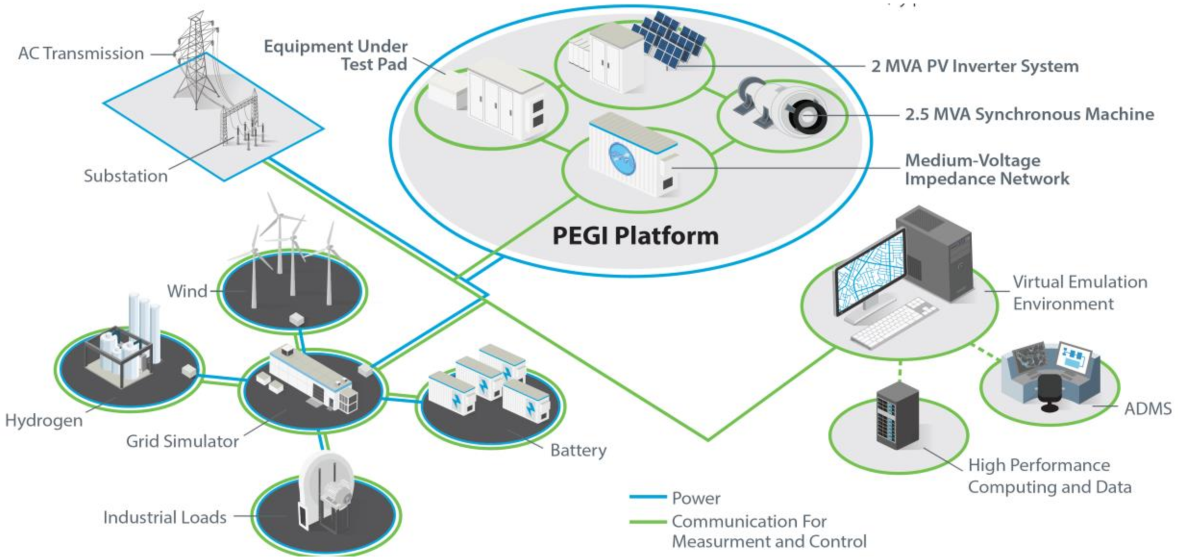


Project link:
1. https://sites.google.com/view/unifi-consortium/home
2. https://www.energy.gov/eere/solar/unifi-consortium

Power Electronics Grid Interface (PEGI) at NREL

A research platform to validate inverter-based resources and power electronic-dominant energy systems

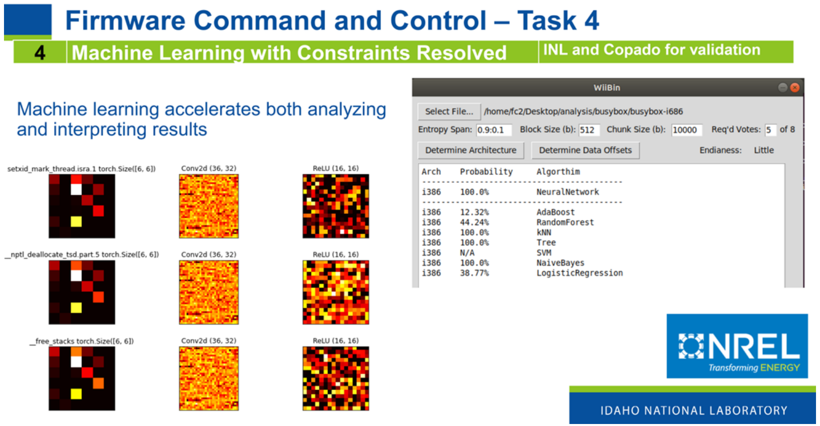
- Industry Workshop, May 24-25, 2023, https://www.nrel.gov/grid/power-electronics-grid-interface-workshop.html
- Call for proposals, DOE provides 50% cost share for partner research

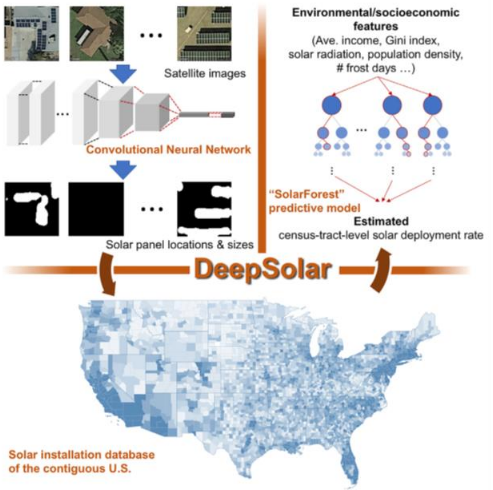


Applications of AI/ML in Solar Energy

01 Using AI/ML for power system modeling, situation awareness, control & optimization, solar and net load forecasting, cybersecurity, PV plant O&M, and much more

02 SETO FY2020 FOA Topic 7, 10 awards selected, https://www.energy.gov/eere/solar/seto-2020-artificial-intelligence-applications-solar-energy





Collaboration between INL, NREL, SNL, and ANL
@DisCo software won R&D 100 award

Stanford / SLAC

Unlocking the Value of Solar Forecasting

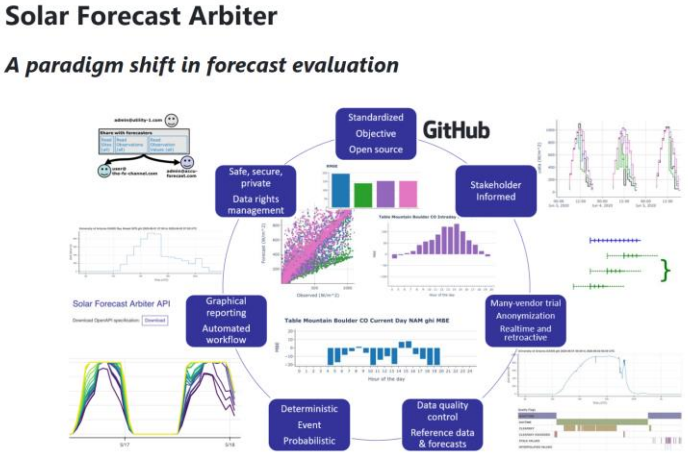
01 Round 1: October 2021, Solar Forecasting Prize
https://www.energy.gov/eere/solar/american-made-solar-forecasting-prize

02 Round 2: February 2023, Net Load Forecasting Prize
https://www.energy.gov/eere/solar/american-made-net-load-forecasting-prize

(Winners announced at RE+ 2023)

Solar Forecasting Funding Programs (2013 & 2017)

- Improve irradiance forecast
- Improve power forecast & utility integration
- Create benchmarking tools



(Source: University of Arizona/EPRI)

Interconnection Standards for Inverter-Based Resources

		Performance	Test & Verification & Model Validation
FERC / NERC?	Transmission	• FERC Orders • NERC Reliability Standards & Guidelines	• NERC compliance monitoring & enforcement
NARUC / State PUCs?	Sub-Transmission	• Not available	• Not available
	Distribution (for DER)	• IEEE Std 1547-2018 ✓	• IEEE 1547.1-2020 • UL 1741 (SB) • IEEE ICAP ✓

IEEE 2800-2022

IEEE P2800.2

DER: Distributed Energy Resource

When adopted by the appropriate authority (e.g., transmission owners/operators, NERC, FERC, distribution utilities), IEEE standards become mandatory

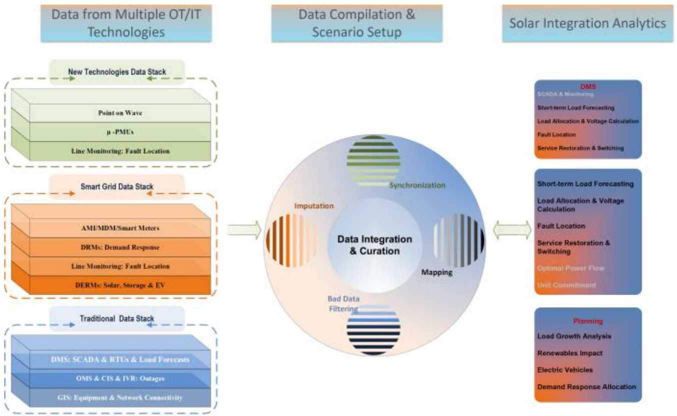
(Source: IEEE P2800 WG, Jens C. Boemer, Andy Hoke, et al)

INTERCONNECTION INNOVATION e-XCHANGE
U.S. DEPARTMENT OF ENERGY

Open Energy Data Initiative (OEDI SI) Model Validation Platform

1. To reproduce simulation results by using OEDI SI data and algorithm.
2. To replicate simulation results by using own data and OEDI SI algorithm.
3. To ensure algorithm is robust by using OEDI SI data and own algorithm.
4. To ensure algorithm and data is generalizable and scalable by extending OEDI SI data and algorithms

OEDI SI



https://openei.org/wiki/OEDI-SI/Overview

https://americanmadechallenges.org/challenges/3D-solar-visibility

Argonne NATIONAL LABORATORY | OAK RIDGE National Laboratory | NREL Transforming ENERGY | Pacific Northwest NATIONAL LABORATORY

Securing Solar for Grid (S2G) Program Activities

1. Regularly meet to assess current industry trends and facilitate discussion and debate on project priorities.
2. Coordinate activities and promotes collaboration with CESER and EERE offices.
3. Facilitate Industry Advisory Board meetings.
4. Facilitate periodic informational webinars, led or supported by the national labs.

Sandia National Laboratories

INL Idaho National Laboratory

NREL Transforming ENERGY

Pacific Northwest NATIONAL LABORATORY

Solar and DER Cybersecurity Research Areas

STANDARDS DEVELOPMENT & BEST PRACTICES

Stakeholder engagement to investigate gaps and develop best practices that can become standards to enable the secure integration of inverter-based resources and DERs.

EDUCATION & WORKFORCE DEVELOPMENT

Development of educational modules and training to increase cybersecurity awareness and knowledge within solar stakeholders.

CYBERSECURITY TOOL KIT & SUPPLY CHAIN

R&D of tools to understand cybersecurity posture, risk assessment to inform investments, and device design security & maturity model for cyber supply chain.

DEVICE

- CyberStrike for Solar
- S2D-C2M2
- Alignment with CESER activities
- ePV-CT
- CAS methods

PLANT

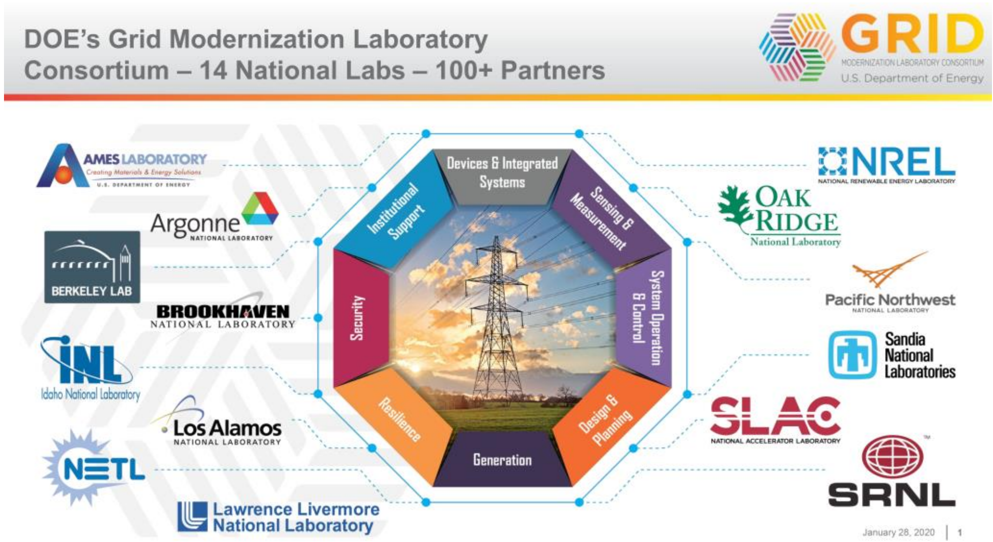
- SolarCERT
- Cyber Strike for Solar
- ePV-CT

SYSTEM

- CyberStrike for Solar
- ePV-CT
- CPYDAR
- UUDEX for solar
- SOAR
- DERMS cyber requirements

INCREASING CYBERSECURITY LEVELS OF SOLAR TECHNOLOGIES

Grid Modernization Initiative – DOE-Wide Collaboration



Collaboration with DOE Offices

GDO
LPO
OCED

EERE (BTO, WETO, ...)
Office of Electricity
CESER
Office of Science

PV-MOD (EPRI)

SETO FY19 Funding Opportunity

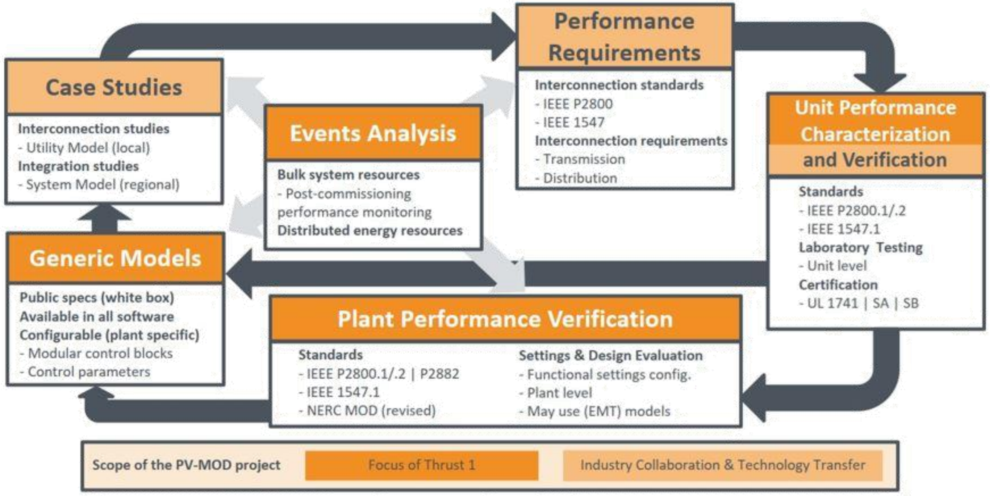
PI: Jens Boemer, EPRI

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



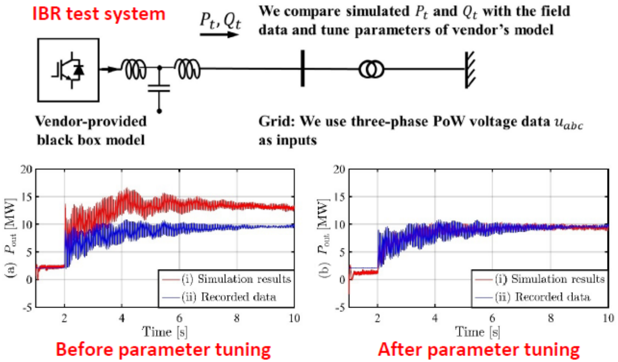
Project website:
https://www.epri.com/pvmod

ParaEMT - An Open Source, and HPC-Compatible Large-Scale Power System Electro-Magnetic Transient (EMT) Simulator

PI: Jin Tan, NREL

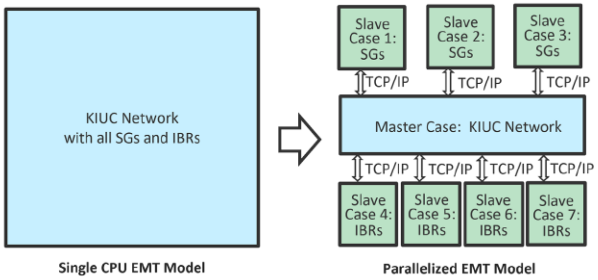
Event Replay: Kaua`i EMT Model Development

Emphasize IBR model validation process



The vendor-provided IBR EMT models should be validated against field data before being connected to the whole KIUC model.

Accelerate EMT simulation speed



Before: 269 s* After: 180 s

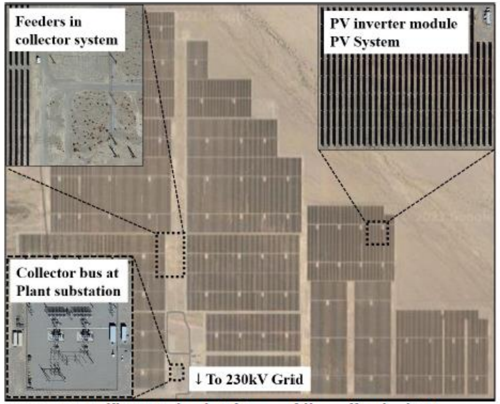
* Simulating KIUC EMT model for 10s in PSCAD

We accelerate the KIUC EMT model simulation speed through parallel simulation.

High Fidelity Modeling of Large-Scale PV Plant for EMT Simulation (ORNL)

PI: Suman Debnath, ORNL

High-Fidelity EMT Dynamic Model of PV Plant:



Specific PV plant-1 (One of the affected PV plants during Angeles Forest fire event)

High-Fidelity Models

- Hundreds-thousands of inverters
  - Non-linear non-autonomous hybrid switched-system models
- Hundreds of distribution transformers
- Many distribution lines
- ***Represent partial momentary cessation and shutdown (or during ride-through)***

Challenges

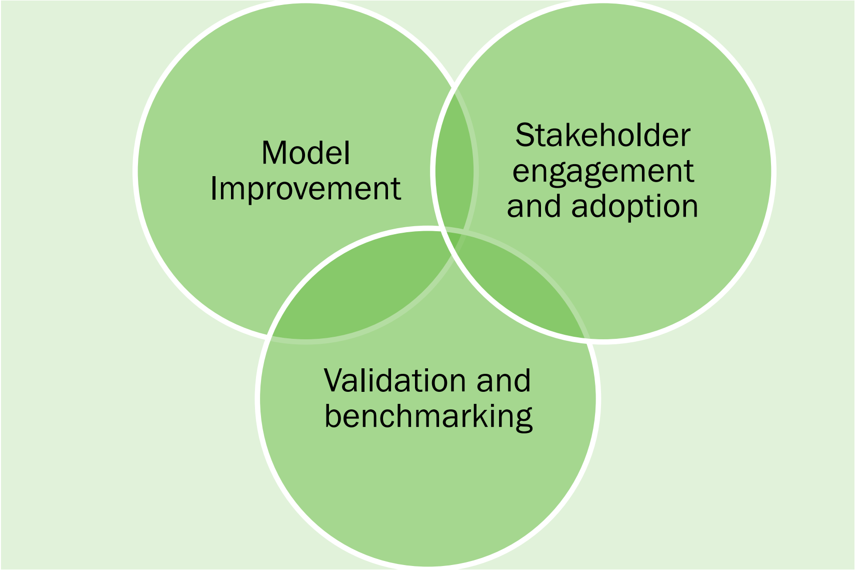
- ***Time consuming nature*** of running these simulations in traditional simulators using library models (e.g., **very long time to run 0.1 s** in a large PV plant model)

Solution

- Use ***advanced numerical simulation algorithms*** to speed-up simulations**

Next Steps

- EMT model improvements (accuracy, complexity, computation speed)
- EMT model validation using real world data
- Standardized use cases and benchmarking tools
- Stakeholder engagement and industry adoption (OEMs and utilities)



Learn About Upcoming 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: guohui.yuan@ee.doe.gov