Distributed Energy Resources Siting and Optimization Tool for California

Partners: Lawrence Berkeley National Laboratory, Lawrence Livermore National Laboratory, SLAC National Accelerator Laboratory, National Renewable Energy Laboratory, Brookhaven National Laboratory, Argonne National Laboratory

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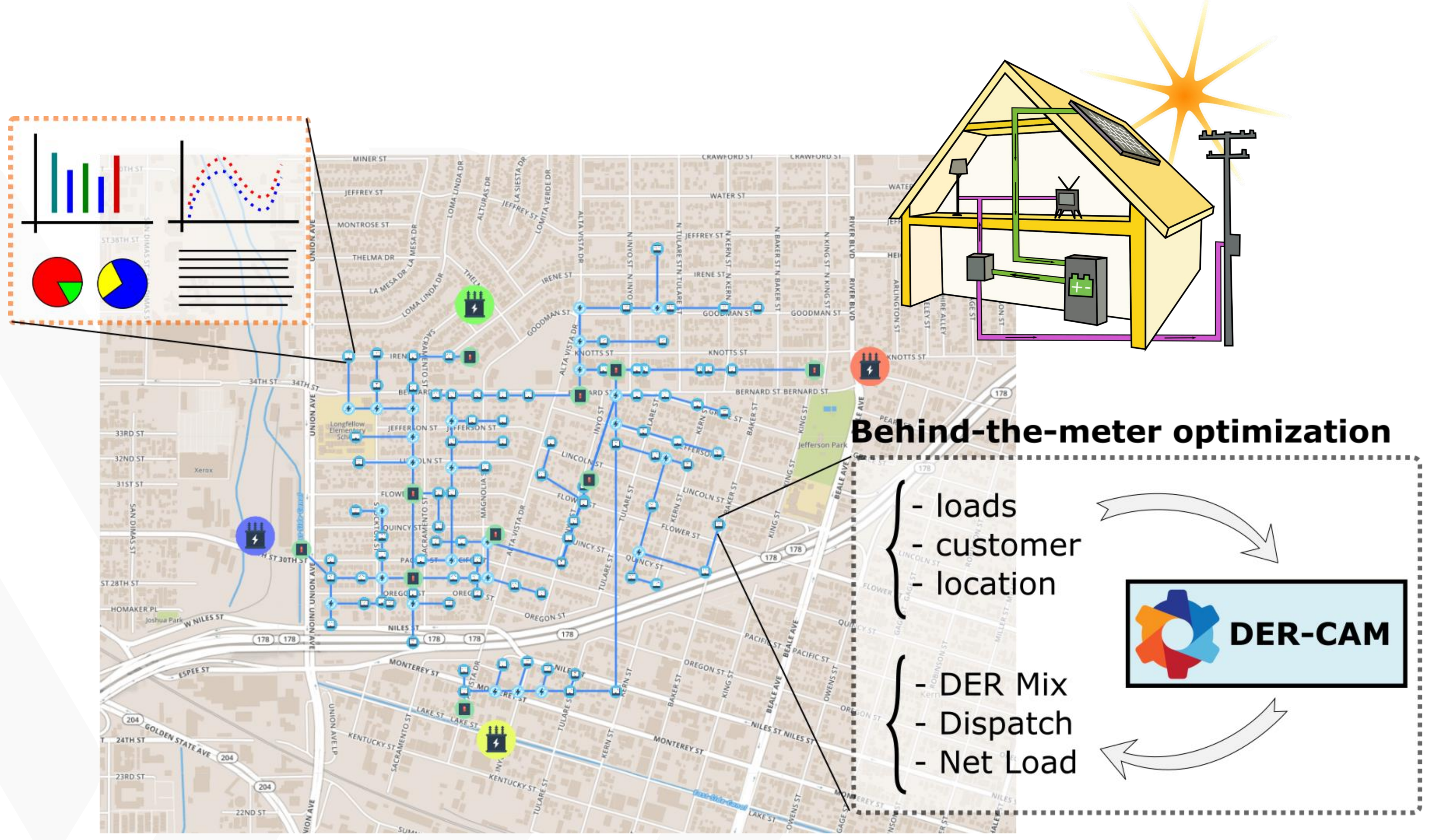
Project Description

Prototype modeling framework for integrated **distributed resource planning and optimization,** able to identify **Distributed Energy Resources (DER) adoption** patterns, **microgrid sites**, and evaluate **DER impacts** on the distribution and transmission grid.

Combines key capabilities from national labs to address gap in DER modeling tools by linking behind-the-meter DER modeling with Transmission & Distribution co-simulation and visualization. Provides first step towards detailed holistic system-wide modeling of DER impacts and benefits.



Many states are deploying DER aggressively, the challenge is lack of tools to understand most cost-effective locations and impact on overall-system reliability.

Expected Outcomes

- Mapping of most cost-effective DER sites
- Identify DER operational strategies
- Analyze value of DER as grid assets
- Evaluate impacts of DER on the bulk electric grid system
- California as starting point for wider application

Significant Milestones	Date
Initial data collection; stakeholder engagement	06/30/16
Data collection & conversion; Behind-the-meter model automation and development of integration components	09/30/16
Finalize development of core software components	12/31/16
Final delivery of software platform, project demonstration, and outreach	09/30/17

Progress to Date

End-to-end DER siting tool prototype:

- Transmission & Distribution co-simulation for California
- Distributed Energy Resources Customer Adoption Model (DER-CAM) enhancements & data
- Model integration and APIs
- Visualization front-end and database

Stakeholder engagements:

- California Public Utilities Commission (CPUC) engagement:
  - Contributions to Distribution Resources Plan working group meetings
  - Validation of Integration Capacity Analysis methods
- Technical advisory committee meeting including CPUC, California utilities, and third-party industry representatives

Alaska Microgrid Partnership

Partners: NREL, LBNL, SNL, PNNL, Renewable Energy Alaska Project, Alaska Center for Energy & Power, Intelligent Energy Systems, Alaska Institute of Social & Economic Research

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Project Description

Develop and implement a pathway of technical and economic assessment leading to a 50% imported energy displacement in remote, islanded Alaskan community microgrids. This project marks the first time a consortium of DOE national laboratories and Alaska organizations is undertaking this type of project in a holistic way.

Expected Outcomes

- Document the full techno-economic development process for reducing imported fuel consumption by at least 50% in remote microgrids in Alaska.
- Identify investible opportunities (i.e., the business case) to attract the funding needed to implement these types of projects on a large scale.
- Create an implementation methodology for other communities to follow by documenting and publicizing the community assessment, data collection, project analysis, and development processes.
- Implement the methodology in two pilot communities, providing models so that additional communities can undertake similar efforts, including seeking private and public funding to implement project recommendations.
- Expand the existing Alaska Energy Data Gateway to make all relevant products from this work available to communities across Alaska.
- Ensure that this process is applicable internationally, helping to address issues around providing reliable power to isolated communities across the globe while providing a baseline of understanding for microgrids in general.

More than 200 Alaskan communities must import energy, typically at very high cost.

Challenges include outdated power system technology and poor energy efficiency.

Pathway for Holistic Community Microgrid Development

- Assess: Determine community readiness (capacity)
- Conduct: Conduct needs assessments (EE, RE, buildings, transportation)
- Analyze: Analyze opportunities using existing analytical tools
- Consider: Determine what new technologies may be appropriate and which options should be considered
- Design: Design projects and systems to meet project objectives
- Finance: Determine the mix of private and public funds necessary to implement design
- Share: Share information to attract project developers and financing (private and public)

Significant Milestones	Date
Complete Community Readiness Indices	7/1/2016
Identify pilot communities	8/1/2016
Complete initial draft of the remote system Design Basis Framework	4/15/2017
Complete generic business case analysis	7/1/2017
Complete final technical and business case studies for two pilot communities	10/1/2017
Complete expansion of the Alaska Energy Data Gateway, making all results available	10/1/2017

Progress to Date

- Developed community readiness indicators to assess capacity of communities to consider a revamp of their energy infrastructure.
- Selected and initiated analysis of the two pilot communities (Shungnak and Chefornak).
- Initiated detailed community-level data collection and design analysis on pilot communities.
- Convened project advisory committee comprised of a diverse group of Alaska stakeholders.
- Met with financiers to understand investment criteria.
- Screened and selected techno-economic modeling tools; screening criteria to be made available.
- Initiated planning for diesel system testing and storage technology options to inform modeling.
- Facilitated ongoing discussion with entities to leverage efforts while reducing potential for project overlap.
- Initiated updating of the Alaska Energy Data Gateway.

Interconnections Seam Study 1.3.33

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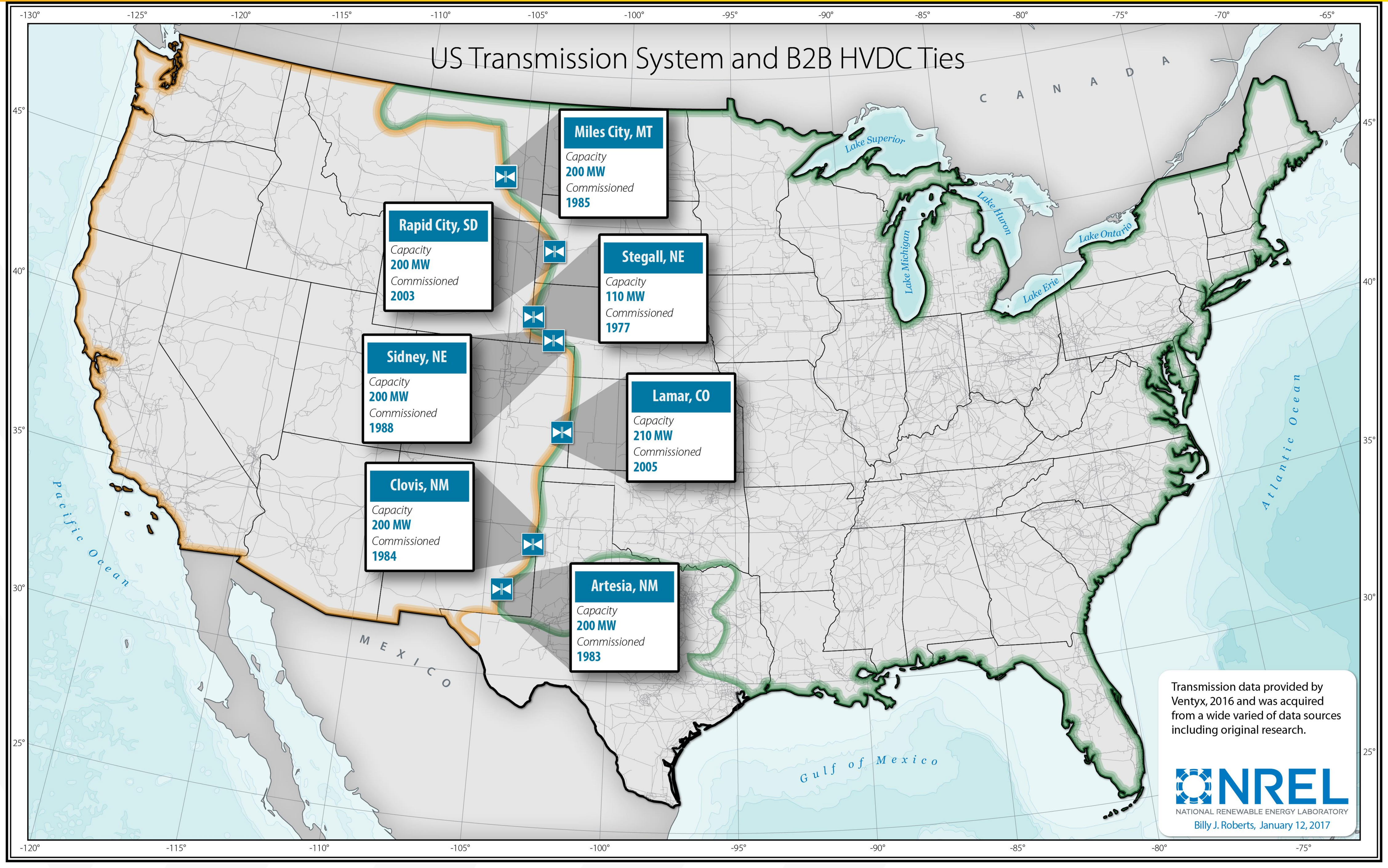
A Diverse and Divided System

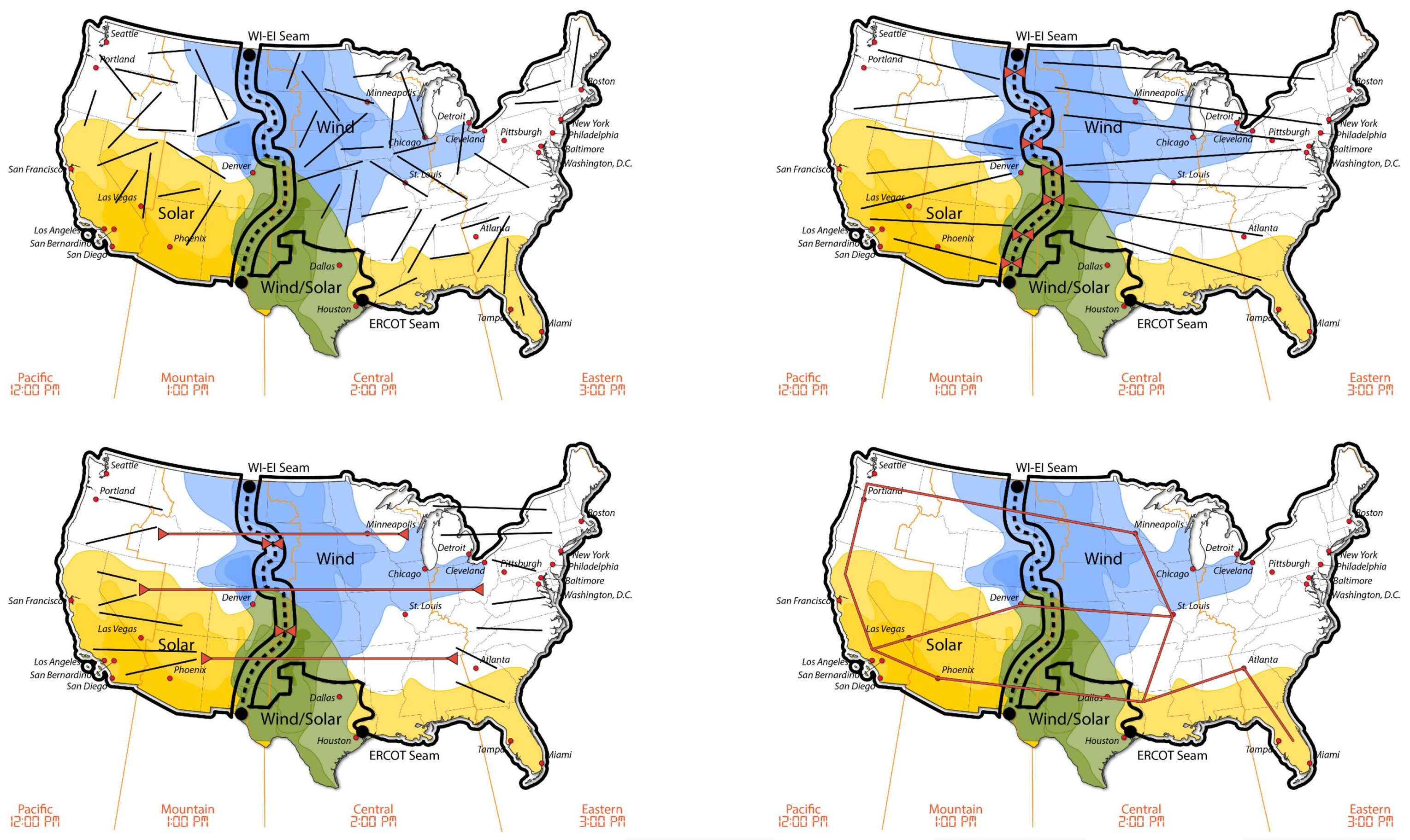
At the western edge of the American prairie, just east of the Rocky Mountains, lies a collection of electrical resources that string together the workhorse of the American economy: the United States power system. Seven back-to-back high voltage direct current facilities (top right) enable ~1,400 megawatts of electricity to flow between the Eastern and Western Interconnections. The 1,400 MW of transfer capability between the interconnections isn't much more than a rounding error compared to the size of the networks they connect—the larger Eastern Interconnection is home to 700,000 MW of generating capacity. But these facilities, located strategically where the East meets the West, are aging rapidly and they present a timely and impactful opportunity to modernize the U.S. electric grid.

System planners in central U.S.—utility executives, entrepreneurs and investors, land use authorities at the local, county and state level, as well as various utility industry regulators—are faced with a dilemma. On one hand, power system planners in this part of the country could act locally, and focus on their individual footprints, meeting their system demand as they see it. On the other hand, system planners could see a national opportunity to use the region's natural resources to drive down electricity costs and drive national economic growth. How big are the differences between these futures, and what are the options for getting the most out of the region's natural resources?



Too Big?

The Interconnections Seam Study is the most ambitious power systems study ever conducted. It is an industry driven regional partnership with the **Midcontinent Independent System Operator**, **Southwest Power Pool**, and **Western Area Power Administration**. These three groups, and a Technical Review Committee (bottom center), knew the questions they wanted to answer, but they needed National Laboratories and **Iowa State University**. They came to DOE to leverage the state-of-the-art data, advanced methods, High Performance Computing, and ability to convene a stakeholders to analyze 4-transmission futures (below).



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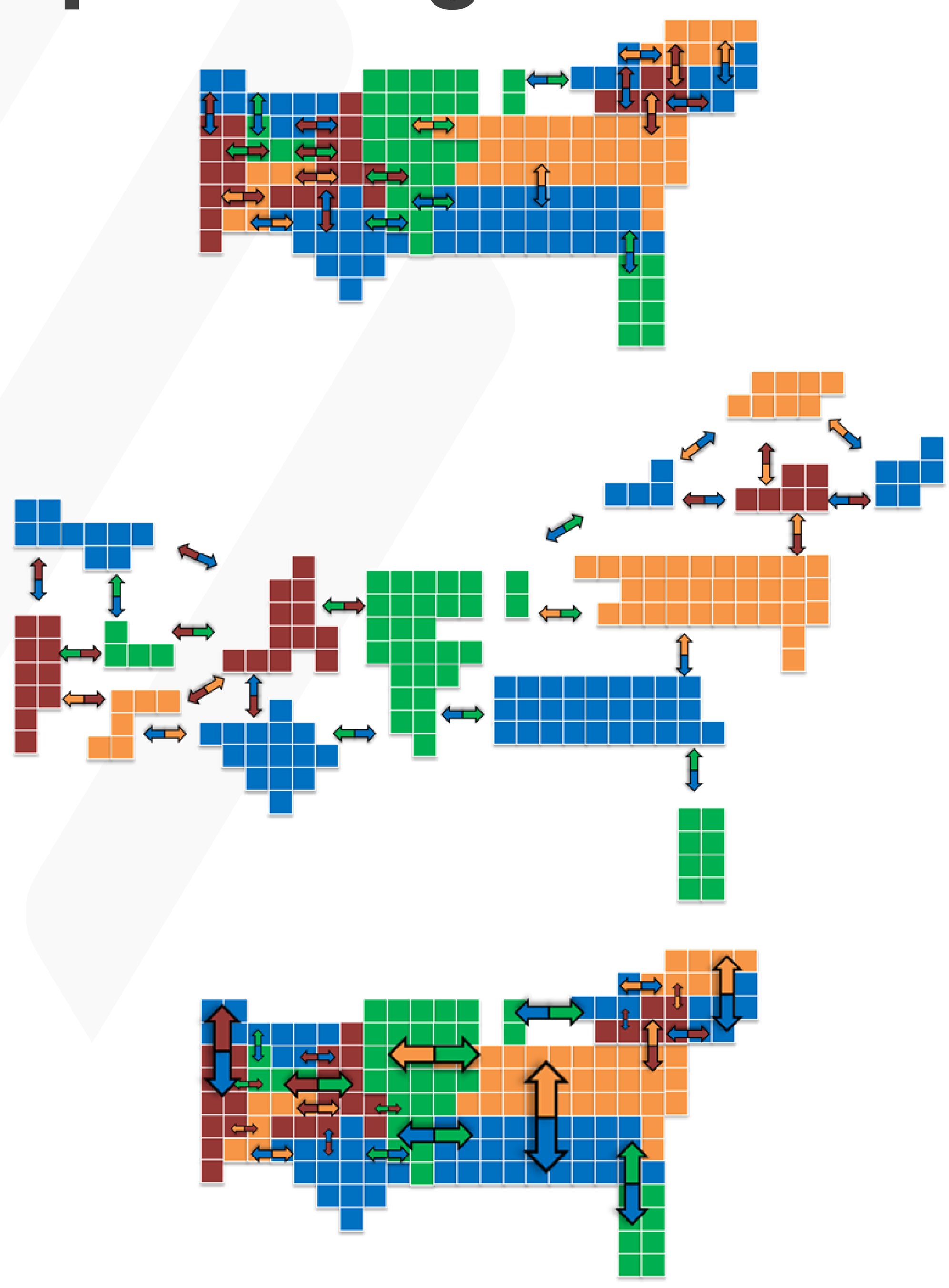
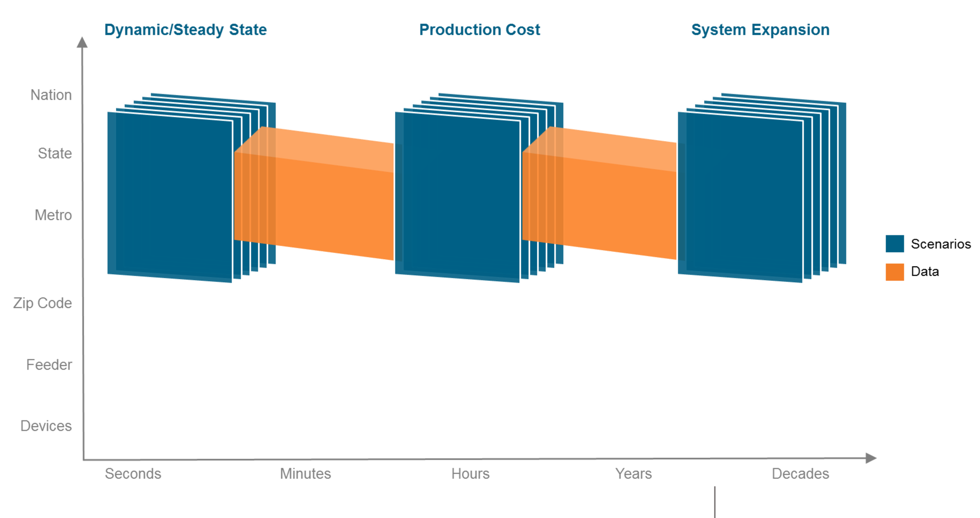
Advanced Methods, Deeper Insights

The Interconnections Seam Study provides a wide area view of the reliability and efficiency of 4-transmission futures for the U.S. The analysis includes three classes of power systems modeling tools: System Expansion, Production Cost, and Steady State (bottom right). This is the first time DOE has funded a project of this scale that includes all three power systems modeling domains. Because of the computational burdens associated with a project this broad, new methods (right) and models are being developed and applied to this work. Using these capabilities they are exploring questions that were never before possible, and they are answering those questions with increased confidence.





Integrated Transmission, Distribution, and Communication Models

Performers: PNNL, LLNL, NREL, ANL, ORNL, SNL, INL

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Project Description

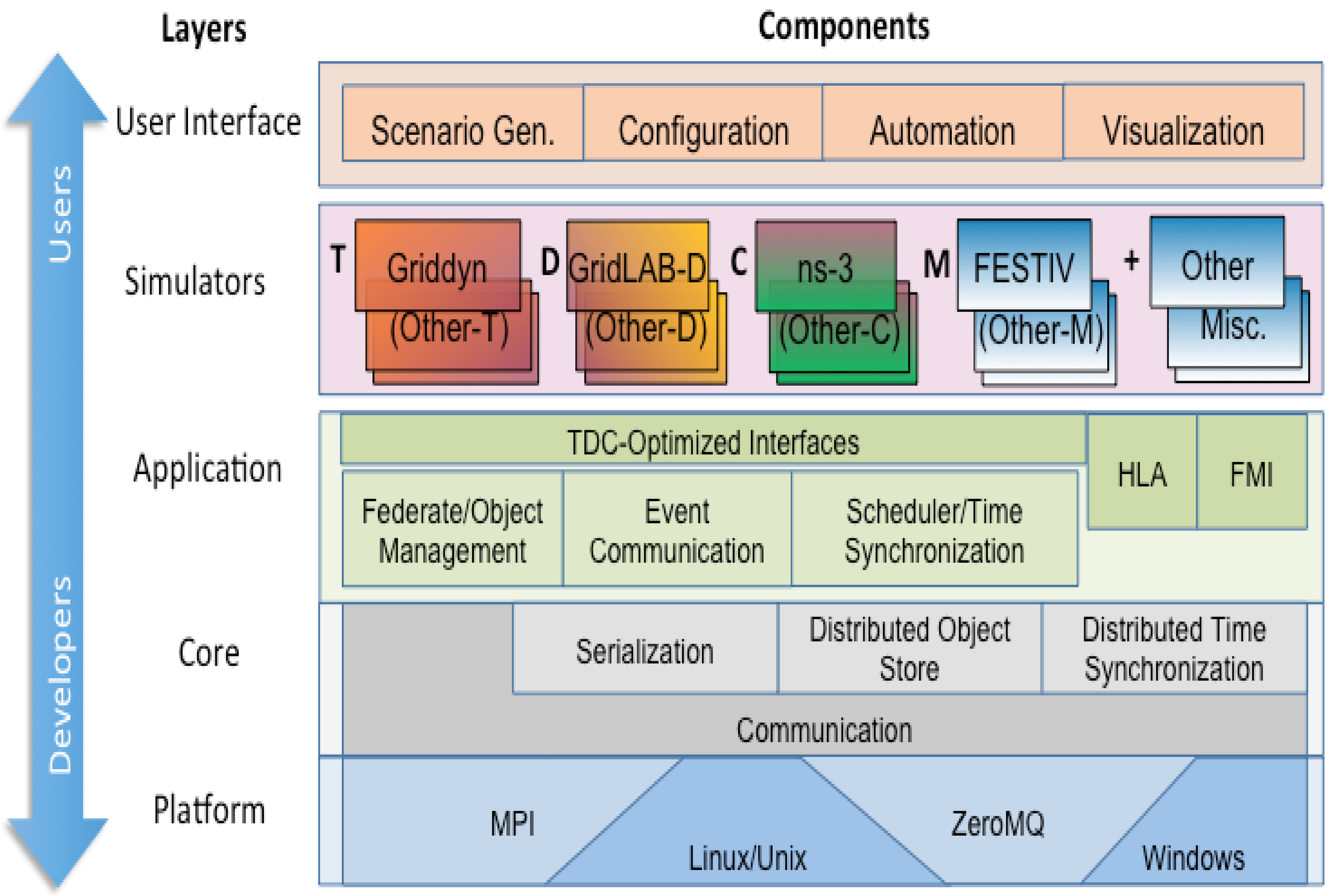
- The electric power system is becoming more integrated and complex with the wide spread of distributed energy resources and abundant communication systems.
- The interdependency and interaction across transmission, distribution and communication systems can no longer be ignored, demanding integrated analysis of the end-to-end power grid.
- This project aims to develop a scalable co-simulation platform and enable such integrated analysis to maximize flexibility and resilience of the grid.

Expected Outcomes

- Fill current gaps in simulation and modeling technology that inhibits integrated planning across multiple domains.
- Bring together best-in-class simulation efforts from multiple national labs.
- Create HELICS™, an **open-source co-simulation platform**, enabling interactions between leading commercial & lab-developed simulators on a wide range of computing environments.

Image from smartgrid.ieee.org

	Significant Milestones	Date
✓	Documented 12 initial use cases.	9/1/2016
✓	Held TRC webinar to review use cases and initial HELICS design.	12/1/2016
✓	Documented requirements, metrics, and design of HELICS through use case analysis.	3/1/2017
	Host technical review meeting with stakeholders.	6/1/2017
	Deliver guiding document on TDC co-simulation.	6/1/2017
	Release v0.1 of HELICS platform to open-source.	6/1/2017



HELICS (Hierarchical Engine for Large-scale Infrastructure Co-Simulation) platform is designed to be modular and flexible to future needs

Progress to Date

- Developed and documented 12 use cases to guide HELICS development and benefit the broad community.
- Developed an initial version of the use-case driven HELICS platform, with documentation, on a collaborative GitHub project repository (>200 commits).
- Implemented 3 prototype use cases with the HELICS platform for demonstration of functionality and value.
- Initiated a "guiding document" to be released in May.
- Conference paper on HELICS design accepted in *2017 Workshop on Modeling and Simulation of Cyber-Physical Energy Systems.*
- Reviewed use cases at TRC webinar in November 2016. Next TRC meeting scheduled for May 2017 to review HELICS.

Technical Review Committee: Southern California Edison, National Grid, PJM, Peak Reliability, InterPSS Systems, MITRE Corporation, University of Arizona, Nexant, Washington State University, General Electric, Electric Power Research Institute, National Rural Electric Cooperative Association

Extreme Event Modeling

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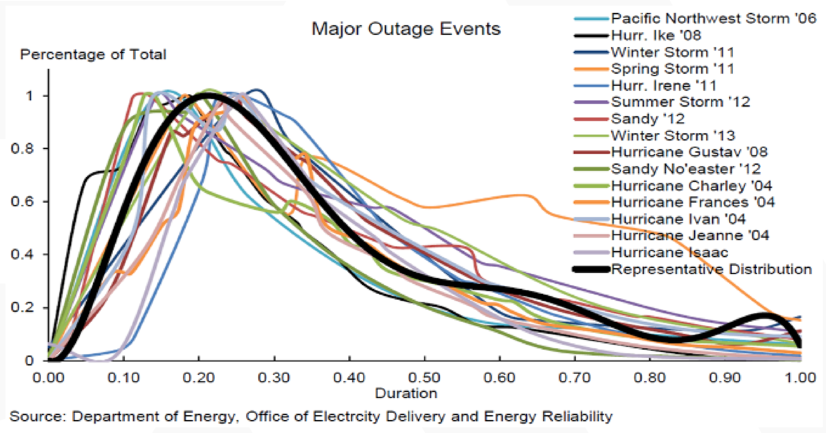
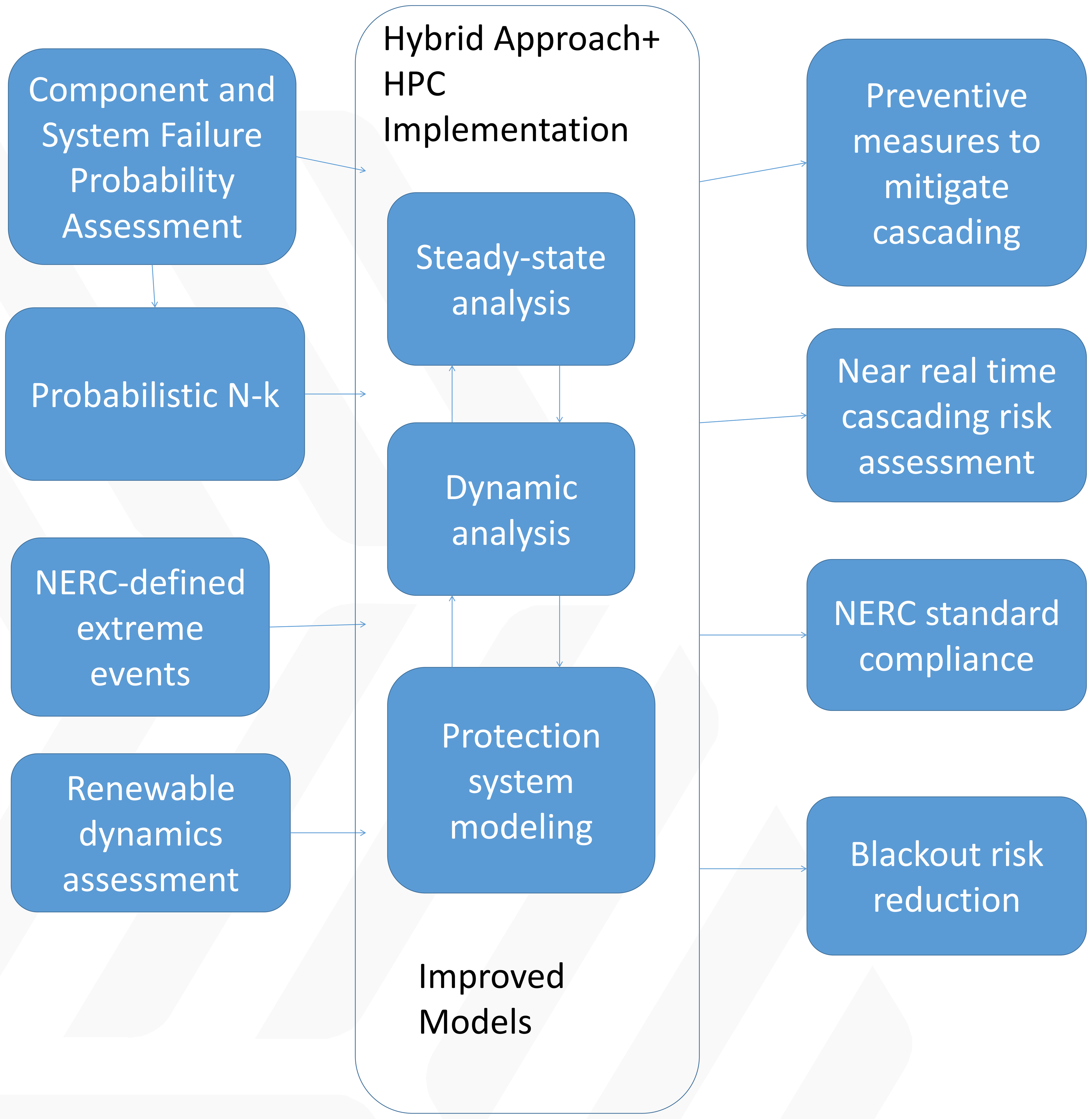
Russell Bent, (LANL) Yuri Makarov (PNNL), Liang Min(LLNL), Junjian Qi (ANL), Yilu Liu (ORNL), Meng Yue (BNL), Kara Clark (NREL), Jean-Paul Watson (SNL)

Project Description

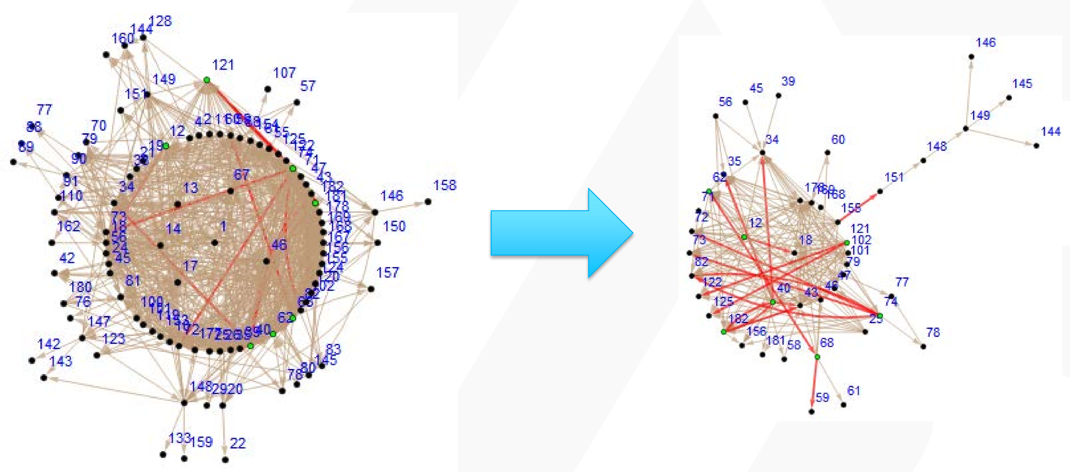
Extreme events pose an enormous threat to the nation's electric grid and the socio-economic systems that depend on reliable delivery of power.

- Superstorm Sandy, Hurricane Katrina, the 2003 Northeast blackout
- Component Failure (N-k) and Sequential Component Failure (Cascade) modeling has large gaps
  - Cascade models having missing details
    - Low fidelity
    - Reliability regulations difficult to satisfy
      Example: NERC TPL-001-4
  - Simulations of cascades are slow
    - Impractical for real-time planning exercises
  - Component failures (N-k contingency analysis)
    - Existing approaches address a small number of failures (k < 4)
    - Existing approaches assume all failures are equally likely

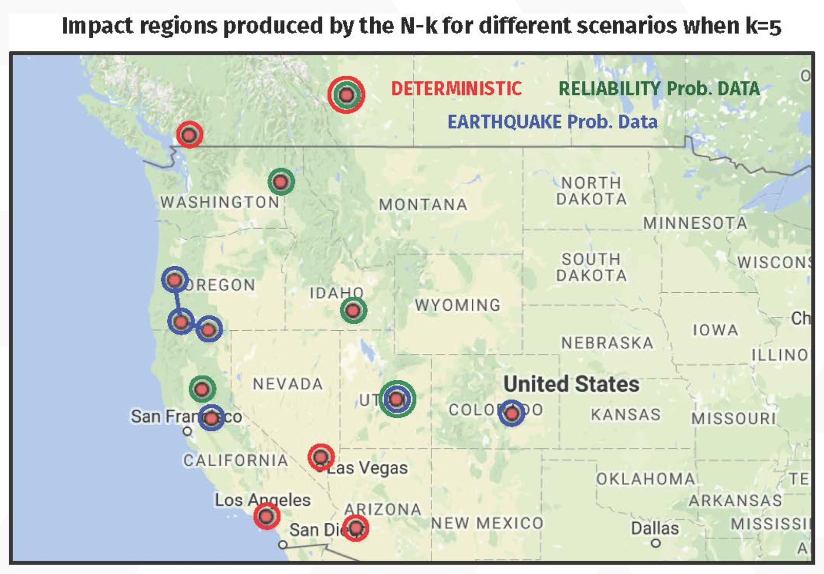




Cascade simulation speed ups



Contingency Analysis with Probabilities



Expected Outcomes

- A prototype set of tools for efficient cascade modeling and probabilistic N-k identification.
- Tools that are 500x faster than existing industry cascade simulation packages
- Identify the worst (probabilistic) k contingencies where k is twice as big as existing practices

Significant Milestones	Date
Implementation of Zone 3 Protection in Cascade Models	1/1/17
Survey of Past Outages and Extreme Events	1/1/17
Extreme Event Research and Development Strategy Document	4/1/17
Cascade modeling tools demonstrate 10x of cascade simulations as compared to existing tools	10/1/17
Scale N-k approaches to networks that are 10x larger than existing tools can handle	10/1/17
Cascade modeling tools demonstrate 100x of cascade simulations as compared to existing tools	10/1/18
Open source prototype tools release that 1) Integrates multiple temporal scales, protection system modeling, and renewables into cascade models, 2) demonstrates 500x speedup of cascade simulations as compared to existing tools, and 3) improves computation of N-k by increasing k by twice as much over existing practices.	4/1/19

Progress to Date

- Extreme event modeling strategy document
  - Gaps in extreme modeling, directions for addressing gaps
- Industry Webinars
  - June 16, 2016, Jan. 25, 2017
  - FERC, Caiso, Idaho Power, MISO, PLM, DOM, SPP, NERC, DVP
- Publications
  - X. Zhang, Y. Xue, Y. Liu, J. Chai, L. Zhu, and Y. Liu, *Measurement-based System Dynamic Reduction Using Transfer Function Models*, submitted to 2017 North American Power Symposium (NAPS)
  - Q. Huang, B. Vyakaranam, R. Diao, Y. Makarov, N. Samaan, M. Vallem, and E. Pajuelo, *Modeling Zone-3 Protection with Generic Relay Models for Dynamic Contingency Analysis*, PES General Meeting, 2017
  - Wenyun Ju, Kai Sun, and Junjian Qi, *Multi-Layer Interaction Graph for Analysis and Mitigation of Cascading Outages*, IEEE Journal on Emerging and Selected Topics in Circuits and Systems, under review

Computational Science for Grid Management

ANL, PNNL, NREL, SNL, LLNL, LANL

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Project Description

- **Computational algorithms** in today's planning and design codes are **too slow** for new mixes of generation, 'smart' controls, and distributed resources.
- Project focuses on key technology gaps for scalable math libraries / frameworks that unify algorithms for optimization, dynamics, and dynamics required in a wide range of grid modeling.
- This project aims to develop a software framework and solvers and reduce time to solution by >100 fold, leading to higher reliability and flexibility.

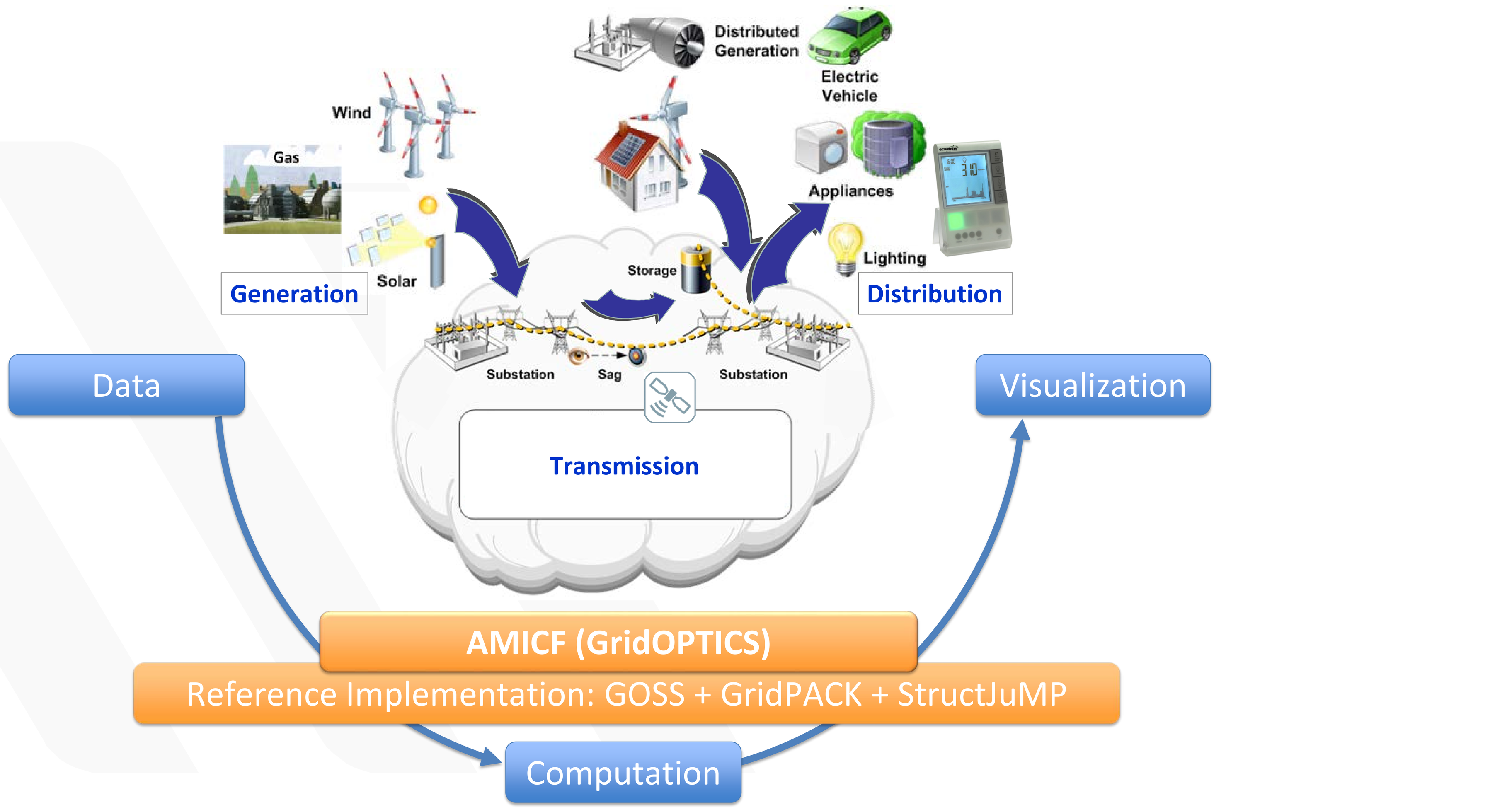
Expected Outcomes

- Improve computing performance – Design and develop open-source solvers for 100x faster performance in grid applications on optimization, uncertainty, and dynamics.
- Reduce software costs – Apply innovations in new computational tools (StructJuMP) to develop advanced framework (AMICF) that allows 10x faster prototyping of computationally-intensive analyses.
- Demonstrate value – Show benefits of the framework and solvers through high-value use cases with interconnection-scale power grids.

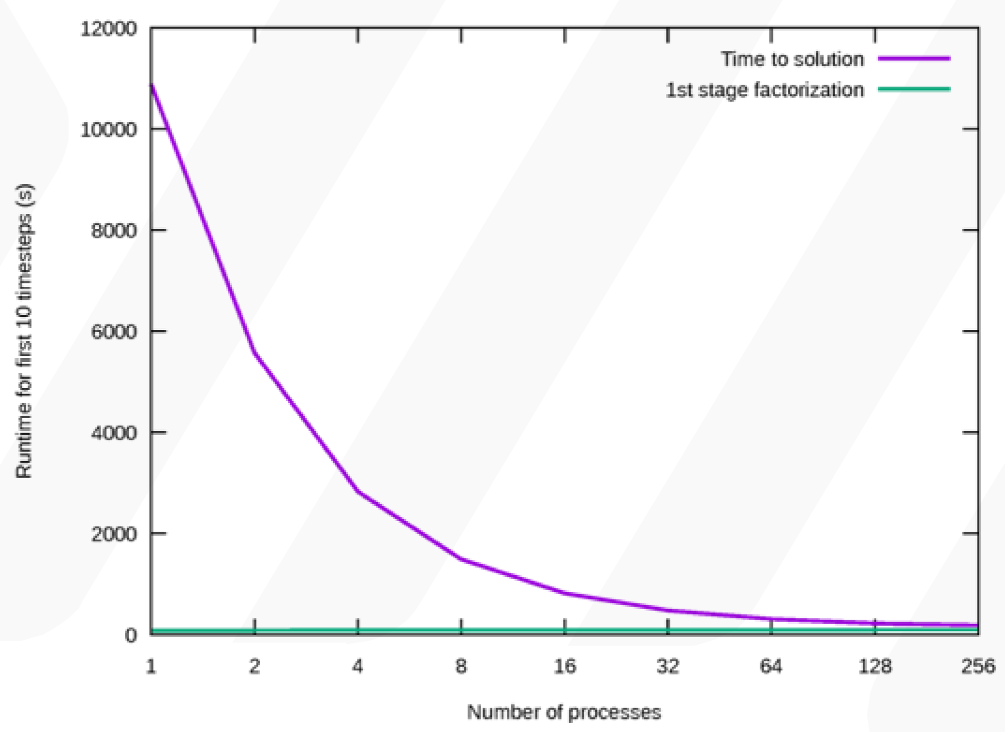
Expected Impact

- Enable leaner-margin grid operation by reducing assumptions and conservativeness through high-efficient computation.
- Improve reliability with predictive analytics only achievable with the improved computational capabilities.
- Increase flexibility of operation and planning through efficient holistic analysis and optimization of the grid and its dependency on other energy systems.

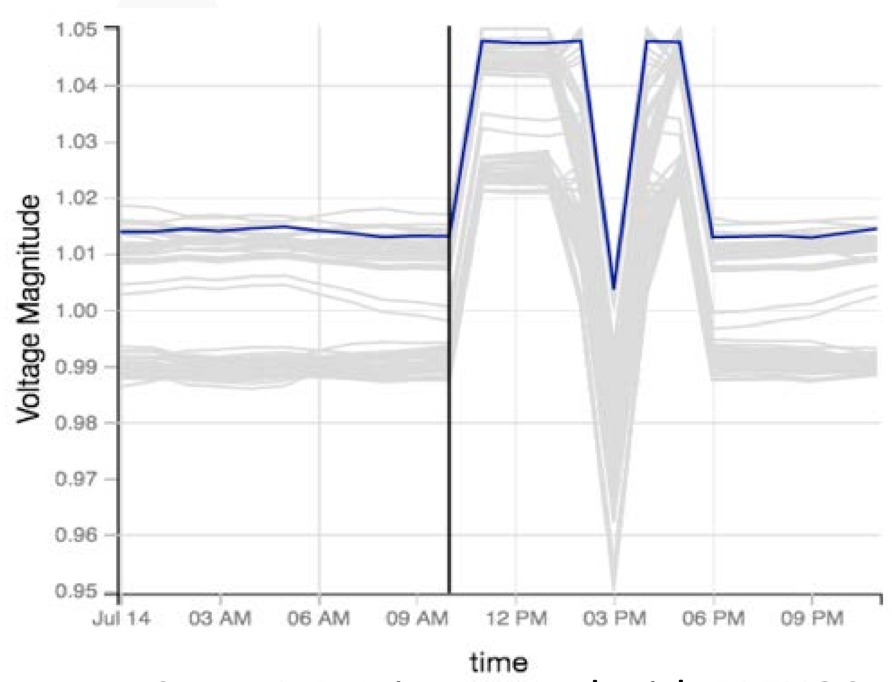
Significant Milestones	Date
Middle of the road parallel runs for SCOPF with the PIPS-NLP suite using StructJuMP annotations.	09/30/2016
Conduct a stakeholder workshop and produce framework design document.	11/23/2016
Demonstrate AMICF prototype on Industry inspired use case using NREL data.	03/31/2017
AMICF parallel nonlinear optimization under uncertainty capability run.	03/31/2017
Estimation of margins reduction due to transient expression in optimization problem.	03/31/2017



Complexity in grid and energy systems demands new computational framework and solvers



PIPS-NLP, reduces StructJuMP SCACOPF Runtime from 10 hours to 10 minutes



StructJuMP integrated with PLEXOS produces voltage swing information

Progress to Date

- StructJuMP, an open-source HPC library for scalable, parallel nonlinear modeling was released in FY 16 Q4.
- Reference implementation of the AMICF framework with GridOPTICS components (GOSS + GridPACK) and StructJuMP, linking data to computation and visualization.
- PIPS-NLP was optimized to solve StructJuMP SCACOPF with *2869 buses and 512 active contingencies in 10 minutes.*
- StructJuMP was integrated with PLEXOS to evaluate uncertainty effects at voltage and congestion levels.
- An industry-attended stakeholder workshop as organized in November 9-10 to provide feedback on framework and the use cases defined to guide the framework/solver development. Industry articipants included ISO-NE, MISO, SCE, General Electric, Powertech Labs, UTRC, GEIRI-NA SGCC, and Glarus.

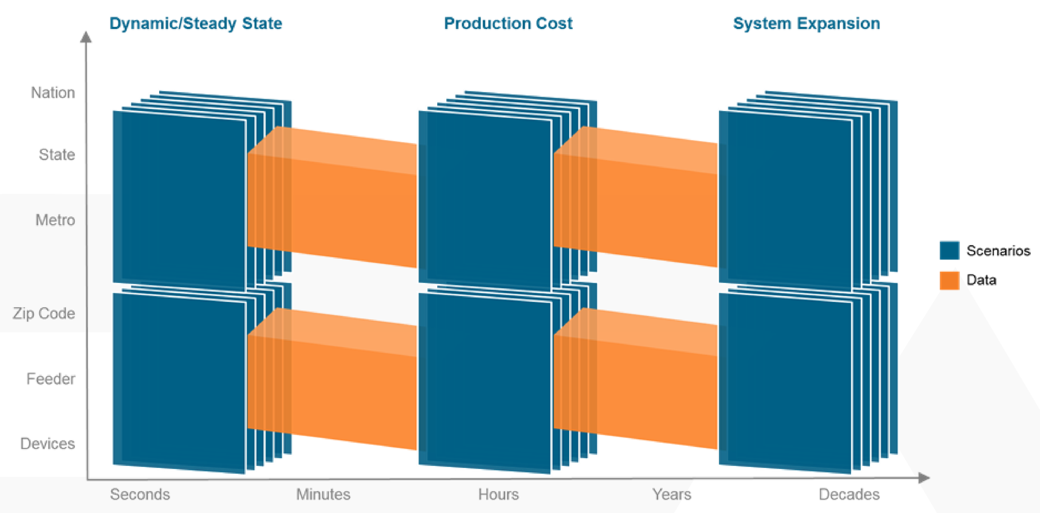
Multi-scale Production Cost Modeling

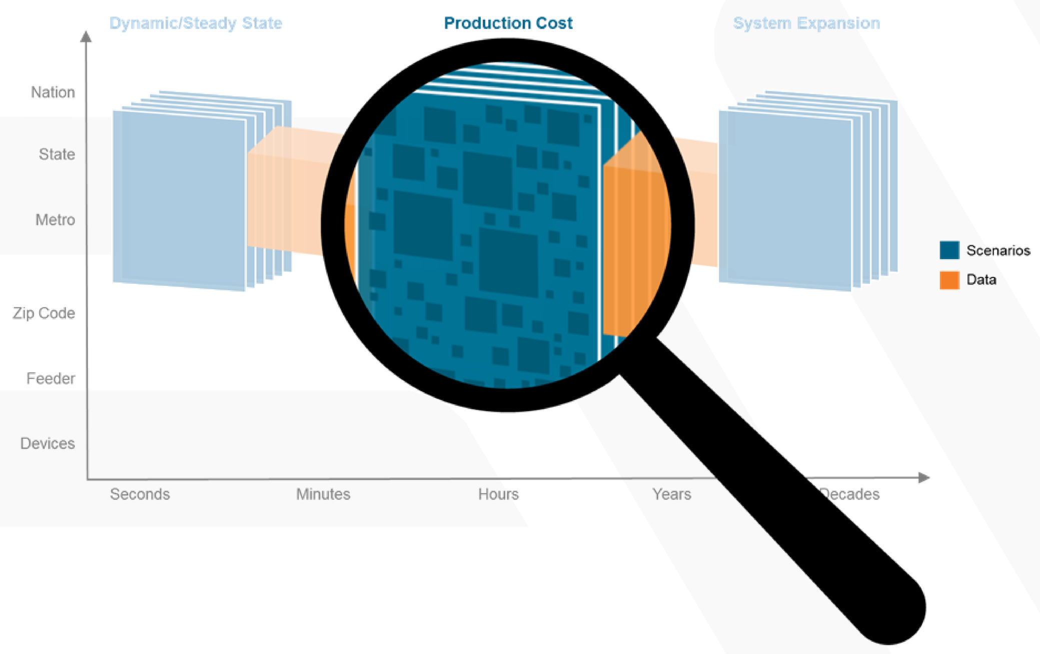
Partners: NREL, SNL, ANL, LLNL, PNNL

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

Project Description

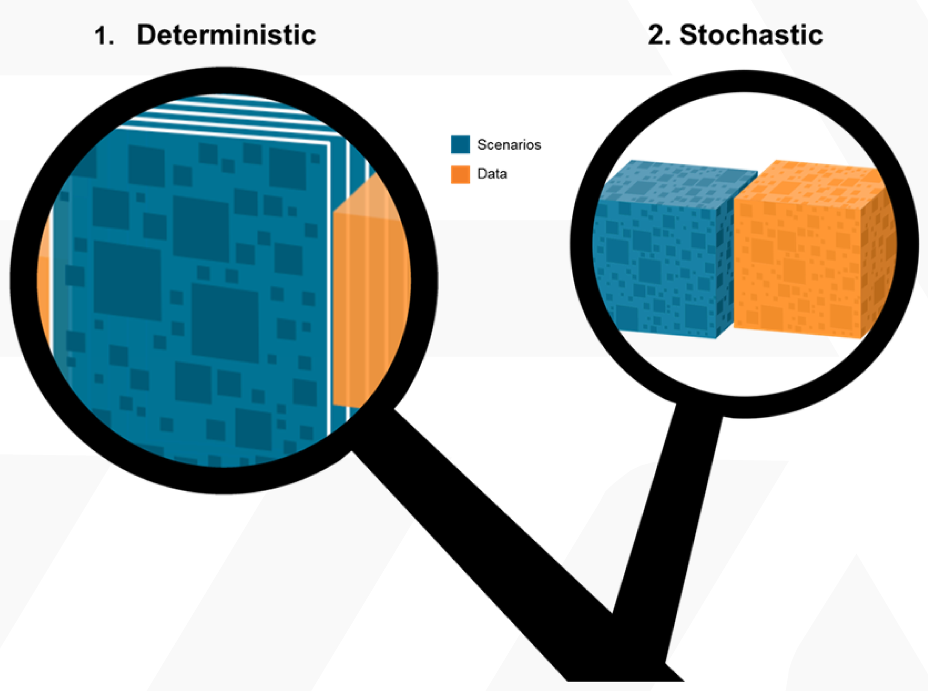
The Multi-scale Production Cost Modeling project aims to improve tools that are used to simulate power system the operations of future power systems. This project is improving the state-of-the-art in production cost modeling to enable industry to conduct more accurate analysis, faster, and in more detail.





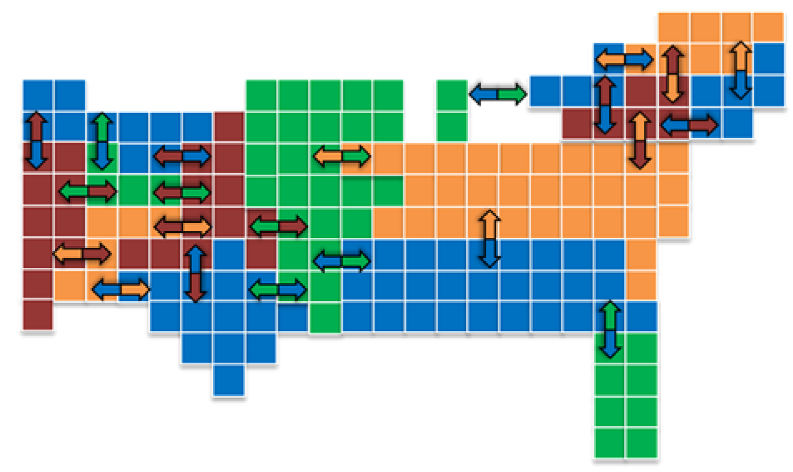
Expected Outcomes

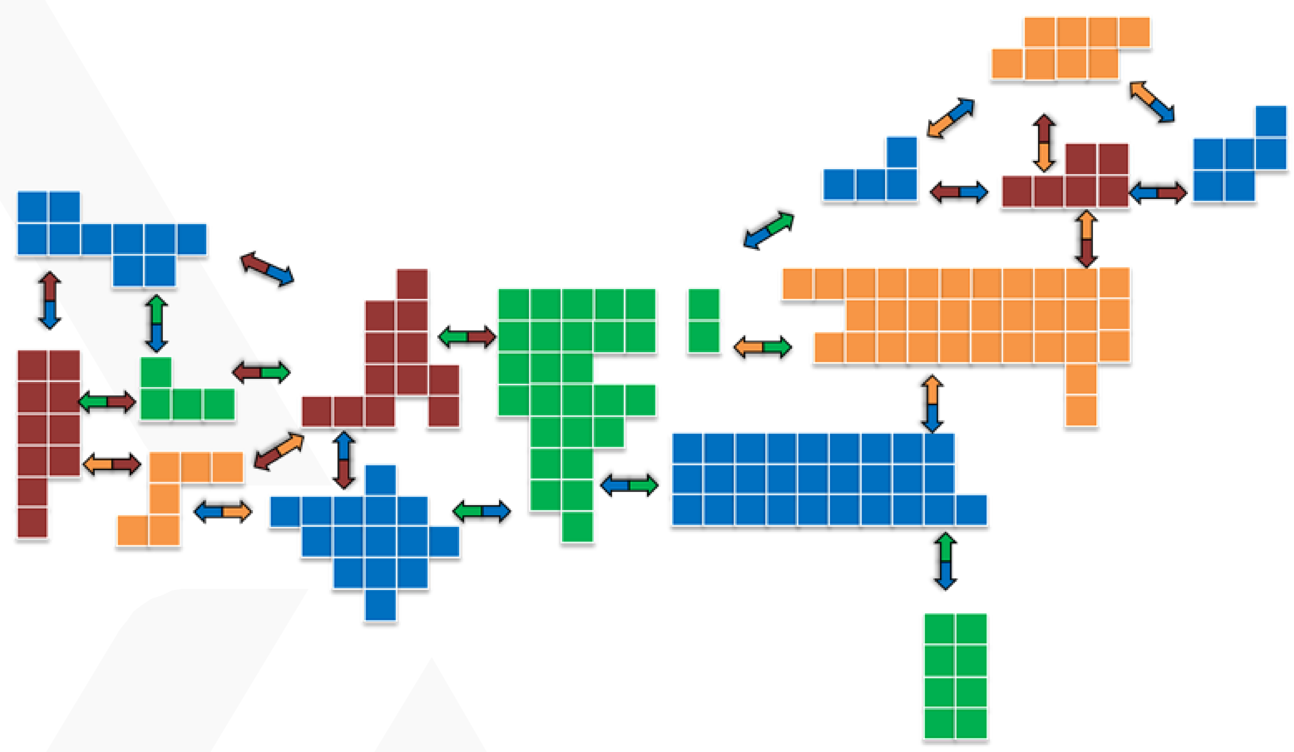
- We are developing several new algorithms, including different decompositions methods, to reduce solve time and increases model accuracy. For instance, geographic decomposition parallelizes the unit commitment problem according to market footprints. Initial results are seeing a 50% reduction in solve time. The computational advances will benefit both deterministic and stochastic analysis of the power grid.
- An IEEE Task Force recently reached out to NREL requesting help in modernizing the RTS-96 test power system which was last updated in 1996. We modernized the test system by adding modern generation resources and by adding spatial and temporal variability and uncertainty.
- By engaging with the production cost model software development and user communities, we are pursuing algorithmic and analytical advancements that can be deployed quickly and accelerate grid modernization. We are using tools such as GitHub to give a new dimension to stakeholder engagement.

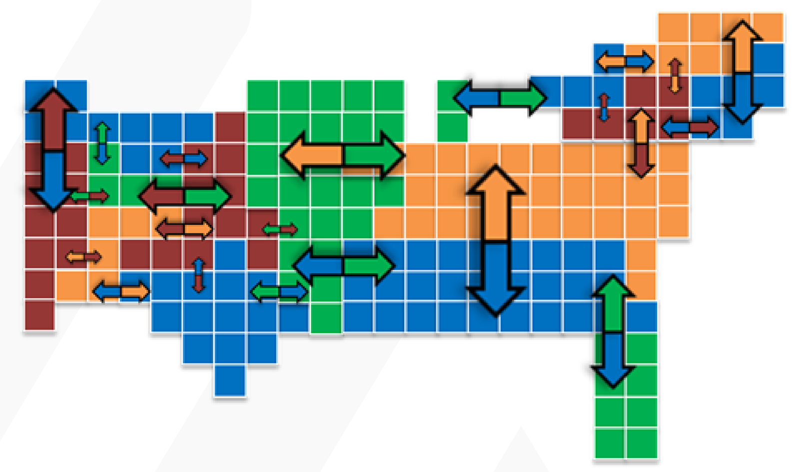


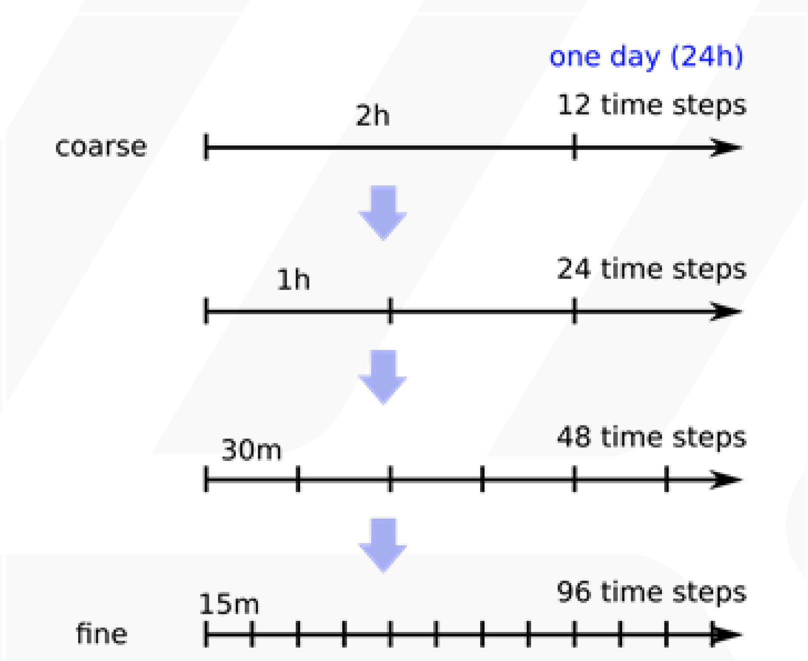
Progress to Date

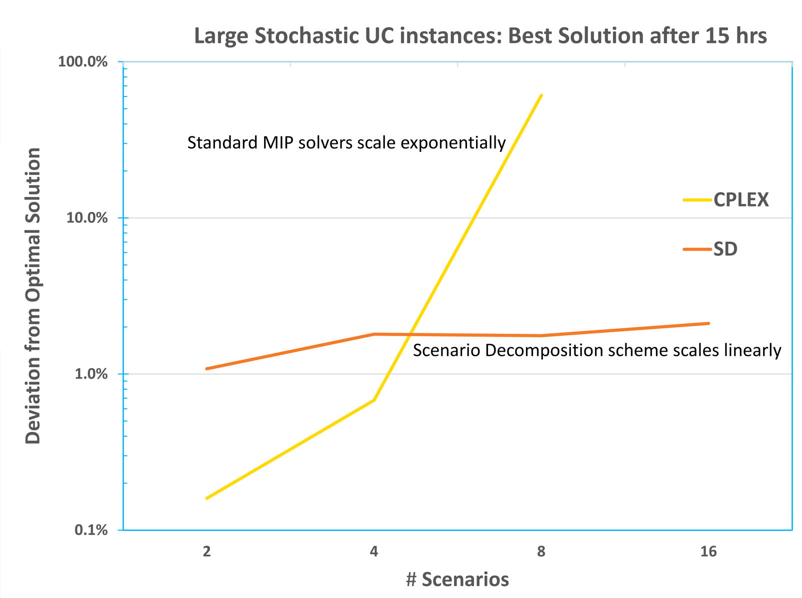
- Technical Review Committee October 2016 ~40 participants
- Advanced PCM Workshop October 2016
- Creation of RTS-GMLC
- Social Coding→ GitHub
- Development of new algorithms
  - Geographic Decomposition
  - MIP Warm Start
  - Temporal Decomposition
  - Scenario Decomposition

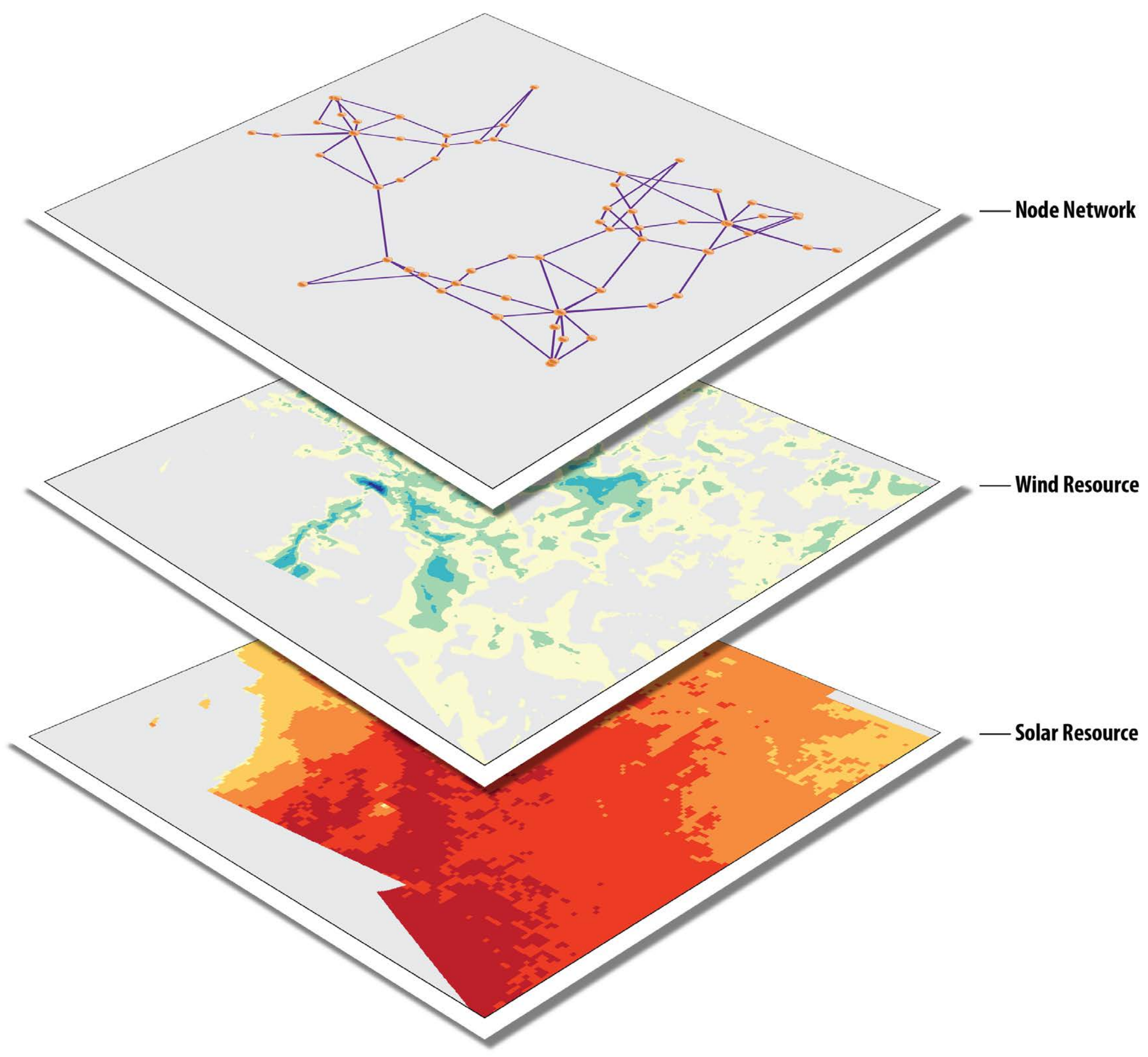












github SOCIAL CODING

- Github.com/GridMod/RTS-GMLC
- Github.com/GridMod/MSPCM
- Github.com/GridMod/Data-Software-WG

U.S. DEPARTMENT OF ENERGY

April 18, 2017

LPNORM: A LANL, PNNL, and NRECA Optimal Resiliency Model

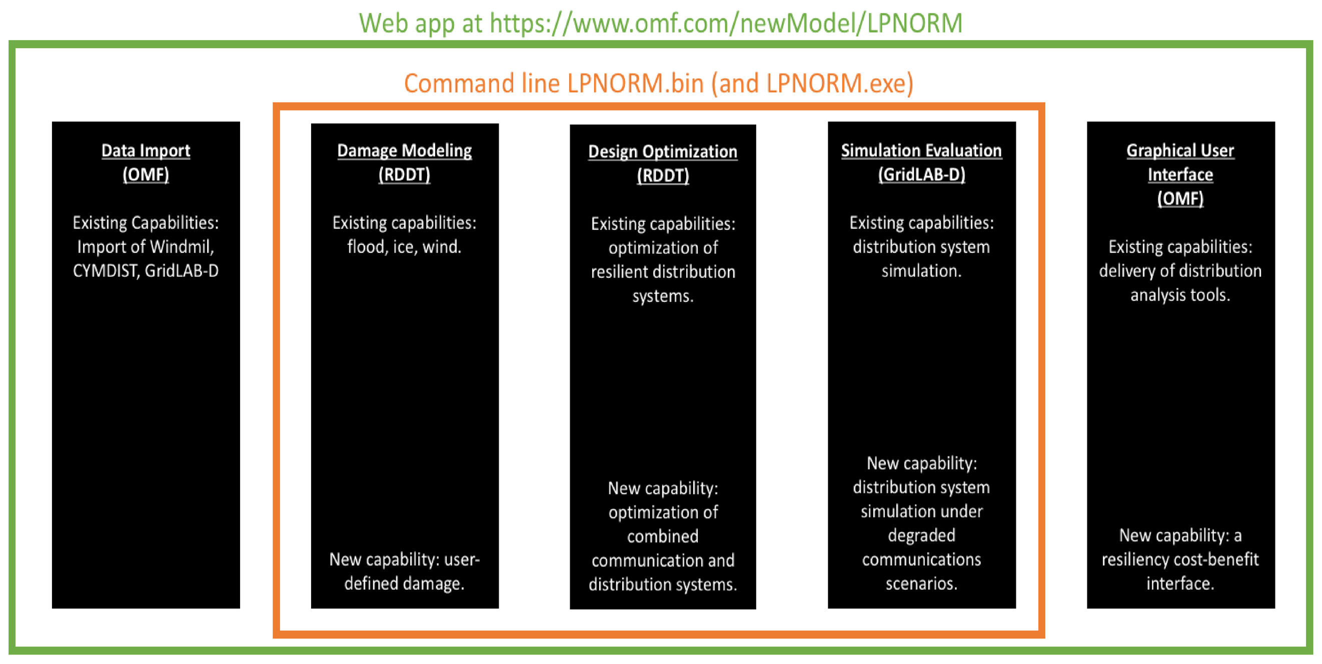
GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

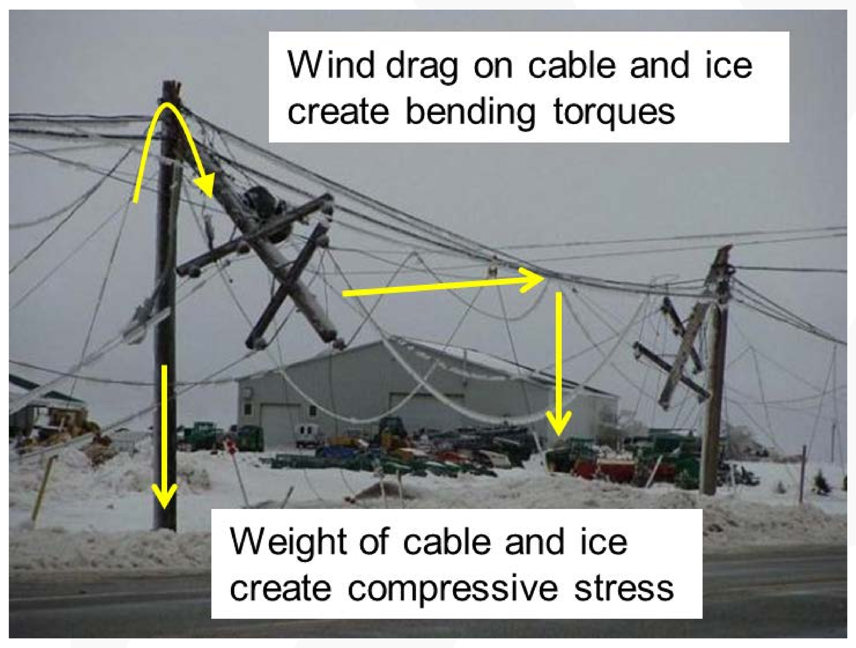
Project Description

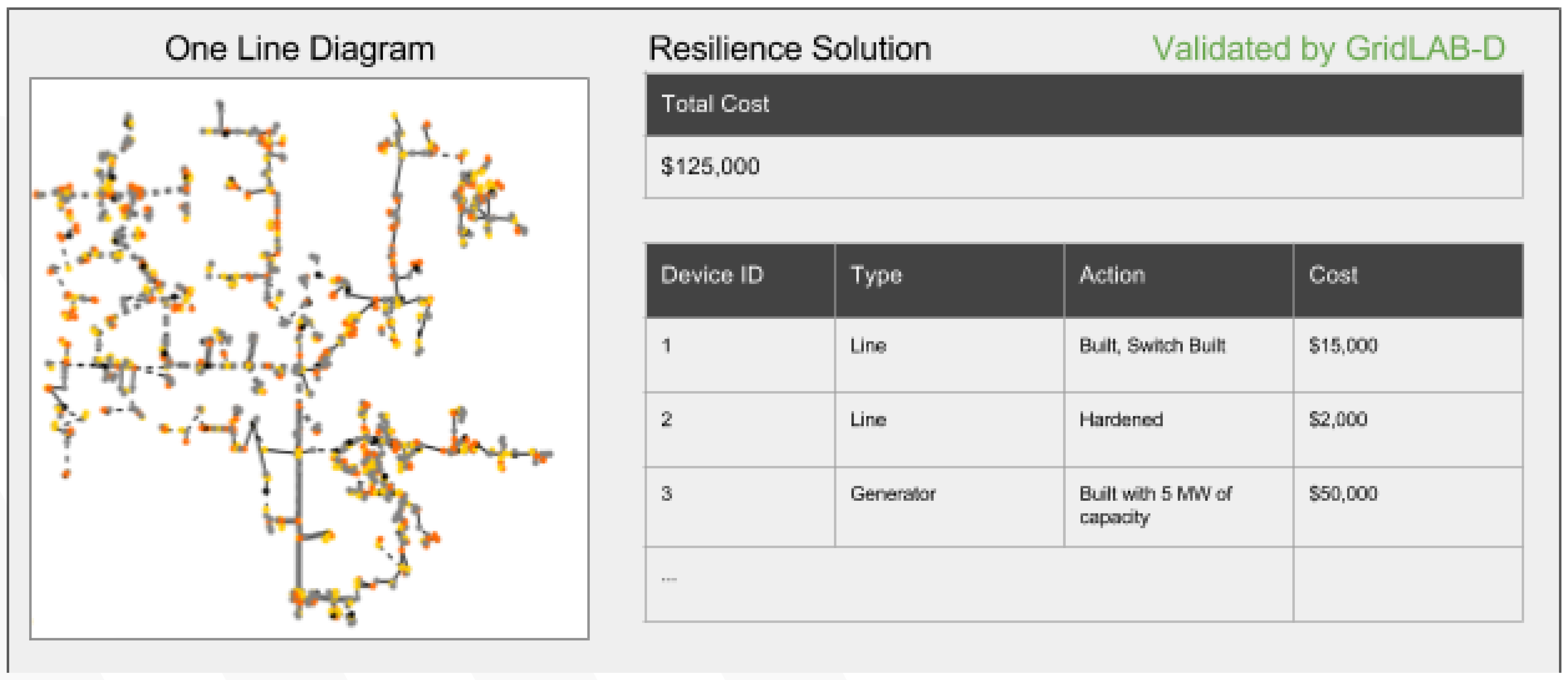
- Extreme weather events pose an enormous threat to the nation's electric power distribution systems
- Distribution utilities lack the tools to help them plan for extreme events.
  - Resiliency assessment
  - Extreme event impact mitigation
- This project develops LPNORM to design resilient distribution systems
  - Import distribution and communication models
  - Specify extreme events
  - Specify resiliency criteria
  - Verify design solution quality with trusted power flow solvers

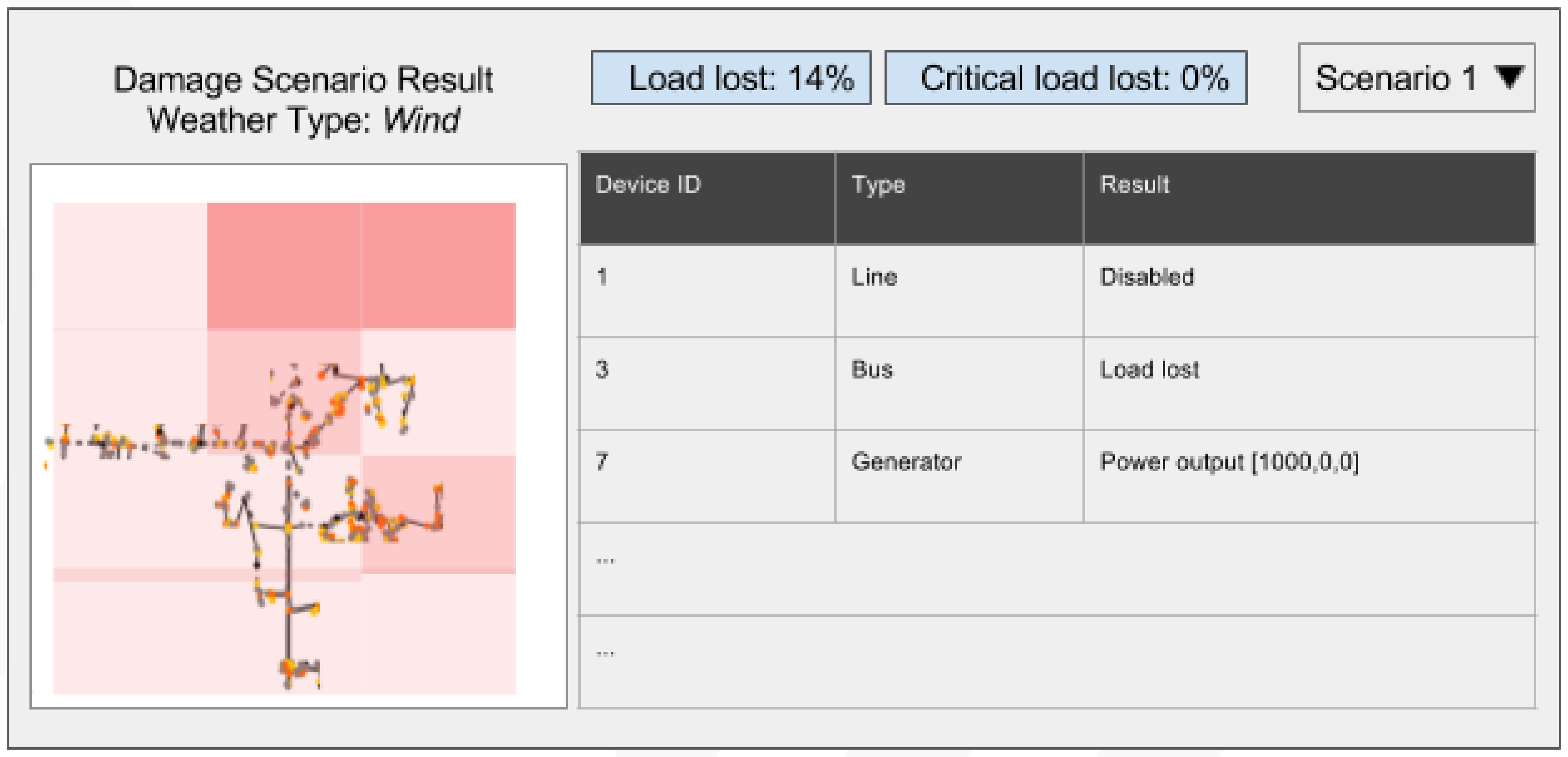
LPNORM System Architecture Sketch

(Black boxes are software libraries. Colored boxes are binaries or web services for end users.)









Expected Outcomes

- An open source software tool that combines NRECA 's Open Modeling Framework (OMF), distribution power system data, LANL's General Fragility Modeling (GFM), LANL's Resilient Design Tool (RDT), and PNNL's distribution power flow tool (GridLAB-D)
- Design systems that can serve up to 98% of critical load during extreme events

Significant Milestones	Date
Demonstration of RDT integrated with OMF distribution system models	10/1/16
LPNORM demonstrated with existing LANL (RDDT), PNNL (GridLAB-D), and NRECA (OMF) capabilities for a single hazard	4/1/17
Alpha version of LPNORM released for review by the utility user group	10/1/17
Peer reviewed paper on communication and distribution system algorithm	4/1/18
Choose two NRECA member utilities to participate in demonstration, beta version released for their participation	10/1/18
Report on user experience and beta tool released on NRECA's Open Modeling Framework	4/1/19

Progress to Date

- Integration of Resilient Design Module with Open Modeling Framework distribution feeders
- Kickoff meeting with co-op Industry Board (Nov 2016)
- Developed Software APIs for module coupling
- Initial work on integrating communication models into Resilient Design Module and GridLAB-D module
- Related Publications
  - A. Barnes, H. Nagarajan, E. Yamangil, R. Bent, and S. Backhaus. Tools for Improving Reliability of Electric Distribution Systems with Networked Microgrids, in preparation.
  - F. Tuffner, Y. Tang, and K. Schneider. Distribution Device Controls for Resilient Operations, in preparation.

Open-Source High-Fidelity Aggregate Composite Load Models of Emerging Load Behaviors for Large-Scale Analysis

PNNL(lead), LBNL, SLAC, WECC MVWG/LMTF, Southern California Edison

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

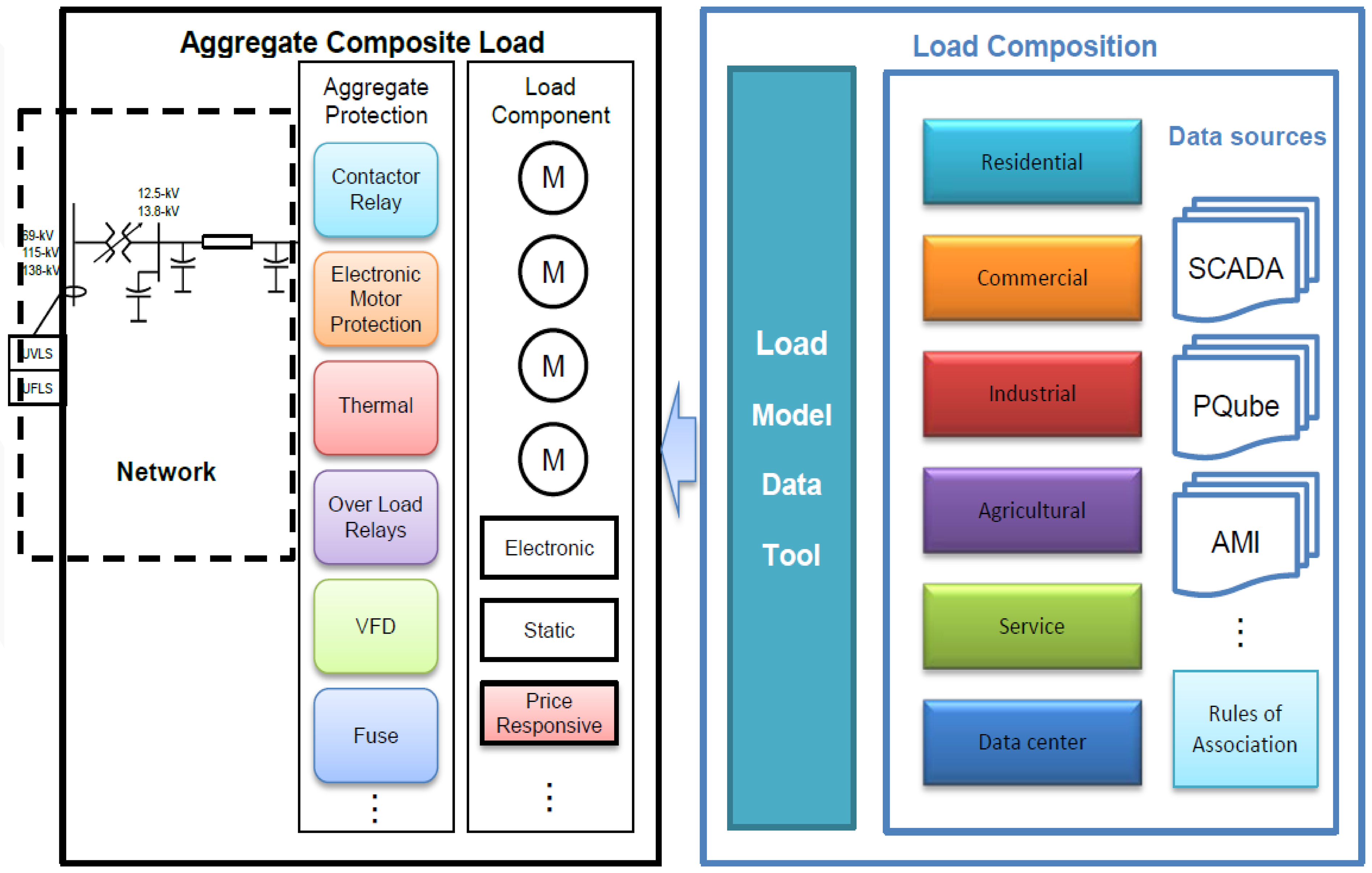
Project Description

The goal of this research is to develop a set of regional–level, scalable, open source load models and tools for power system planning and operation.

Expected Outcomes

- Models for large-scale aggregate load protection and price-responsive demand
- Next-generation load composition model
- Next-generation load model data tool
- Enable better decisions in power grid planning and operation as well as help avert power outages and contingencies, thus providing cost savings to U.S. power providers and consumers.

Significant Milestones	Date
Complete initial prototype of the next generation regional level load composition model	6/1/17
Complete initial data analysis for model validation	9/1/17
Release of technical report on short-term elasticities for time-based electricity rates	7/1/18
Pursue commercial integration or open-source dissemination	10/1/18



Aggregate Composite Load Modeling

Progress to Date

- Completed framework development for the next-generation regional-level load composition model.
- Documented data sources of protection devices in geographic-distributed regions and summarized the current best practice of load protection models.
- Completed the requirements of price-responsive aggregate load model.
- Completed the requirements and specifications of the next-generation load model data tool.
- Presented results in the Western Electricity Coordinating Council Modeling and Validation Work Group/Load Model Task Force meetings.

Models and methods for assessing the value of HVDC and MVDC technologies in modern power grids

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

Project Description

This work aims to develop the models and methods for assessing and amplifying the value of DC technologies. The multi-objective control and DC system models developed in this project target solutions to current and future RTOs/ISOs/Utilities' issues by HVDC systems.

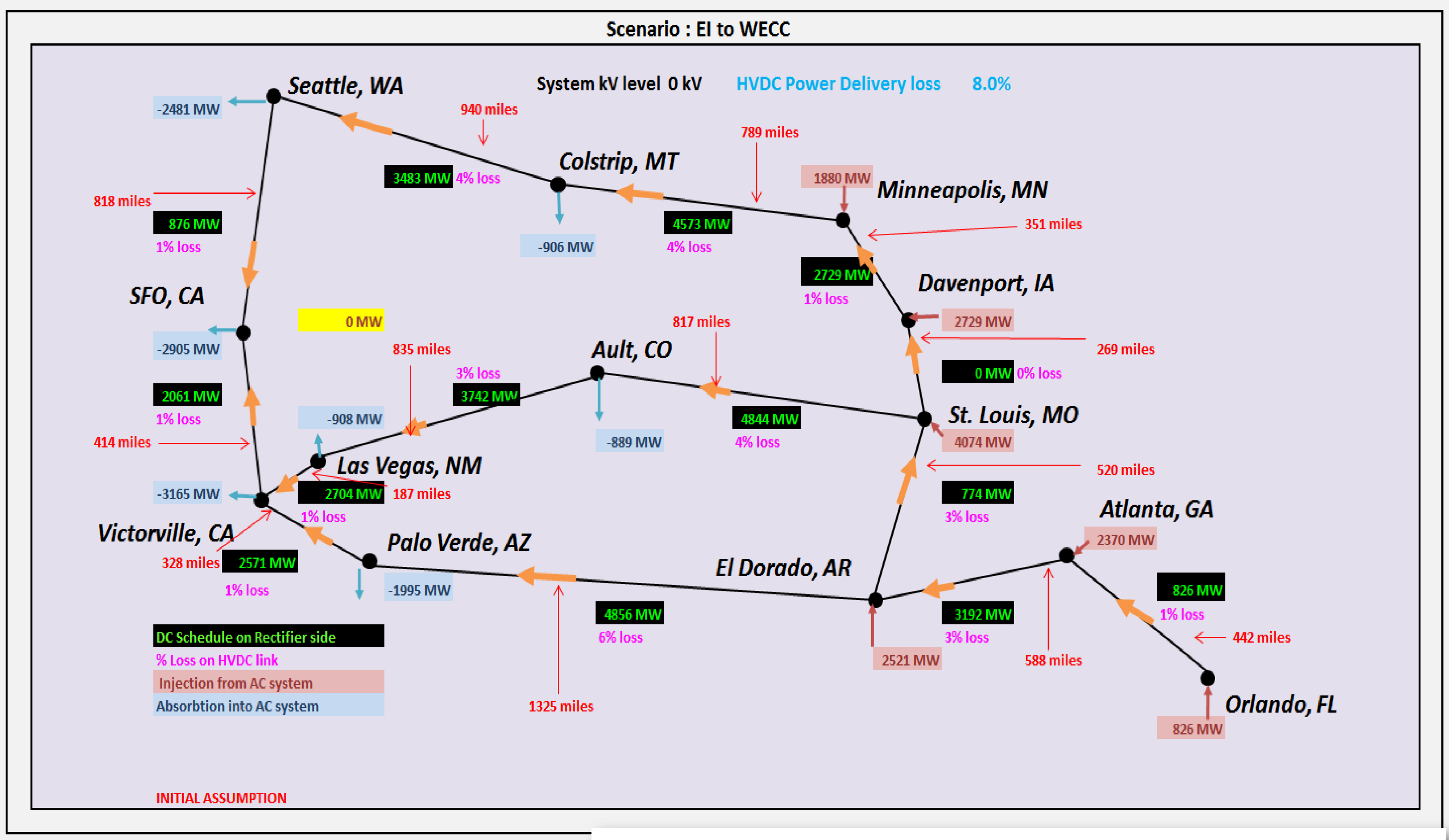
Expected Outcomes

- Use cases in which DC lines will be controlled to support healthy values of AC power transfers, provide ancillary services, and prevent instabilities
- Study the technical benefits of both HVDC systems embedded in AC interconnections and interlinks between AC interconnections
- Develop accurate models of DC technologies and explore multi-objective DC control methods
- Initial focus is on congestion management and frequency/inertial response services.

Significant Milestones	Date
Power system model of study: WECC + EI + HVDC macro grid (industry-grade models)	12/31/2016
EMT model of MMC HVDC and its interface with terminal models	12/31/2016
Converter-level control strategies	03/31/2017
System-level control strategies	06/30/2017
Finalize MMC HVDC models	06/30/2017
Show benefits of control strategies in overall AC/DC system model	06/30/2017

Project team

PNNL: Yuri Makarov, Marcelo Elizondo, James O'Brien, Qiuhua Huang, Harold Kirkham; **ORNL**: Madhu Chinthavali, Suman Debnath; **MISO**: Nihal Mohan, Warren Hess, David Orser, David Duebner, Dale Osborn; **Siemens**: James Feltes, Divya Kurthakoti Chandrashekhara, Wenchun Zhu; **SPP**: Harvey Scribner, Eddie Watson, Jay Caspary; **GMLC Technical Area Lead:** John Grosh (LLNL); **US DOE:** Kerry Cheung



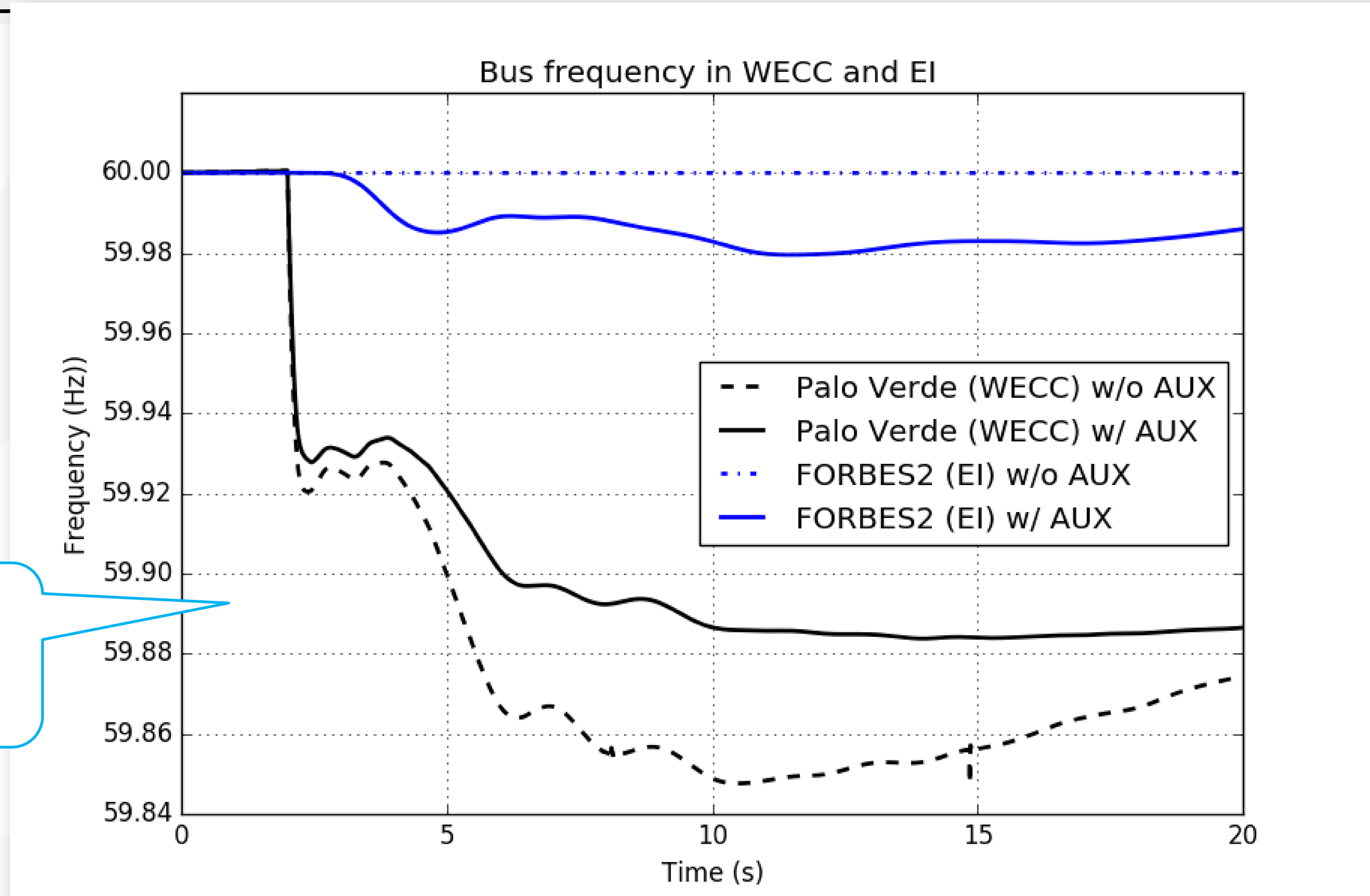


Figure: HVDC macro grid topology and transfer scenario (upper) and frequency response to large generator drop with and without HVDC auxiliary control (right)

Progress to Date

- Full, industry-grade, power-flow and dynamic models of North America's western and eastern interconnections joined through HVDC macro grid model
- Defined use cases
- MMC HVDC model and converter level control strategies
- Initial definition and tests of both system-level and converter-level control strategies
- Industry advisory board meetings in September and December 2016
- Journal paper in preparation, for CSEE Journal of Power and Energy Systems

Measurement-Based Hierarchical Framework for Time-Varying Stochastic Load Modeling

Presenter: Jianhui Wang Ph.D.
Project team: Argonne National Laboratory, NREL, Iowa State University, SIEMENS PTI

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

Project Description

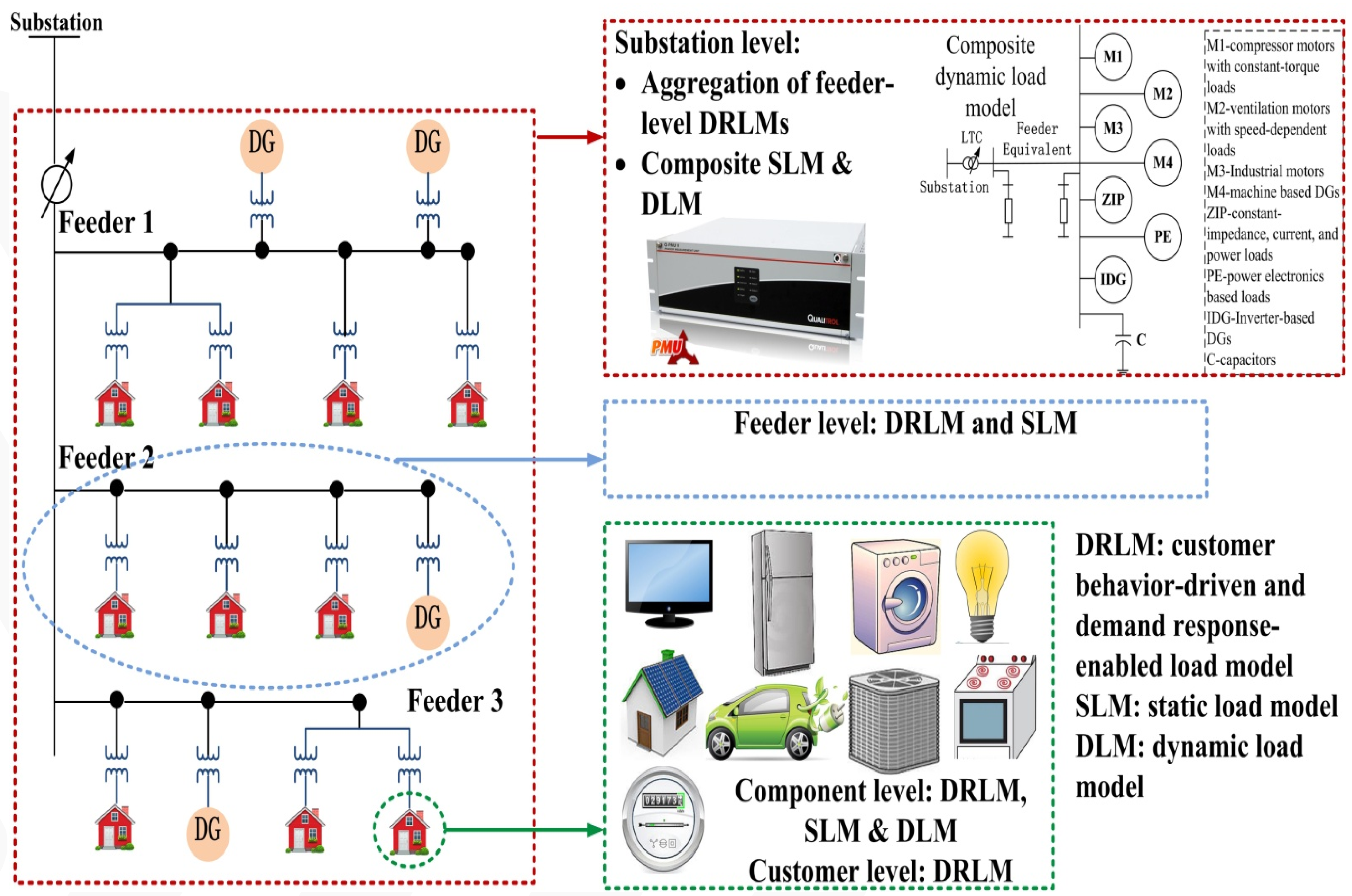
This project, led by ANL, is to develop a hierarchical load modeling structure to build time-varying, stochastic, customer behavior-driven and DR-enabled load models by leveraging practical utility data and laboratory experiments. The load modeling techniques leverage practical AMI, SCADA and PMU data at component, customer, feeder and substation levels.

Expected Outcomes

- Static and dynamic load models at component, customer, feeder and substation levels, which are generic and applicable to various practical systems.
- Customer behavior-driven and demand response-enabled load models at component, customer, feeder and substation levels, which are generic and applicable to various practical systems.
- Load model identification techniques which are robust to measurement noises and bad data and suitable for on-line identification of model parameters.
- Recommendations on typical load model parameter values, ranges and probabilistic distributions.
- A set of commercially available software tools with developed load models, which include PSS/E at transmission level, CYME at distribution level, and RTDS/OPAL-RT at customer and component levels
- Technical reports and journal papers with detailed descriptions of load models, assumptions/limitations, laboratory/utility data tests, demonstrations with commercially-available software tools.

Milestones

#	Milestone Name/Description	End Date
1	Overview of power system load modeling/industry practice, and Data Collection.	Month 6
2	Development and testing of load model identification algorithms with trained and validated data-driven models for load composition identification.	Month 12
3	Development and validation of load models at Component, Customer, and Feeder levels.	Month 18
4	Development and validation of load models at substation level.	Month 21
5	Typical ranges and time-varying probabilistic distributions of load models provided.	Month 24
6	Integration of developed load models to existing power system analysis tools with quantification of the operational benefits using the developed load/DG models	Month 30
7	Final reports documenting all models developed with examples of practical operation.	Month 36



Hierarchical load modeling framework

Progress to Date

- Completed Review of Load Modeling Techniques: Peer Reviewed Article Under Review – IEEE Transactions on Smart Grid
- Heuristic Load Type Identification Approach Developed: Peer Reviewed Article Ready for Submission
- Completed the development of robust time-variant load model identification algorithms
- One peer reviewed article on static load modeling is accepted by IEEE Transactions on Smart Grid
- One journal paper on composite load modeling is ready for submission
- Data Collection: Utility Data Obtained from ComEd including PMU, SCADA and Distribution-PMU Data
- IAB: Bi-weekly Project Discussion and Industry Consultation

Protection and Dynamic Modeling, Simulation and Analysis of Cascading Failures

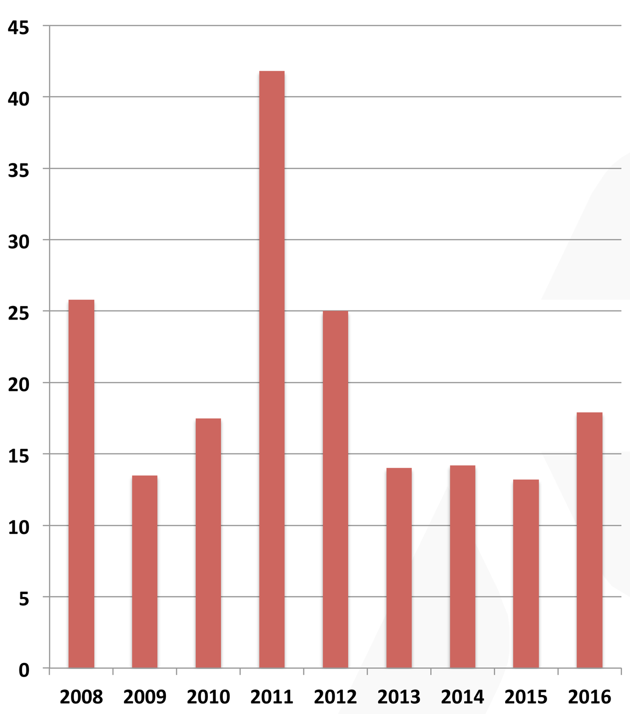
Shrirang Abhyankar, Junjian Qi (Argonne National Laboratory)
Ian Dobson (Iowa State University)
Alexander Flueck (Illinois Institute of Technology)
Sandro Aquiles-Perez (Electrocon International Inc.)

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

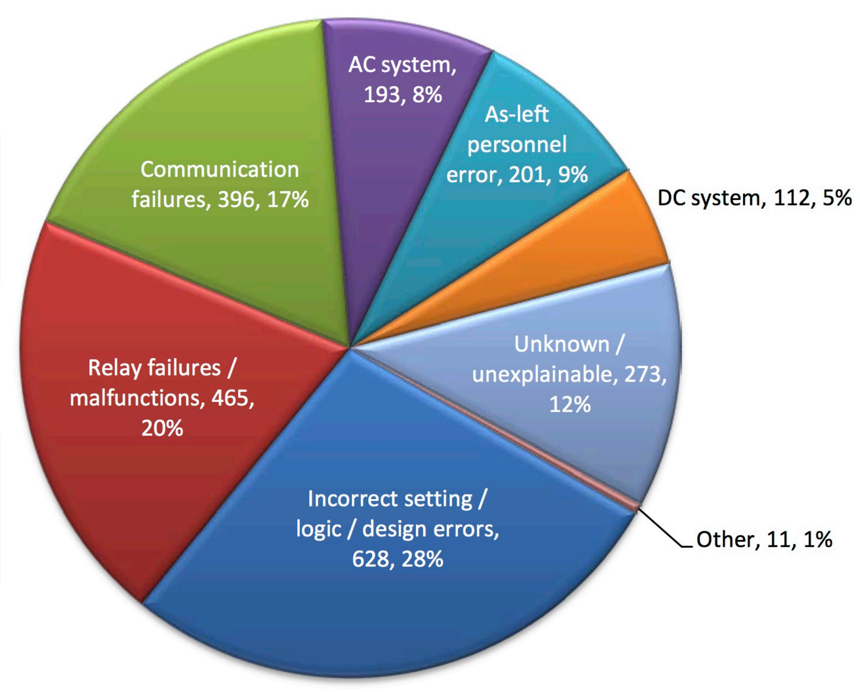
Project Description

Lack of **high-resolution models** is a **critical technology gap** in **predicting blackouts**.

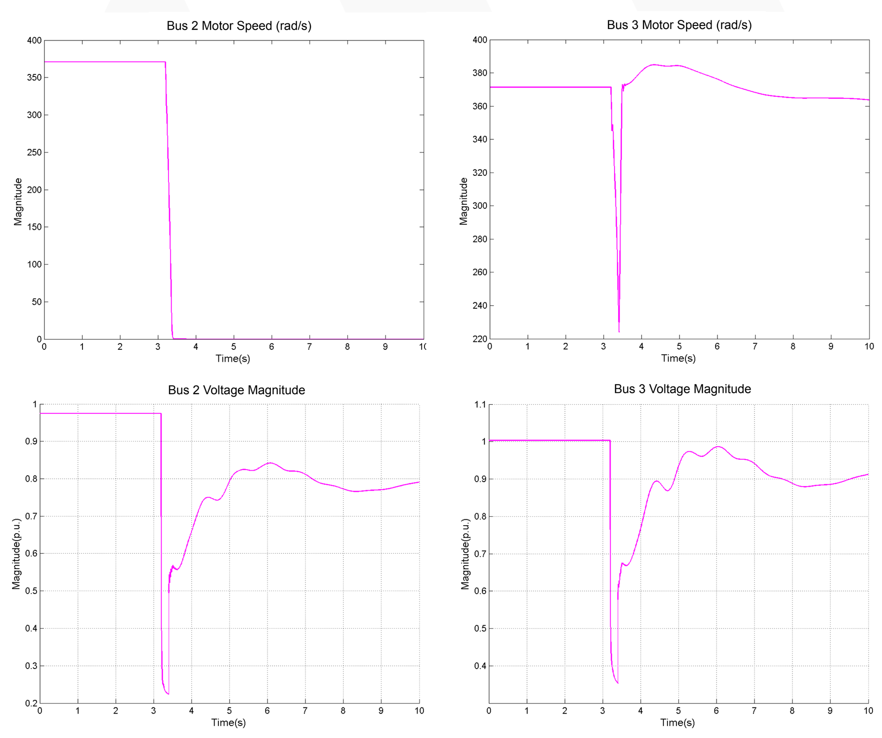
Project Goal: Develop state of the art grid protection and dynamic modeling, simulation, and risk analysis tools to **identify vulnerabilities** and support development of mitigation strategies for cascading failures in the Nation's grid.

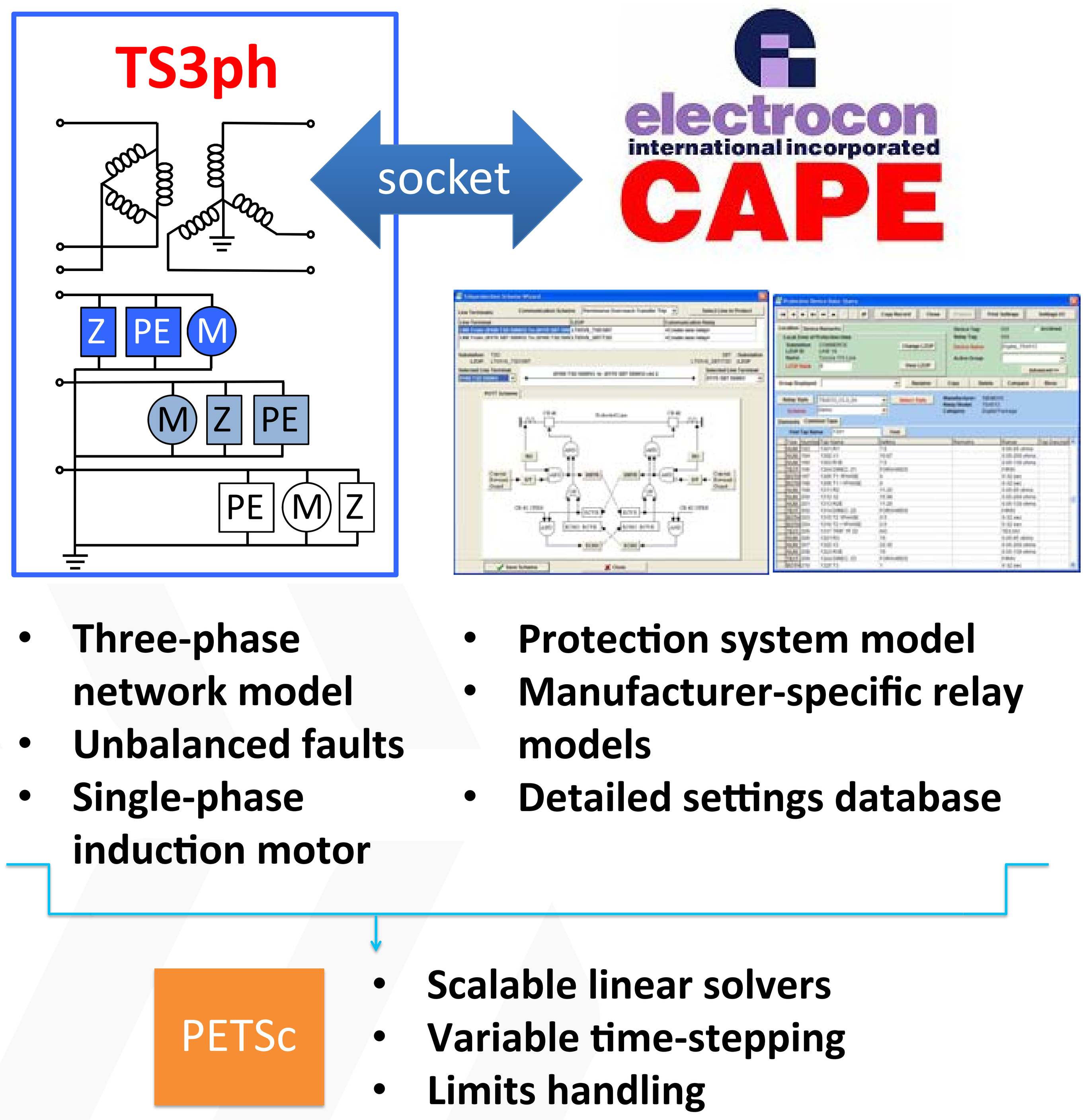


People affected by power outages (millions)
Source: Eaton Blackout Tracker



Protection system misoperation by cause
Source: NERC (2011Q1-2012Q1)

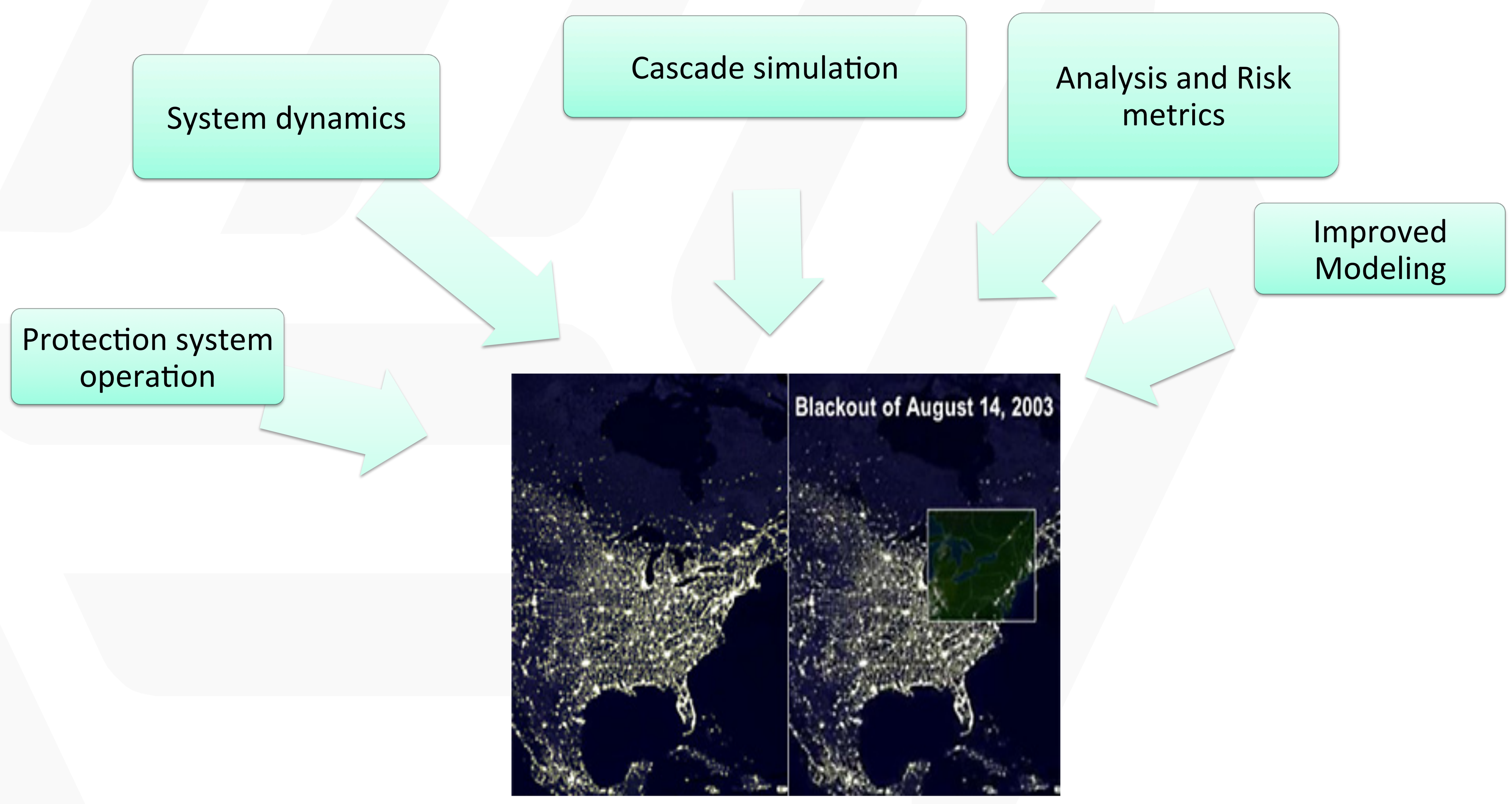

Induction motor speeds (1 stalled, 1 recovered) and bus voltages following fault at Bus 1



TS3ph-CAPE: Dynamics and Protection Simulator

Expected Outcomes

- **Final Outcome**: Cascading failure simulation and analysis with
  - Detailed unbalanced three-phase network
  - High-fidelity protection models
  - Cascading risk analysis
- **Impact to Nation, stakeholders, and individual customers**:
  - Reduction in energy costs and outage costs
  - Decrease in integration costs of distributed energy resources
  - Increase in grid resiliency



Expert cascading failure modeling, simulation and risk analysis

Significant Milestones	Date
Handling of discontinuous events in simulator	Sep 2016
Node-breaker model and zero-sequence network model	Dec 2016
Report on practical processing methods for simulator output	Dec 2016
Cascading simulation on 100-bus system	Jun 2017

Progress to Date

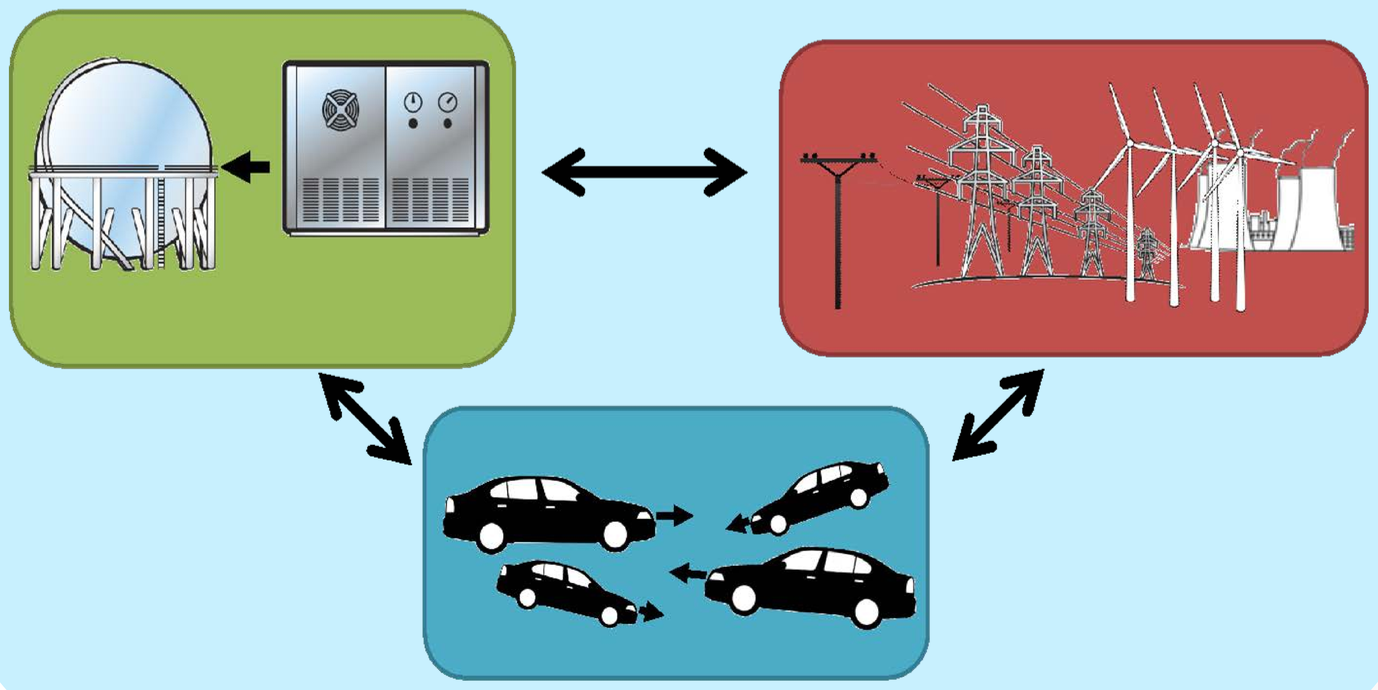
- Verified unbalanced fault currents with CAPE
- Implemented single-phase induction motor model with stalling capability
- Verified unbalanced operation of control devices, e.g., SVC response during and following unbalanced fault
- Utility partners: ComEd, AltaLink, Southwest Power Pool

Integrated Systems Modeling of the Interactions between Stationary Hydrogen, Vehicle, and Grid Resources

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

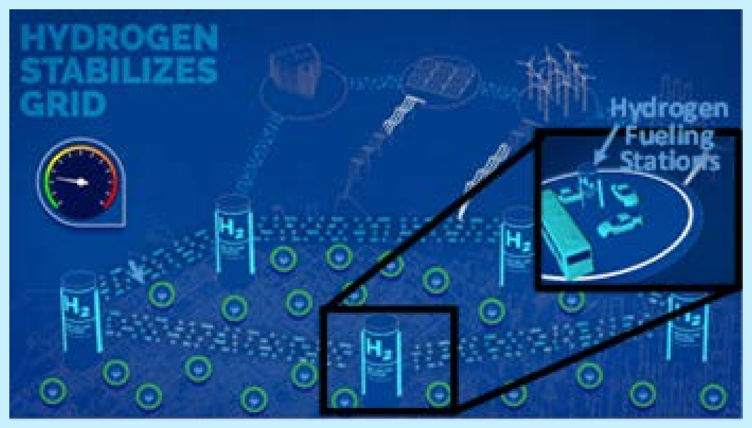
Project Description

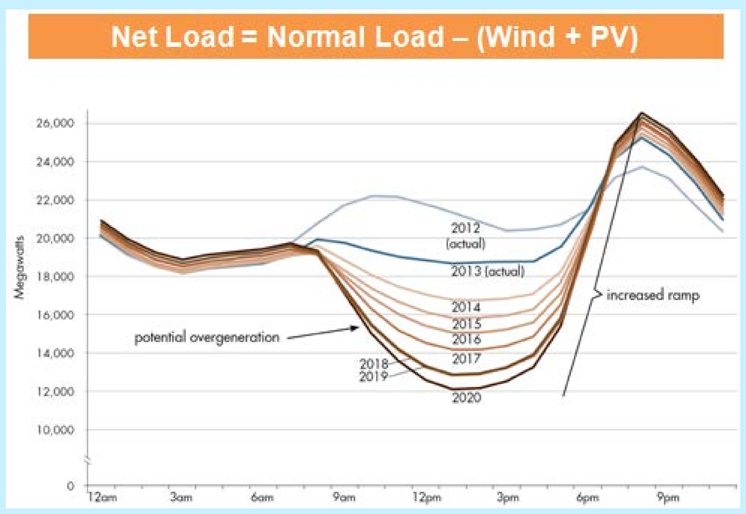
Establish the available capacity, value, and impacts of interconnecting hydrogen infrastructure, and fuel cell electric vehicles to the grid.



Motivation and Relevance

- Support greater utilization of grid assets for grid reliability, and integration of renewable generation (e.g. mitigating the California net load curve)
- Quantify the co-benefits and value streams for hydrogen resources to provide grid support

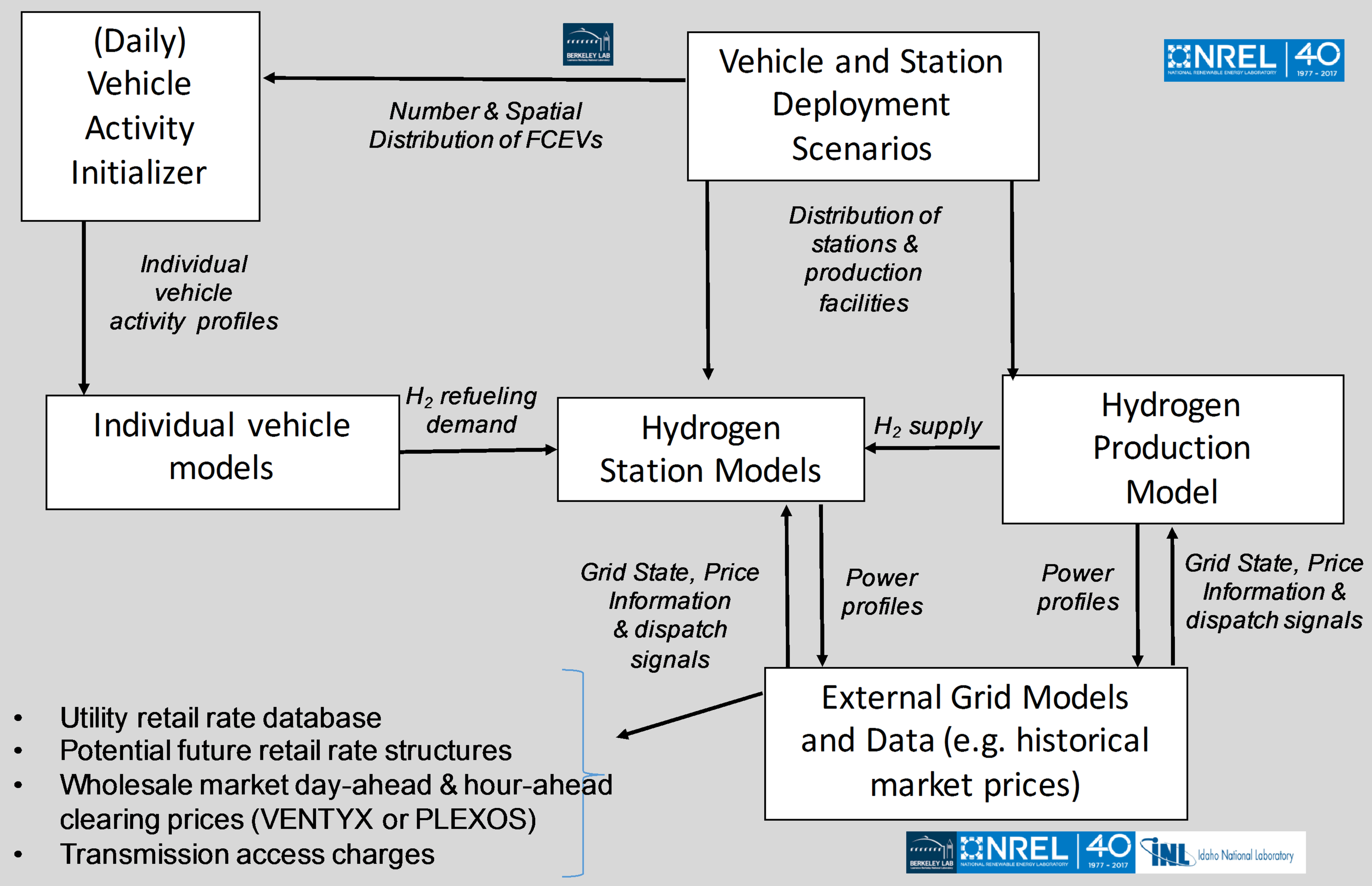




Stakeholder Benefits

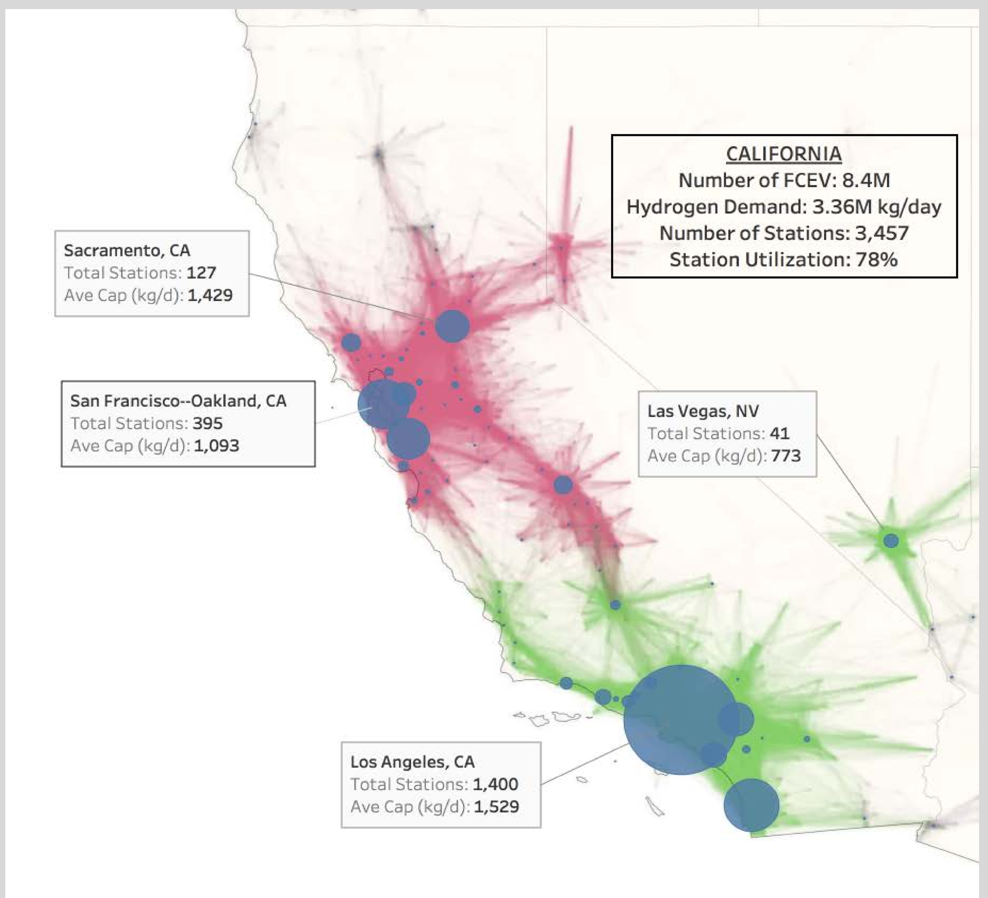
	Benefits of H_2VGI Toolset	Case studies
Policy makers	Understand co-benefits of investment in H_2 fueling infrastructure	Support decision making in deployment
Automotive	Design of grid-integrated FCEVs	Support value proposition
Researchers	Open-source toolset	Foundation for future R&D
H_2 station owners	Justify investment in H_2 stations	Quantify value of H_2 to grid support

Research approach



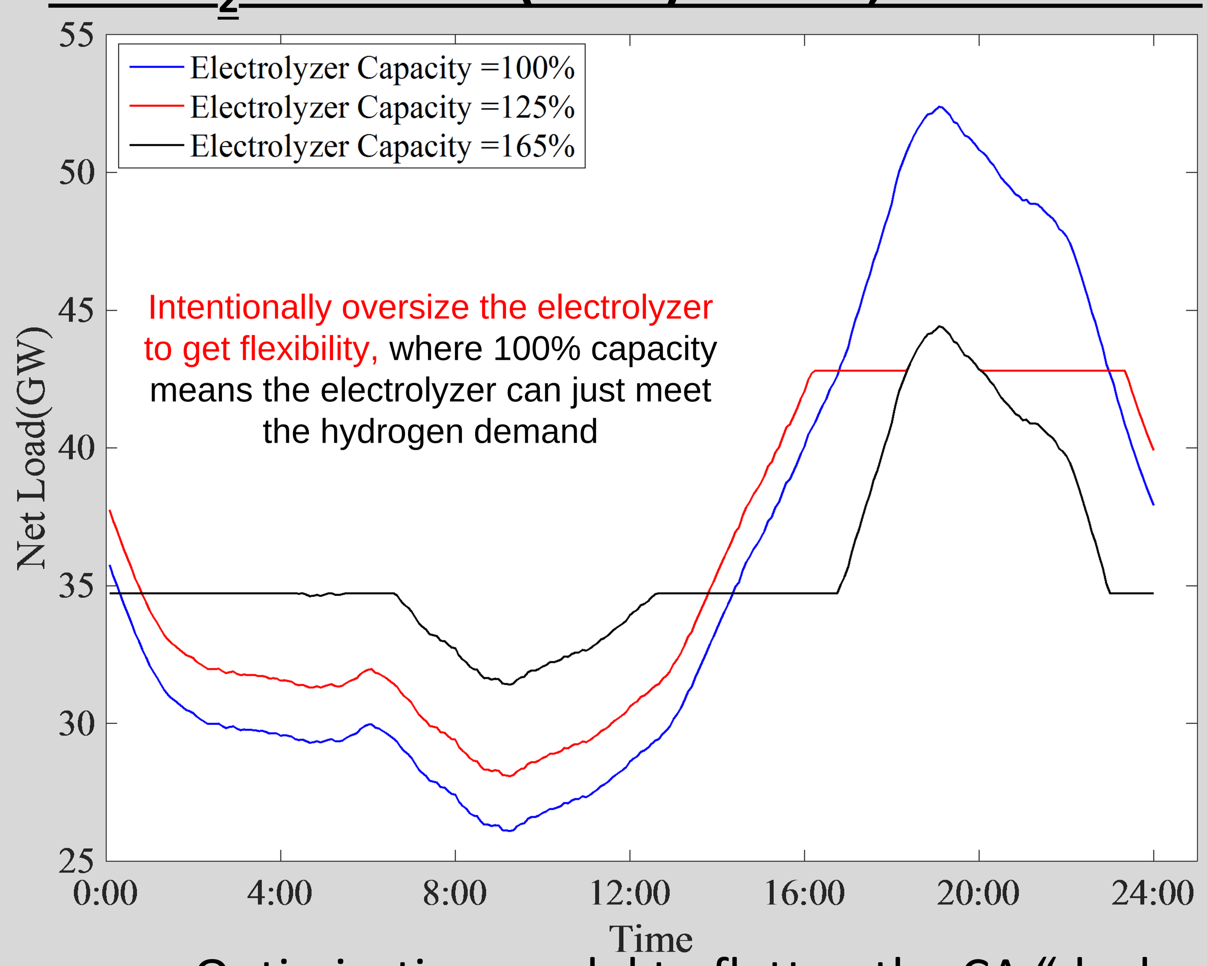
The hydrogen-vehicle-grid integration (H_2VGI) toolset is a multi-scale software toolkit, that combines several existing sub-modules to quantify and optimize the complex interactions between hydrogen demands, hydrogen systems, and the grid.

FCEV Deployment Scenario development (NREL)



- Geospatially and temporally resolved vehicle adoption in each urban area in California based on demographics and early adopters metrics
- Annual vehicle mileage based on empirical evidence
- FCEV fuel economy improvement over time
- Vehicle stock turnover

Example of case studies: CAISO Net Load Shaping with H_2 resources (LBNL) – 2025, 8.4M FCEVS



- Optimization model to flatten the CA "duck curve" using the H_2VGI toolset and various FCEV scenarios
- Ramping mitigation/valley filling/peak shaving can occur under different H_2 system configurations (H1G/H2G).

Significant Milestones	Date
LBNL-NREL H_2VGI framework development	FY 2017 Q1
Integration of FCEV H_2 consumption sub-models from LBNL with hydrogen production and dispensing models developed by NREL.	FY 2017 Q2
Testing and I/O validation of fully integrated mobility and hydrogen station sub-models within the H_2VGI toolset	FY 2017 Q3 **(Go-No Go)**

Expected Outcomes

- Quantify potential **grid support** and **balancing resources** from flexible hydrogen systems (e.g., dispatchable production of H_2 by electrolysis)
- Develop methods to **optimize the systems configuration and operating strategy** for grid-integrated hydrogen systems.
- Develop and demonstrate **H_2VGI toolsets and datasets** to model hydrogen systems and grid interactions (e.g., hydrogen station-vehicle-grid and optimal configurations).

Progress to Date

- Integrated vehicle deployment scenarios (**NREL**) into H_2 consumption sub-models (**LBNL**)
- Quantified potential net load shaping in CAISO from H_2 electrolyzer resources (**LBNL**)
- Definition of case studies on the scale of opportunity for H_2 vehicle-station-grid integration (**LBNL, NREL, INL**)
- Architecture definition for the Front End Controller ***(INL)***

Next Steps

- Interconnect all H_2VGI sub-models, finalize data linkages and being to validate model output
- Implement case studies using integrated model to quantify economic benefits for hydrogen vehicle grid integration

U.S. DEPARTMENT OF ENERGY

April 18, 2017

Rapid QSTS Simulations for High-Resolution Comprehensive Assessment of DER

PIs: Robert Broderick (SANDIA), Barry Mather (NREL)
Project Team: Matt Reno and Matt Lave (SNL), George Scott and Manohar Chamana (NREL), Francis Therrien and Jean-Sebastien Lacroix (CYME),
Project Team: Roger Dugan and Davis Montenegro (EPRI), Jeremiah Deboever and Xiaochen Zhang (Georgia Tech.)

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

Project Description

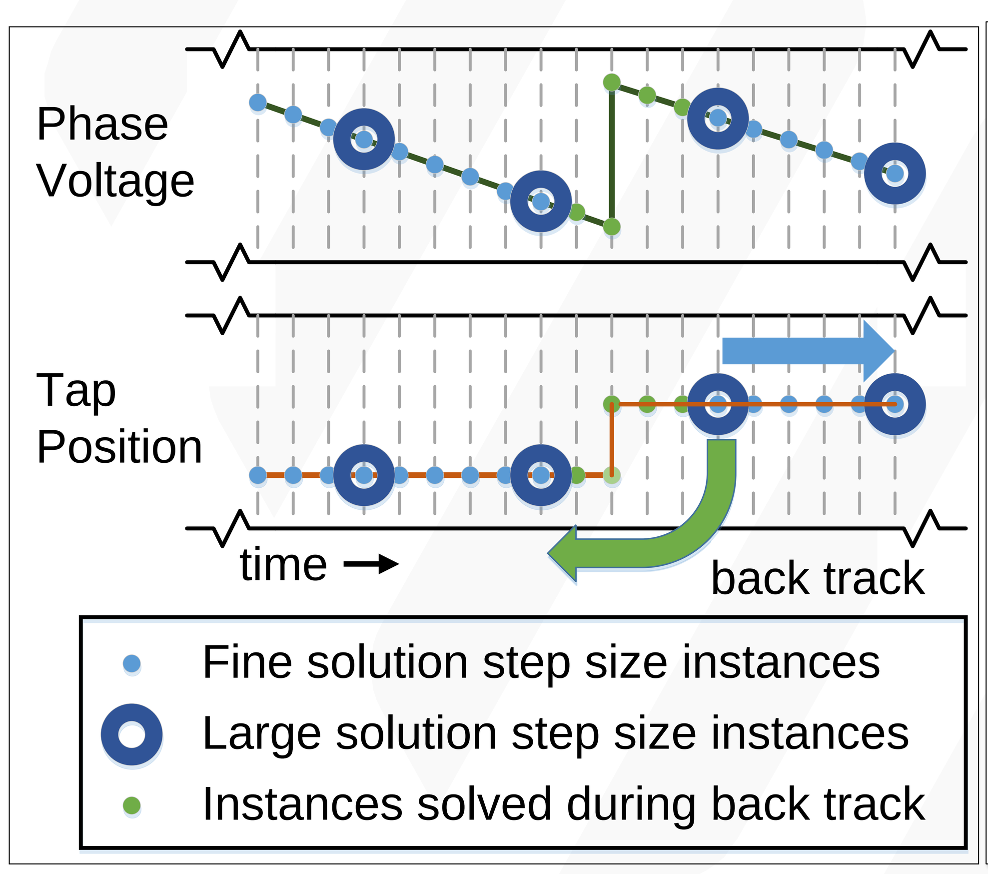
Future distribution system analysis with high-penetrations of distributed energy resources (DER) will require Quasi-Static Time-Series (QSTS) analysis to model the variability caused by new distributed generation, storage and EV charging. The time-dependent aspects of the power flow and their impact on distribution systems cannot be accurately determined with existing snap shot tools and methods.

Challenge: A yearlong QSTS simulation with 1-second resolution has the computational burden of solving 31.5 million power flows taking **10-120 hours** with existing methods for one feeder. This analysis time becomes unmanageable with 1,000+ feeders in a service territory & 5-10 impact studies per year per feeder: ***137 years of simulation time.***

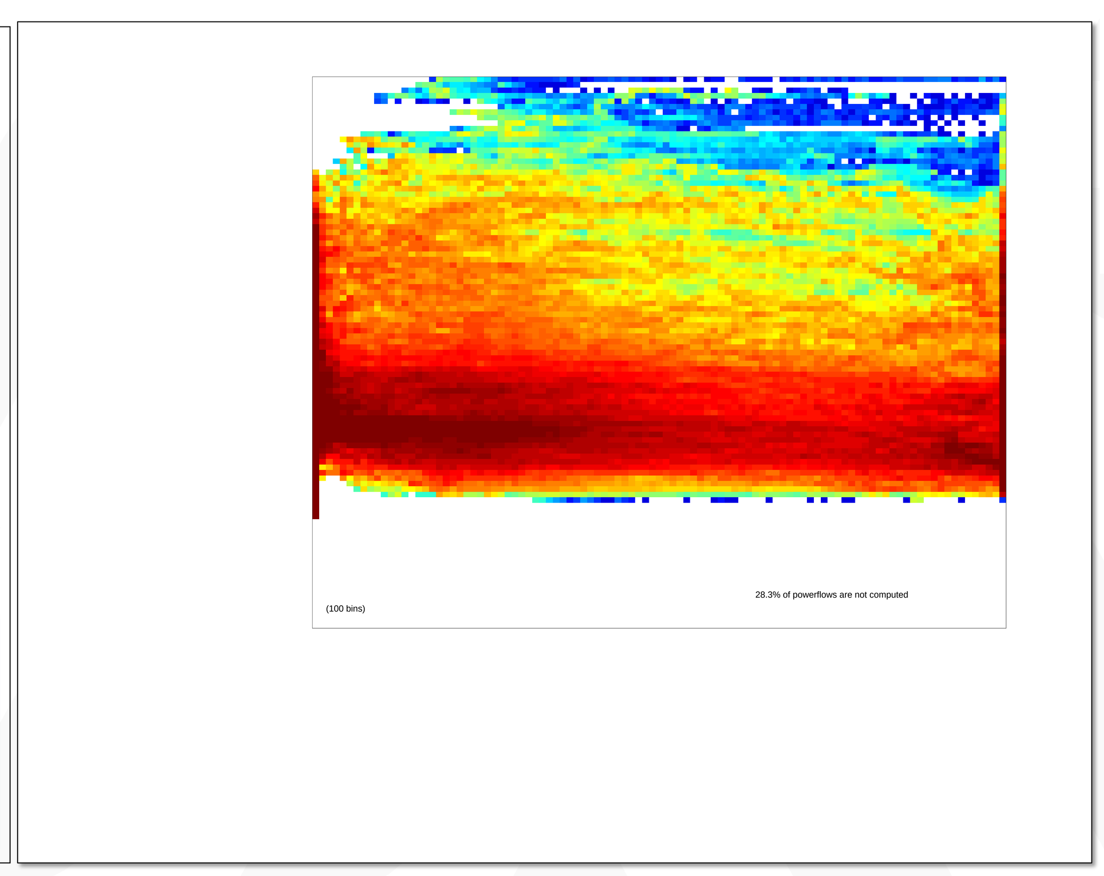
Goal: Develop new and innovative methods for rapid QSTS simulations.

1) Reduce the number of QSTS power flows and their computational time to **less than 5 minutes** with high accuracy
2) Create algorithms to create and manage high-resolution time-series input data for QSTS simulations

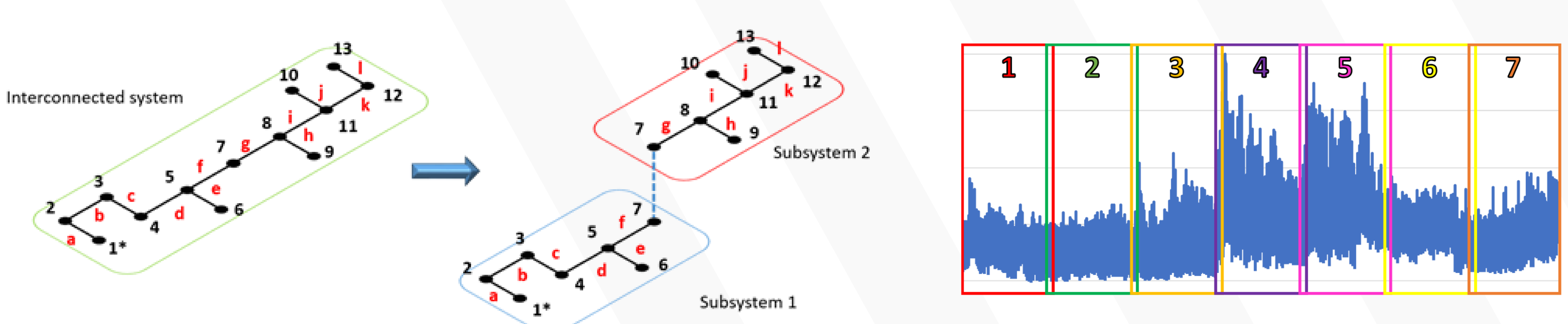
Promising Methods and Tools



Causal Variable Time Step



Vector Quantization

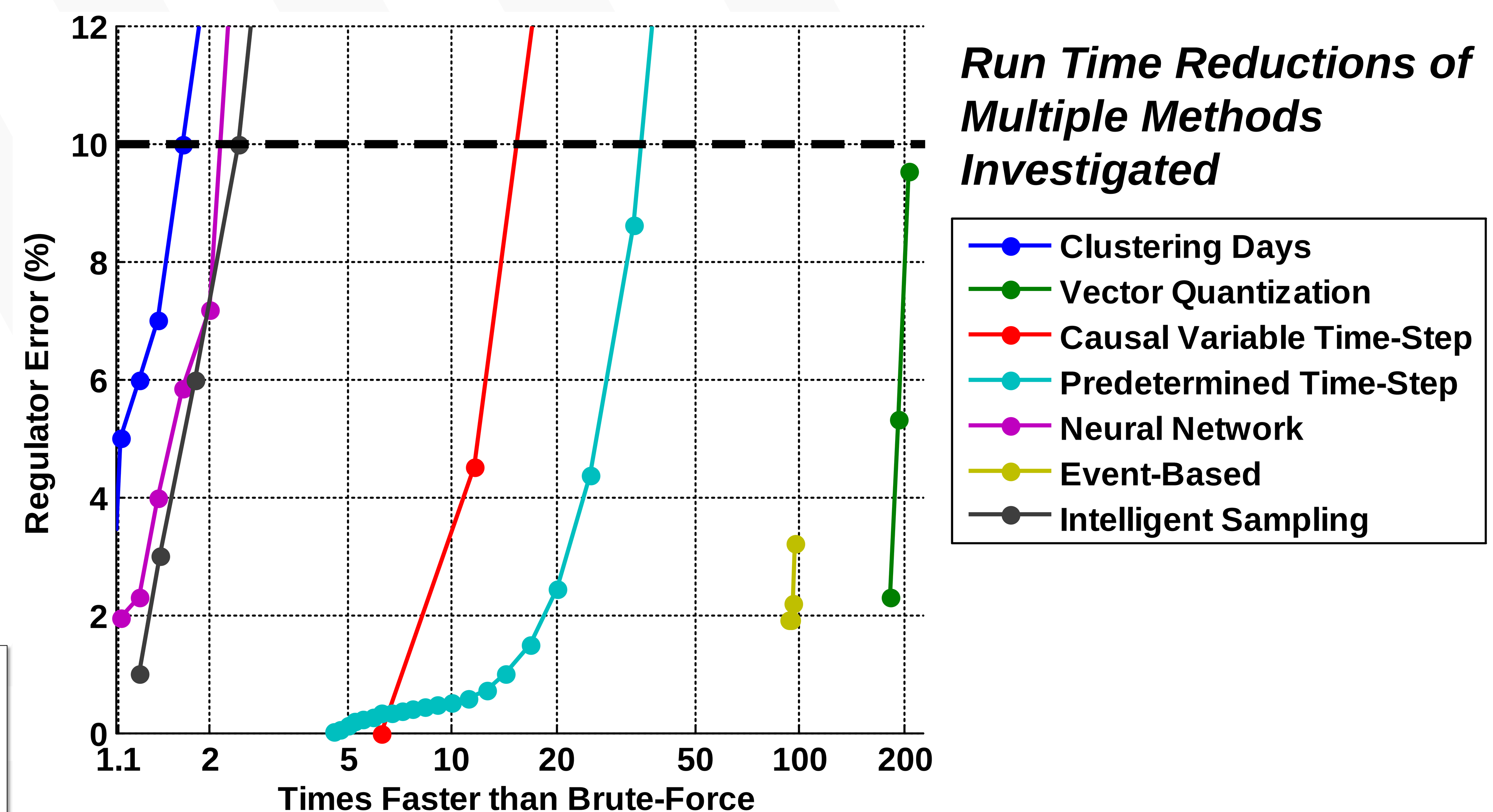


Parallel computing: Spatial and Temporal

Partners: CYME International T&D, Georgia Tech, EPRI Electric Power Research Institute

Milestone Progress to Date

- 4 time-series methods developed with 90%+ runtime reduction w/ good accuracy
- Improvements in commercial software with 90%+ runtime reduction in Year 1
- Dissemination: 2017: 13 conference papers, 3 journal papers & 2 panel sessions. 2016: Presented results at 5 different conferences.



Run Time Reductions of Multiple Methods Investigated

Expected Outcomes

- ❑ ***Combined speed improvements of 1000+ fold***
- ❑ Implementation of QSTS improvements in both commercial and open-source distribution system analysis tools
- ❑ Multiple time-series approximations for QSTS analysis that reduce computation runtime by 90% or more while maintaining the accuracy of key PV impact metrics
- ❑ Improvements in power flow solution algorithms specifically for QSTS analysis with a 40% or more reduction in runtime
- ❑ Methods for temporal and spatial (diakoptics) parallel computing of QSTS simulations with less than 2% MAE of automatic voltage regulation equipment operations for parallel processes utilizing 52 cores
- ❑ Models and methods to create synthetic solar and load variability sets for use in QSTS impact studies.

CyDER: A Cyber Physical Co-simulation Platform for Distributed Energy Resources in Smart Grids

GRID
MODERNIZATION INITIATIVE
U.S. Department of Energy

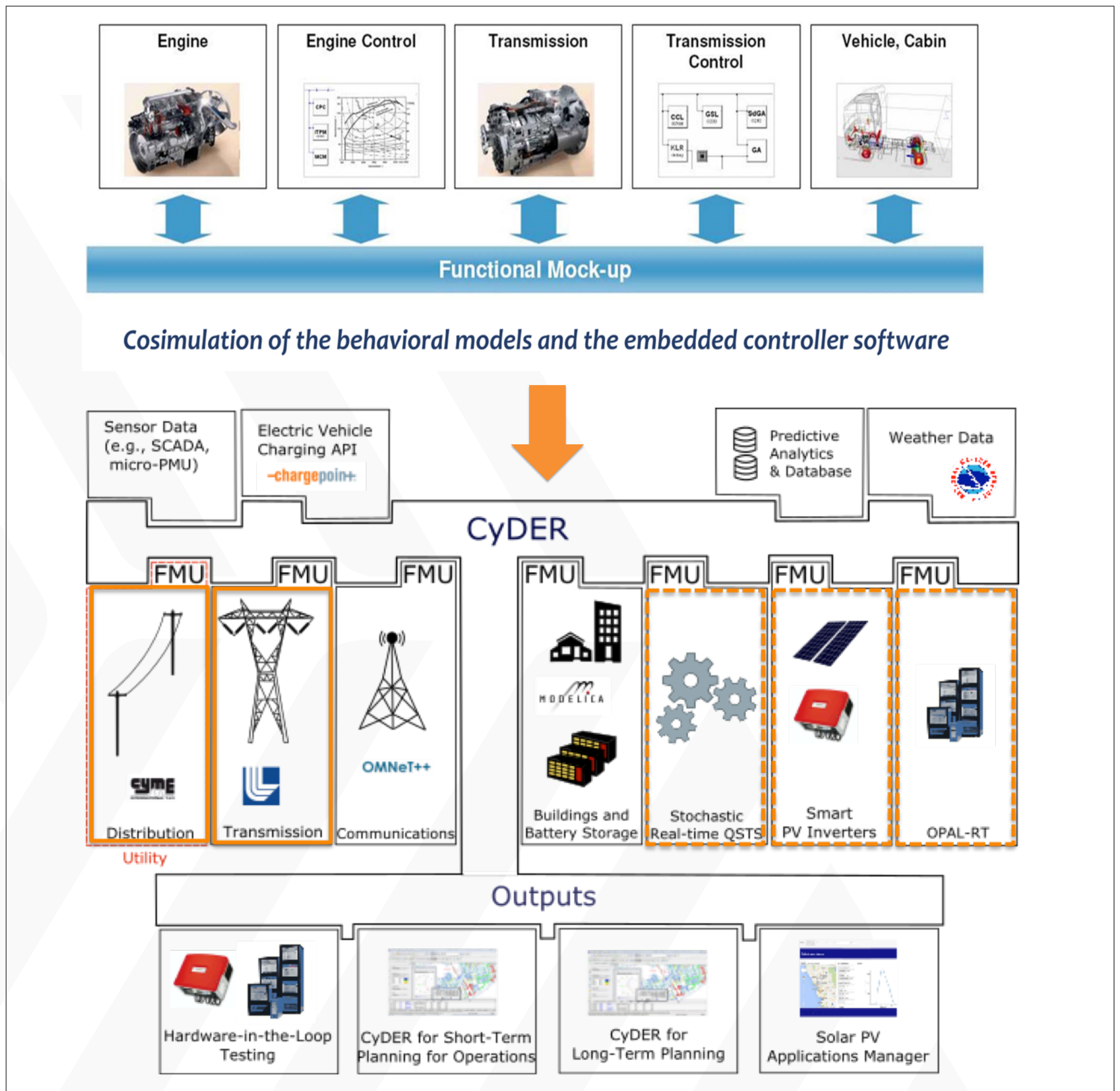
Project Description

- An **open-source**, **modular** and **scalable** tool for power system planning and operation based on that will work seamlessly with existing tools in the utilities and will be **interoperable** with future utility software, data streams, and controls
- **Quasi-static time series (QSTS)** co-simulation and optimization, **real-time data acquisition**, and hardware-in-the-loop (**HIL**) applications
- Combines **transmission and distribution** system simulation, data collection and analysis, power generation and load **forecasting**, load flexibility (especially electric vehicle **(EV) charging**) and **real-time control of solar photovoltaics (PV)**

Expected Outcomes

- Power system planning and operation tool based on the well-established **functional mock-up interface (FMI) standard** to co-simulate transmission and distribution systems
- CyDER for **short-term planning for operations**
  : 4-12 hour-ahead contingency analysis and schedule of inverter setpoints for utilities
- CyDER for **long-term planning**
  : infrastructure investments and novel control strategies to accommodate high PV penetration
- CyDER **PV Application Manager**
  : streamline processes to approve PV installation for utilities

Significant Milestones	Date
Development and Integration of individual modules for CyDER QSTS Simulation success within integrated modules for PV, grid, and EV, with the interfaced modules between the distribution transmission and FMI tools	**May 2017** (95% complete)
Predictive analytics module for PV & EVs Relative root-mean square errors (RMSE) below 30% achieved for PV forecasting, EV forecasting	**May 2017** (90% complete)
Establishing interoperability in between CyDER modules and development of **hardware-in-the-loop (HIL) setup** CyDER has successfully coupled grid simulation, building simulation, sensor data streams and smart PV inverter control	May 2019
Scenario analysis and performance assessment for CyDER under different planning and operation conditions PV penetration potential for analyzed 50 feeders based on real utility data	May 2019
Development of the CyDER **PV Applications Manager**	May 2019



CyDER architecture

Progress to Date

- Development of CYMDIST FMU, GridDyn FMU, and coupling of them using PyFMI
  : successful integration of CYMDIST (distribution simulation tool) + GridDyn (transmission simulation tool by LLNL) under CyDER platform
  - GitHub Repository at https://github.com/LBNL-ETA/CyDER
- Demonstration of use case scenarios with **different PV penetration levels and EV adoptions** at **multiple feeders and buses**
  : housing development project scenarios on actual distribution feeder models from utility partner + IEEE 14-bus test system

Team

LBNL (lead), LLNL, SolarCity, ChargePoint, PG&E

Assessing the Value and Impact of Dispatchable Concentrating Solar Power in a SunShot Future

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

Project Description

This project will improve the ability to assess and quantify the benefits of concentrating solar power (CSP) to provide essential reliability services and reduce the cost of providing electricity. These new capabilities will used to evaluate the ability of CPS to increase the overall penetration of solar energy in the U.S. Southwest, and mitigate the variability impacts of solar PV and wind.

Expected Outcomes

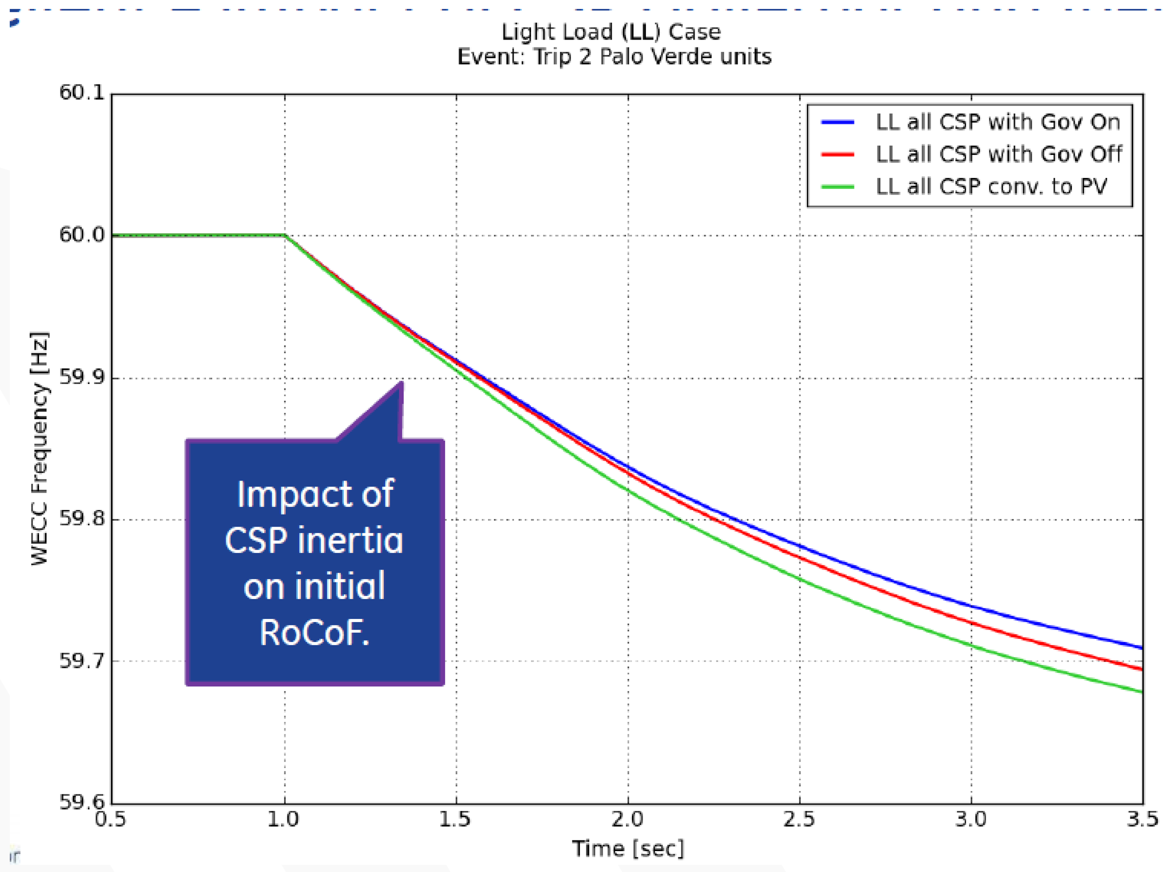
Innovation:

- New methods and tools to enhance the utility sector's ability to evaluate the reliability and operational benefits of CSP technologies integrated with thermal energy storage. These include more accurate representation of CSP providing inertia, primary frequency response and regulating reserves in software tools used by utilities and system planners, using real world data from recently commissioned CSP power plants.

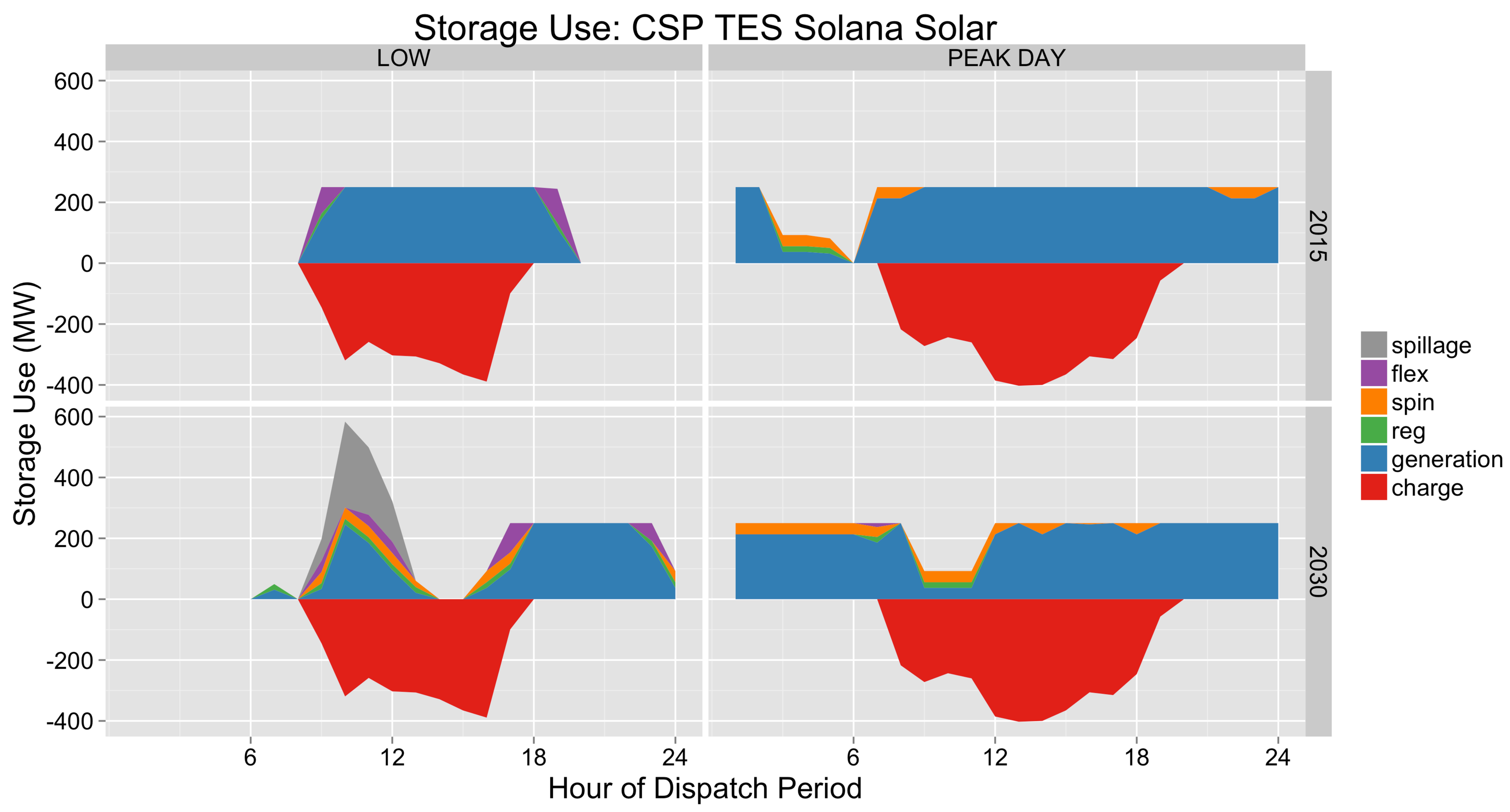
Impact:

- This project will help utilities and grid operators identify the optimal allocation of generation technologies including solar, maximizing the reliability and operational benefits to the regional grid and enabling greater integration of variable generation resources. Analysis from this project will lead to better understanding of the value of CSP with thermal storage from the utility/ISO perspective.
- This project will improve the ability of the nation's utilities to reliably integrate low cost solar technologies while maintaining (and improving) essential reliability of the grid, thereby helping DOE meet strategic goals for solar in the SunShot Vision study.

Significant Milestones	Date
Simulate CSP plant behavior in commercial dynamic performance software (e.g., PSLF, PSSE)	9/30/16
Estimate operational value of CSP plant providing inertia and primary frequency response	9/30/17
Calculate value of CSP redispatch in responding to short-term forecast errors	9/30/17
Long term capacity credit of CSP including operation and value of electricity-storage TES throughout the southwestern U.S.	9/30/17
Calculate value of multiple CSP flexibility attributes in southwestern U.S.	9/30/18



System response to the trip of 2 Palo Verde units (~2750MW), showing benefits of CSP inertial response on arresting frequency decay



Improved dispatch representation in the Resource Planning Model of a parabolic trough power plant

Progress to Date

- Improved and validated representation of CSP in PSLF model for testing system stability
- Development of detailed chronological simulations of CSP in the RPM capacity expansion model: E. Hale, B. Stoll, and T. Mai, 2016 "Capturing the Impact of Storage and Other Flexible Technologies on Electric System Planning," National Renewable Energy Laboratory, http://www.nrel.gov/docs/fy16osti/65726.pdf
- Incorporated new CSP performance parameters in the RTS-2016 PLEXOS model

Research Team: NREL, GE

Improvement and Validation of the System Advisor Model

NREL: Janine Freeman, Nicholas DiOrio, Nate Blair

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

Project Description

Part of the long-term solar system modeling project, SAM & PVWatts enable accurate system assessment via state-of-the-art techno-economic evaluation. We combine detailed models for a wide breadth of solar technologies with sophisticated financial models, powerful scripting, and advanced analysis features not available in any other tool.

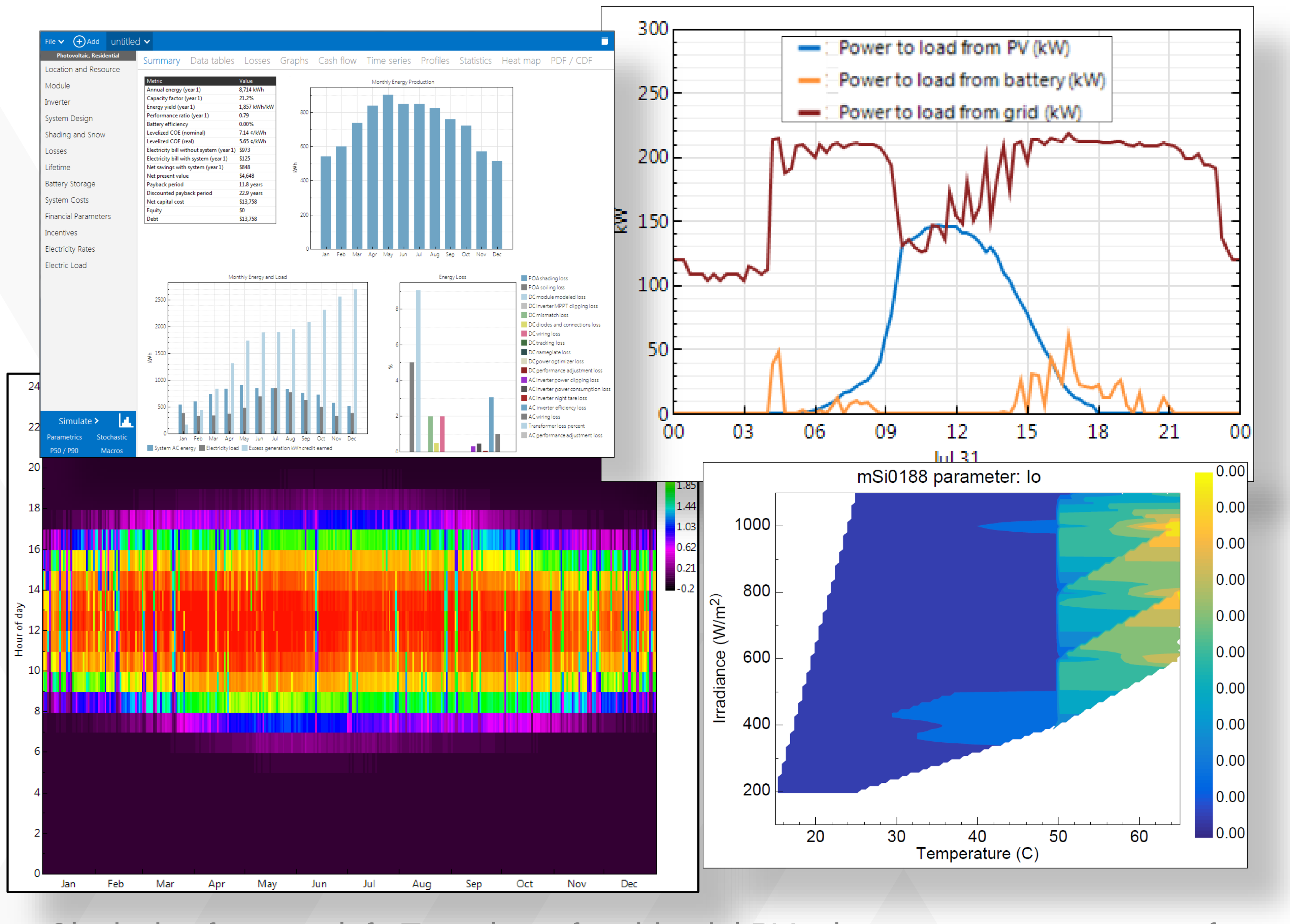
Expected Outcomes

Impact: Reduces risk to financiers, evaluates cost reduction potential, and reduces the cost of capital to lower the cost of solar

Innovation: SAM is the only tool that provides the combination of detailed technology and financial models; and is the only publicly available option for:

- PV + Storage: Integrated PV + battery modeling for both behind-the-meter and utility-scale systems, empowering the industry to better predict the potential applications of energy storage in integrating renewables and providing grid services
- Unique and validated IEC 61853 module model: Achieve greater PV modeling accuracy by directly using test data from the new module testing standard, and validate the model against measured data
- Open code (forthcoming): Enables a new way for users to interact with, understand, and contribute to the underlying algorithms

	Significant Milestones	Date
✓	Utility-scale batteries in SAM	Sep 30, 2016
✓	Automated battery dispatch model	Sep 30, 2016
	Migrate PVWatts website to new NSRDB	Sep 30, 2017
	Open-sourcing SAM & new SAM release	Sep 30, 2017



Clockwise from top left: Two plots of residential PV + battery systems, a map of how short-circuit current changes as a function of irradiance and temperature produced by the IEC-61853 module model, and a heat map of PV system output

Progress to Date

- SAM is launched ~**every 3 minutes**
- Over **35000** active users in **130+** countries
- **2000+** citations in papers and presentations
- 3 webinars with **>2900** views on modeling residential PV & battery systems
- Presentations and papers at **9** industry conferences and workshops
- **>88%** improvement in module performance prediction errors using the IEC-61853 model
- Users include: SolarCity, SunRun, Xcel Energy, Southern Company, EPRI, Enphase, others

VADER – Visualization and Analytics with high penetration of Distributed Energy Resources

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

Project Description

An open source and open access big data analytics platform where state-of-the-art machine learning techniques are utilized for monitoring and planning distribution systems with high penetration of Distributed Energy Resources.

Large number of heterogeneous historical and real-time data are ingested, cleaned and organized to enable comprehensive situational awareness, including scenario analysis and system state estimation.

Expected Outcomes

- Develop software architecture to realize the platform that is scalable and dynamically adaptable to any PV penetration level
- Apply modern machine learning and statistical inference techniques to understand the system state and provide scenario analysis for DER planning decisions
- Demonstrate real-time visualization, monitoring and control

Significant Milestones	Date
VADER Technical Workshop and First TAG Meeting	3/30/2016
DOE Visit	7/15/2016
Second Technical Advisory Group (TAG) Meeting	9/15/2016
First VADER concept demonstration	10/15/2016
Budget Year 1 Project Review	11/9/2016
Demonstration of data analytics for distribution grid monitoring	12/31/2016
VADER System architecture implemented	12/31/2016
VADER Hands-On Lab and 2nd Technical Workshop	3/21/2017

Publications

Y. Weng, Y. Liao, and R. Rajagopal, “Distributed energy resources topology identification via graphical modeling,” *IEEE Transactions on Power Systems*, PP(99):1–1, 2016.

Y. Liao, Y. Weng, and R. Rajagopal, “Urban Distribution Grid Topology Reconstruction vai Lasso,” *Proceedings of IEEE Power and Energy Society (PES) General Meeting*, 17-21 July 2016, Boston, USA.

Y. Liao, Y. Weng, C.W. Tan, and R. Rajagopal, “Urban Distribution Grid Line Outage Identification,” *IEEE Conference on Probabilistic Methods Applied to Power Systems (PMAPS)*, 16-20 October, 2016, Beijing, China.

J. Yu, Y. Weng, and R. Rajagopal, “Data-Driven Joint Topology and Line Parameter Estimation for Renewable Integration,” *IEEE Power and Energy Society General Meeting (PESGM)*, Jul. 2017, accepted.

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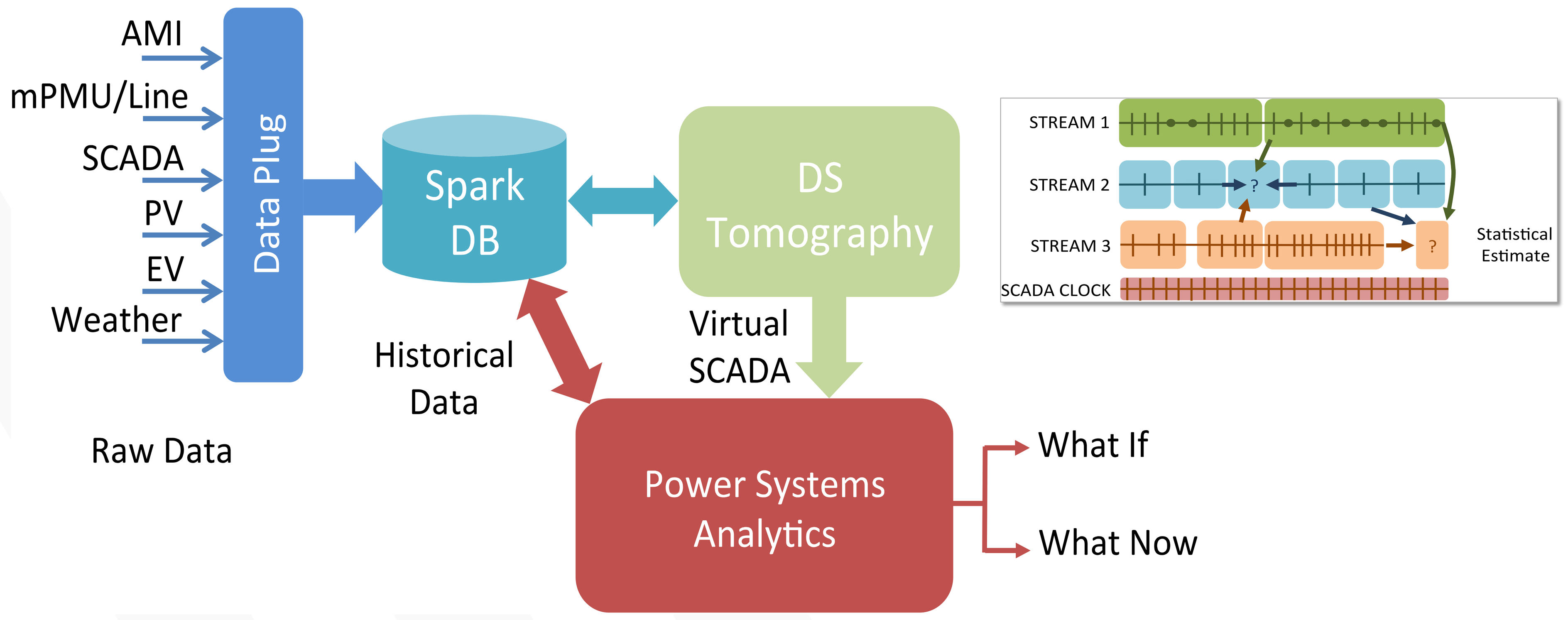


Fig. 1 VADER ingestion pipeline. Raw data accessed via various API’s are cleansed into ‘virtual-SCADA’ stream which are then used in DER motivated power systems analytics.

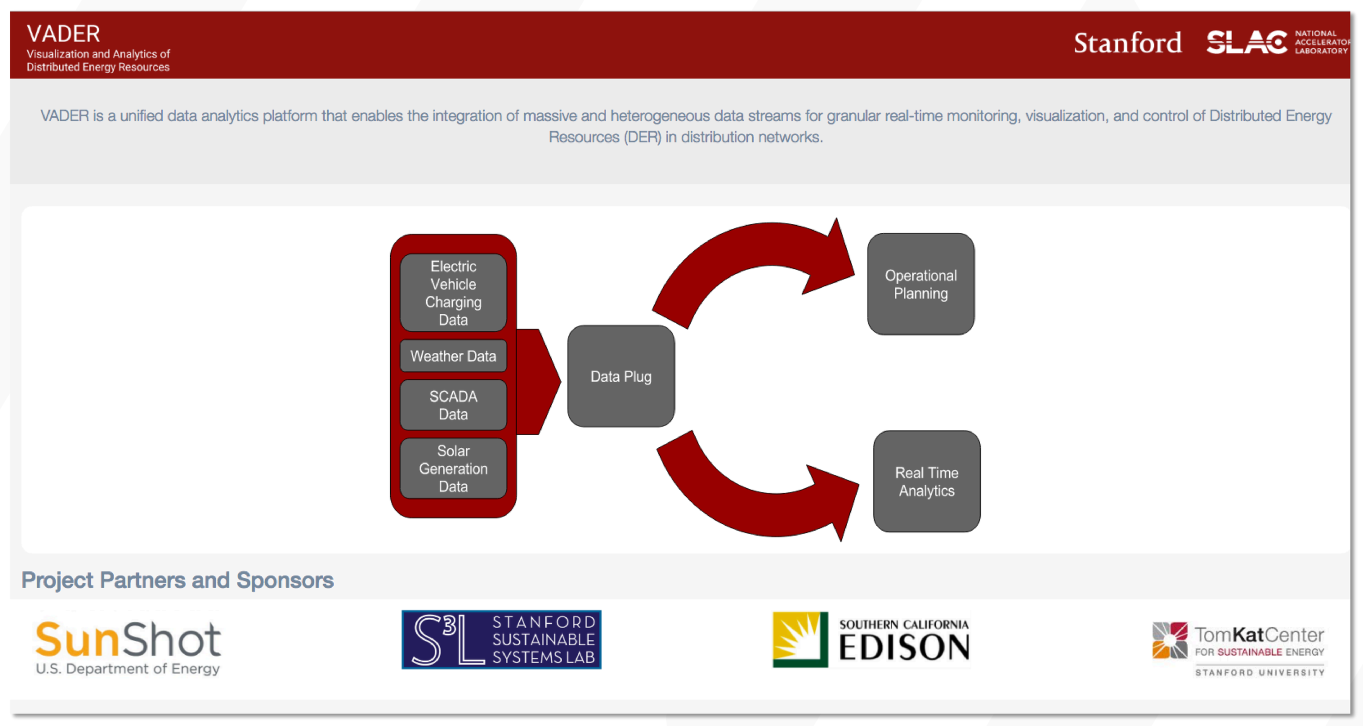


Fig. 2 VADER demonstration page providing access to persistent data and visualization tools

Progress to date

- Developed and demonstrated the software architecture using real-time data from GridLab-D and historical data from utility partner.
- Built and demonstrated visualization capability including a dashboard and map views of the systems
- Developed and demonstrated following analytics:
  - Machine learning-based power flow
  - Load forecasting
  - Topology reconstruction
  - Solar disaggregation
  - Switch state reconfigureation

NARIS

North American Renewable Integration Study

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

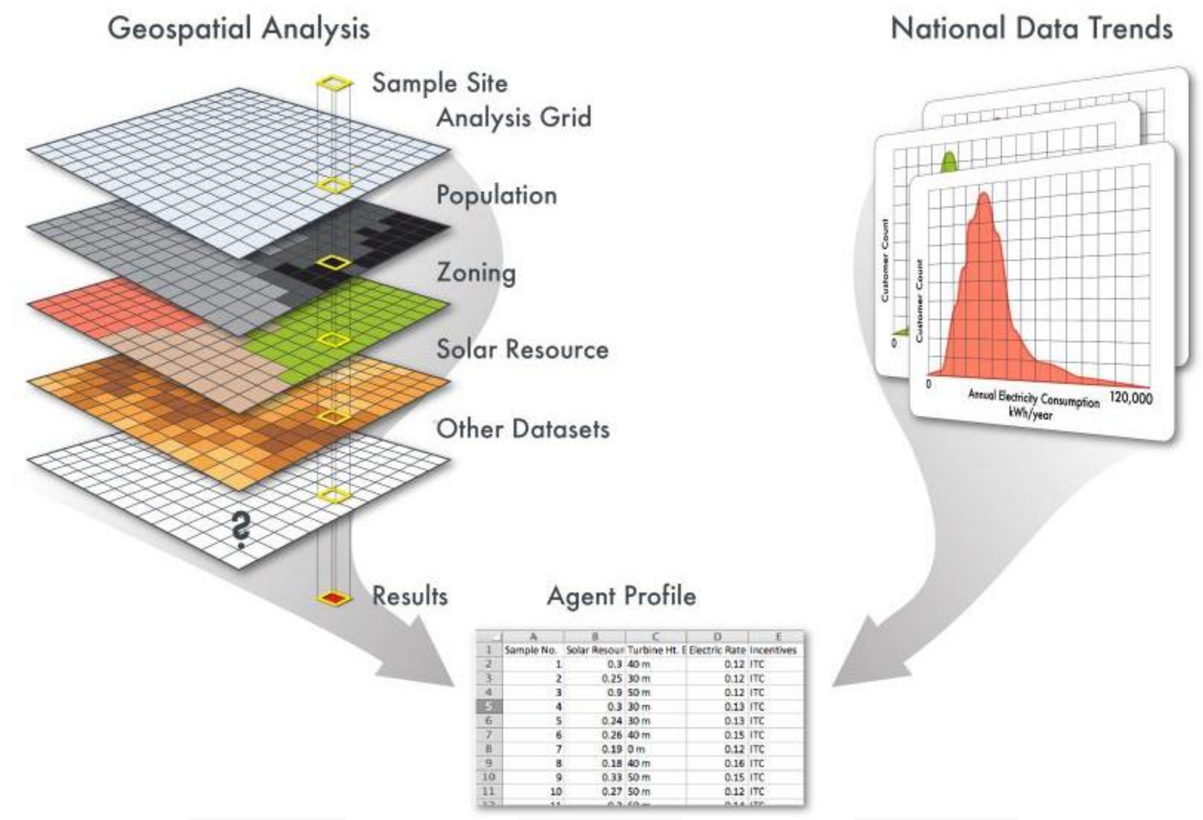
Continental Impact

The North American Power systems weren't originally planned to work together. However, the importance and history of the relationship between these countries can be traced to the first hydropower generators at Niagara Falls. As electricity generation patterns and technologies change, power systems planning and operating practices may need to change, too. In the North American Renewable Integration Study, a group of industry thinkers, engineers, and economists started wondering what would happen if these systems were planned to work together. NREL is leading the analysis to understand the impacts of infrastructure investment and changing operational practices on costs of providing electricity in the modern electricity grid in North America.

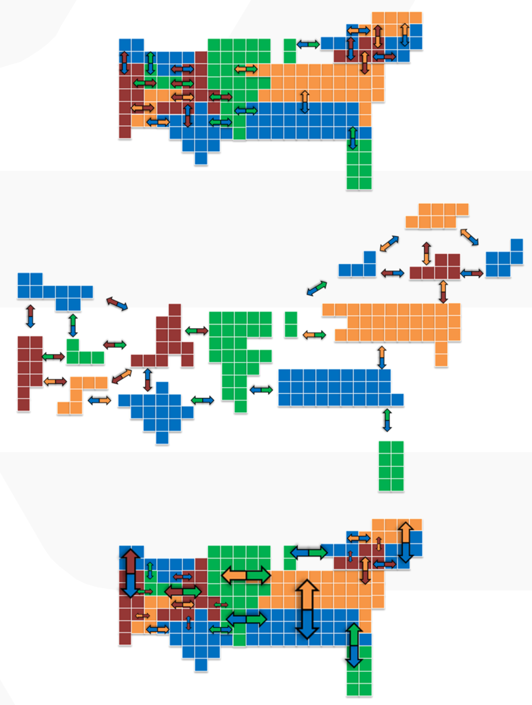
Progress to Date

- New datasets for Canada, Mexico, and the United States for distribution market penetration (dGen model), capacity expansion planning (ReEDS model), and production cost modeling (PLEXOS).
- Novel methods developed for production cost modeling (e.g., geographic decomposition), data analysis (e.g., heat rate curve-fitting), and application of models at a larger scale than ever before.
- Hosted a Technical Review Committee meeting of 40 stakeholders in Golden, Colorado, USA.
- NARIS has been presented to stakeholders in all three countries and to audiences throughout the world.

Cutting Edge Tools

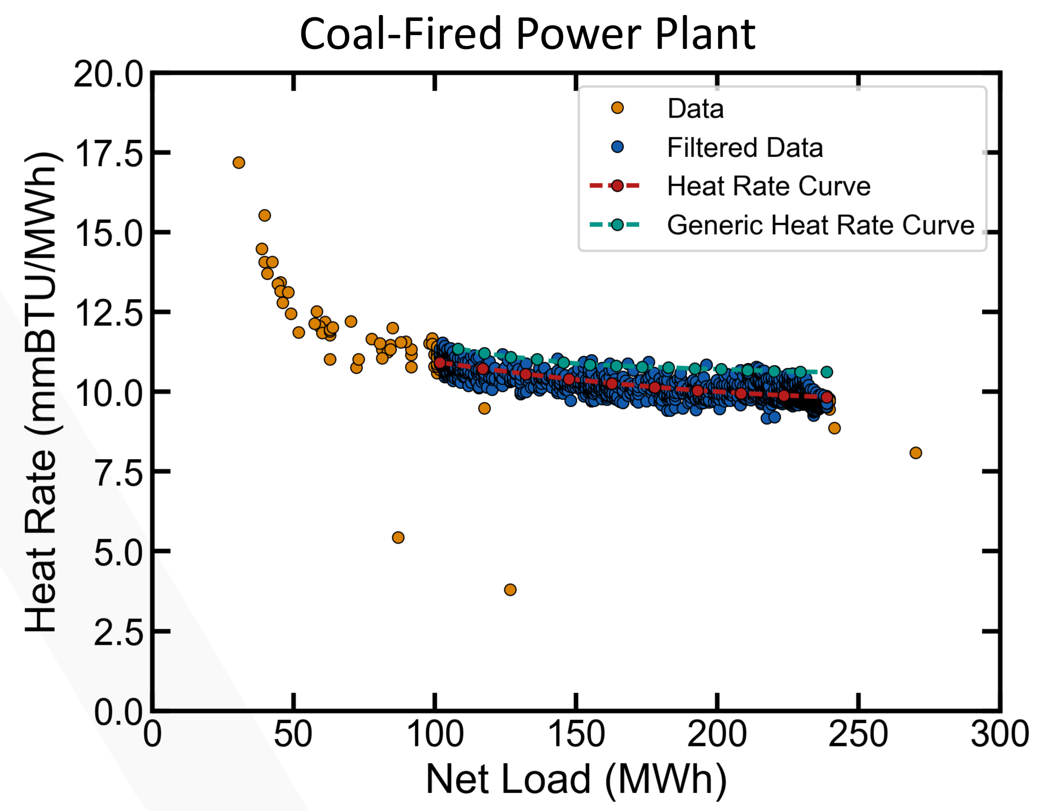


In order to understand how international policy and infrastructure could impact the cost of providing electricity you need some pretty unique tools. NARIS has helped develop world class tools for the analysis of the United States, and scaled them to include Canada and Mexico. The image above is from our distributed generation model dGen. It helps us to understand how consumer level decisions about distributed photovoltaics might impact the needs of the wholesale markets.

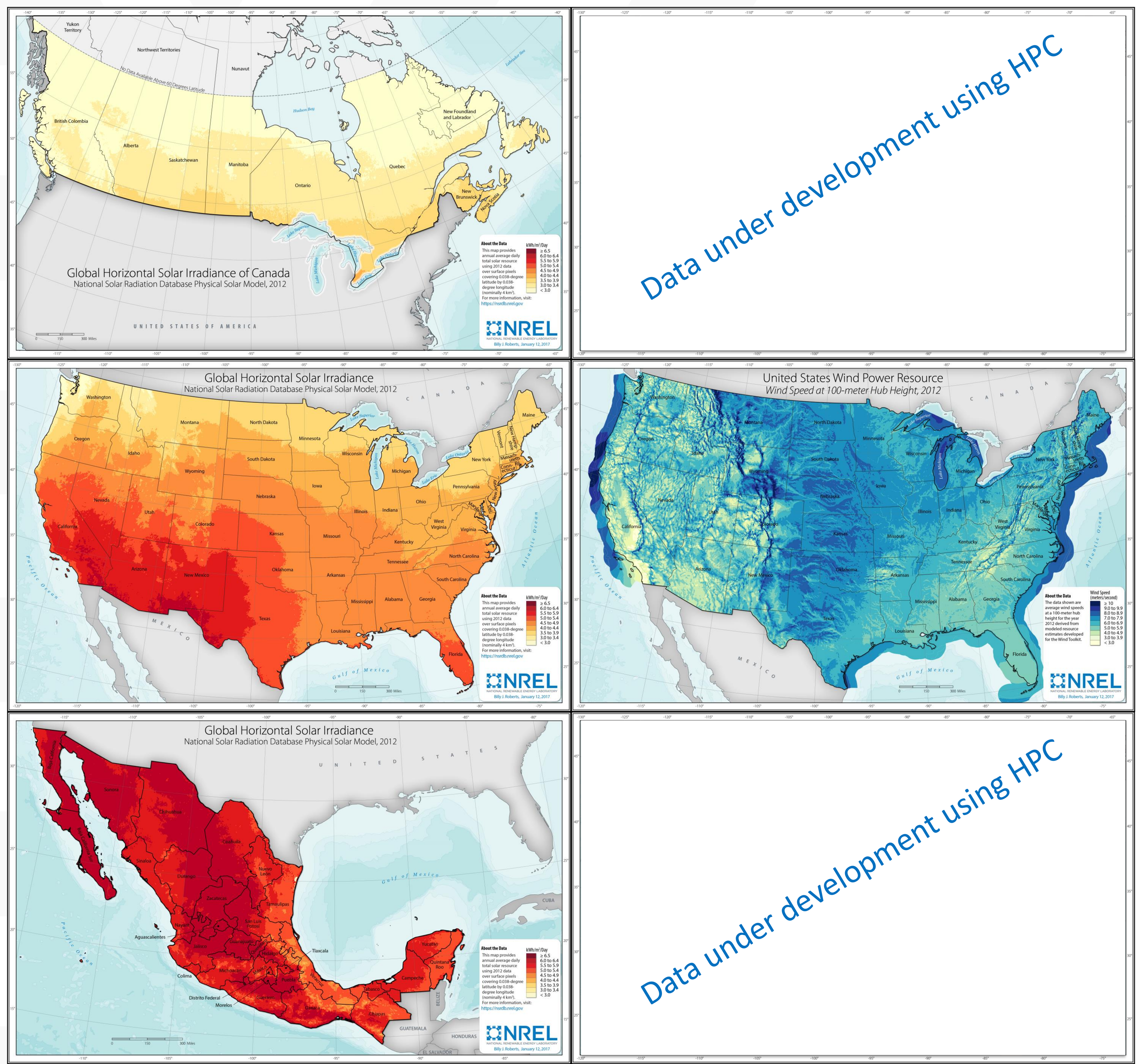


A server isn't enough to crunch the math necessary to solve the Unit Commitment and Economic Dispatch problem in NARIS; we needed new methods for decreasing computation constraints to solve a problem this big while still meeting industry expectations for analysis. By coordinating with other GMLC activities we have developed a new algorithm called geographic decomposition. Initial testing shows a 50% reduction in solve time from this new algorithm which both increases model accuracy through explicit representation of the market footprints, but also reduces solve time substantially.

Rich Datasets



State-of-the-art analysis depends on state-of-the-art data. Good power system data can be difficult to find because there are many entities and the data is often buried inside obscure reports and behind restrictive security and trade secret rules. In NARIS, we work with industry stakeholders to develop the right data, despite these challenges. In the image above, we see how NREL staff analyzed heat rate data from the Continuous Emissions Monitoring System to create heat rates for every thermal plant in the U.S. This is critical to a realistic representation of thermal fleet flexibility and efficiency in a modern grid. Below we see images of the wind and solar resources for North America. This data is generated from satellite images (solar) and numerical weather prediction models run on the Peregrine supercomputer.



U.S. DEPARTMENT OF ENERGY