GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

HELICS for Integrated Transmission, Distribution, Communication, & Control (TDC+C) Modeling

SETO Workshop on Challenges for Distribution
May 17, 2019
Washington, DC

HELICS

Presented by: **Bryan Palmintier**

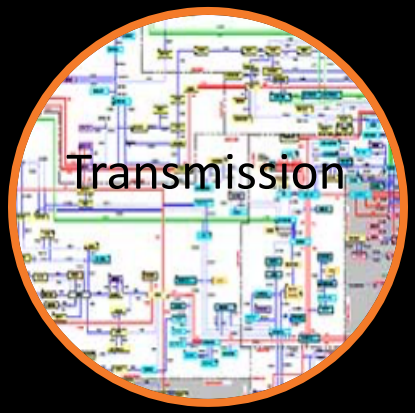
Henry Huang, Liang Min, Jason Fuller, Philip Top, Dheepak Krishnamurthy, Shri Abhyankar, Manish Mohanpurkar, Kalyan Perumalla, David Schoenwald

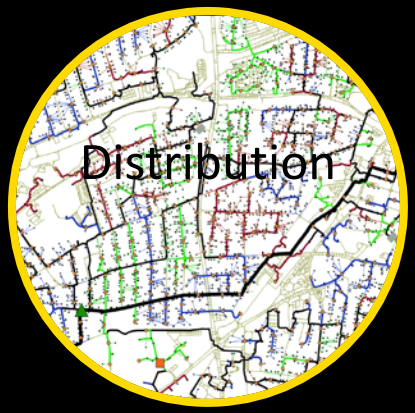
Pacific Northwest NATIONAL LABORATORY
Lawrence Livermore National Laboratory
NREL
Argonne NATIONAL LABORATORY
OAK RIDGE National Laboratory
Sandia National Laboratories
INL Idaho National Laboratory

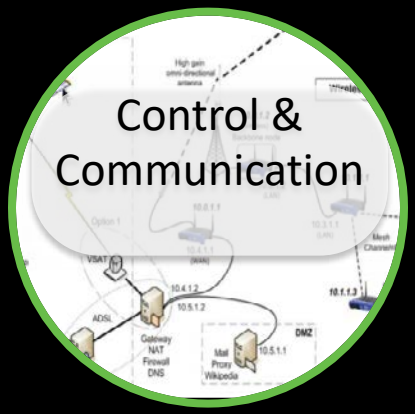
U.S. DEPARTMENT OF ENERGY

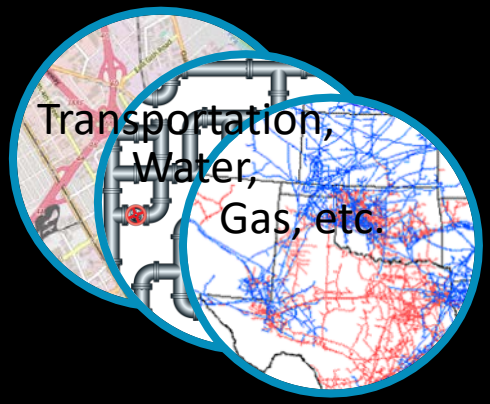
NREL/PR-5D00-73977

Grid modernization requires integrating multiple infrastructures…

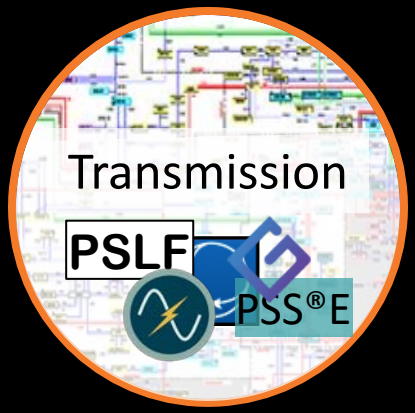


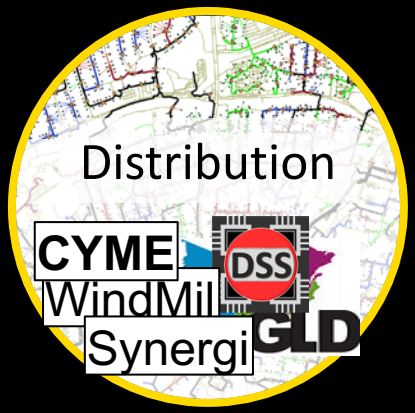


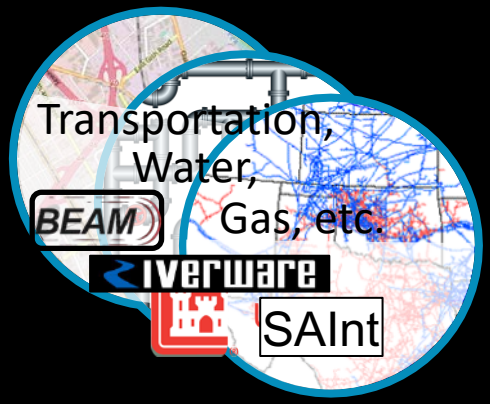




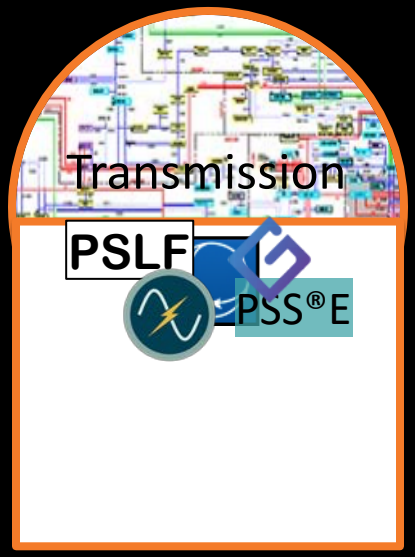
And we have many, well trusted tools to model each…

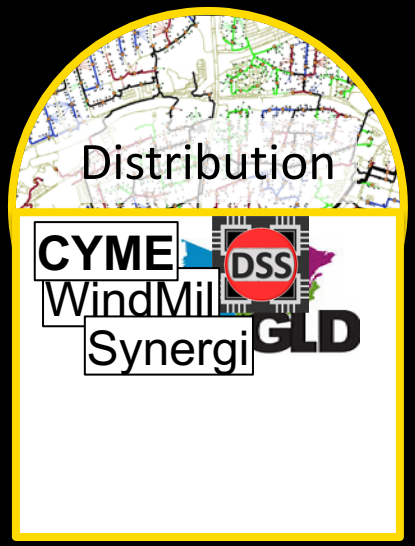


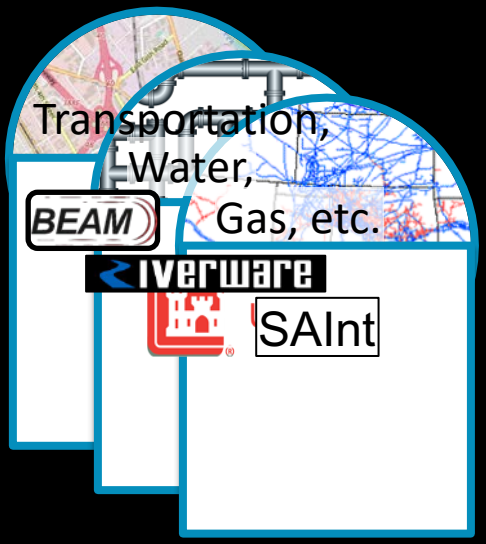




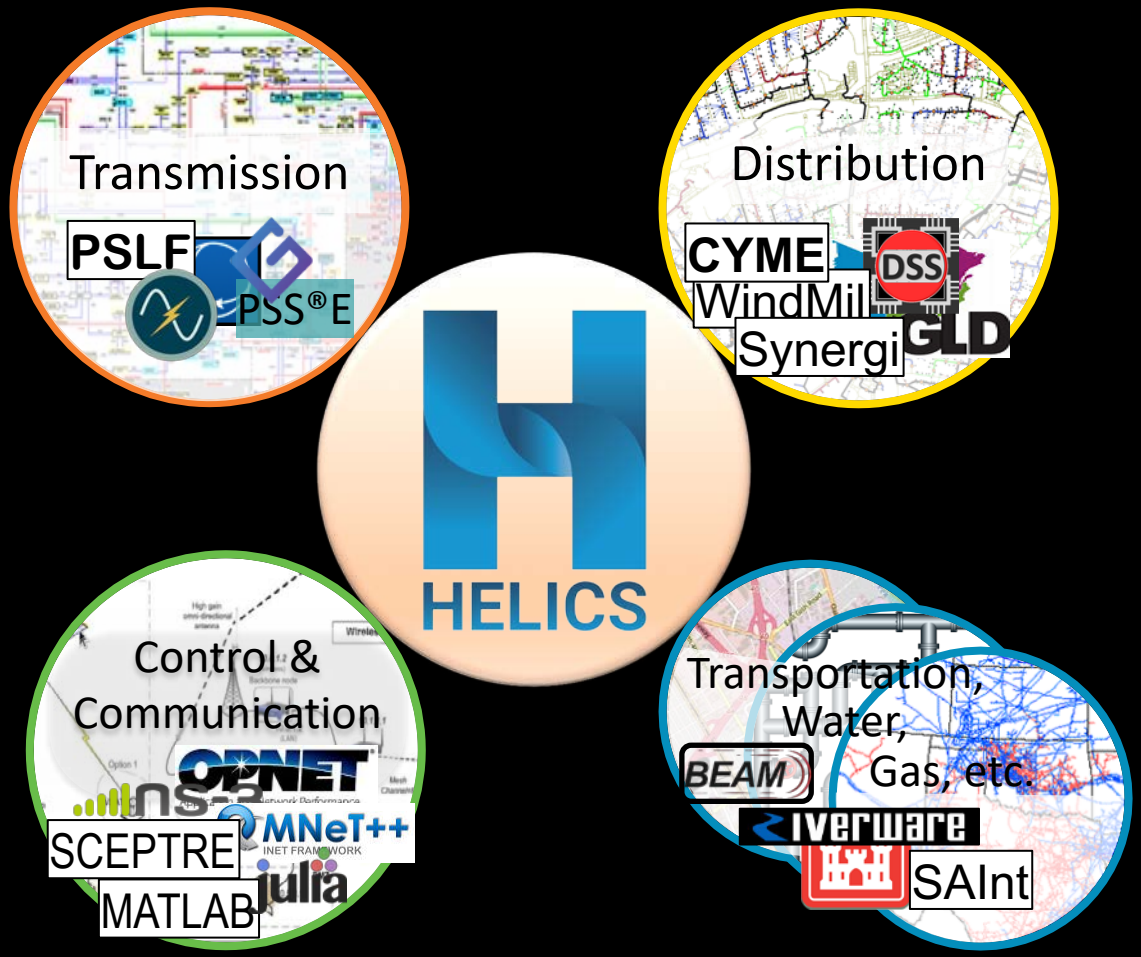
However they are largely used within their own silos of excellence.







HELICS enables easily bringing together two or more existing tools, exchanging data as time advances, to form a tightly integrated ***co-simulation***.



HELICS™: Hierarchical Engine for Large-scale Infrastructure Co-Simulation

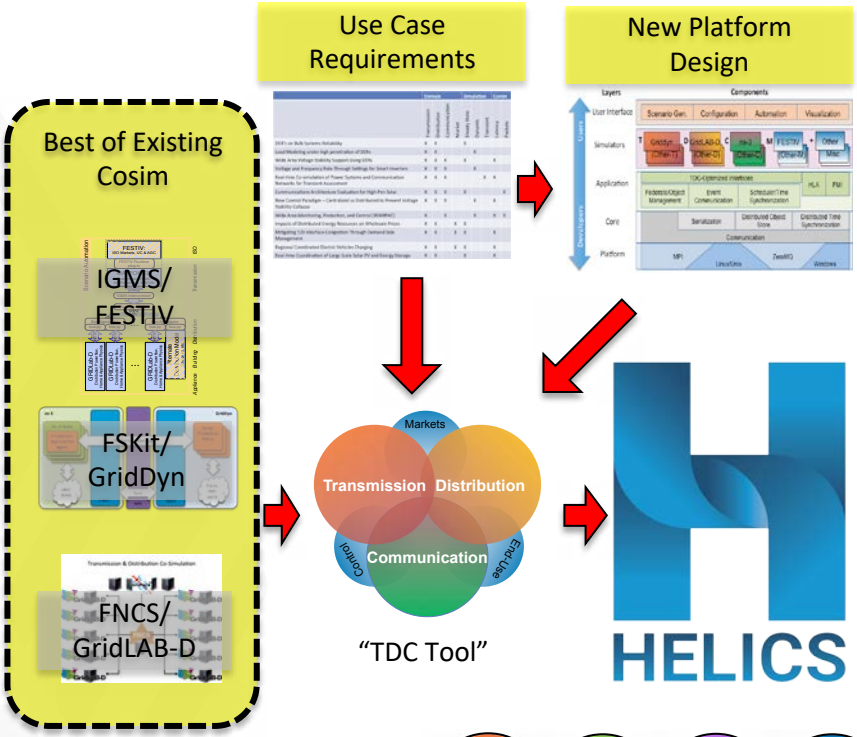
GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

Project funding: GMLC 1.4.15

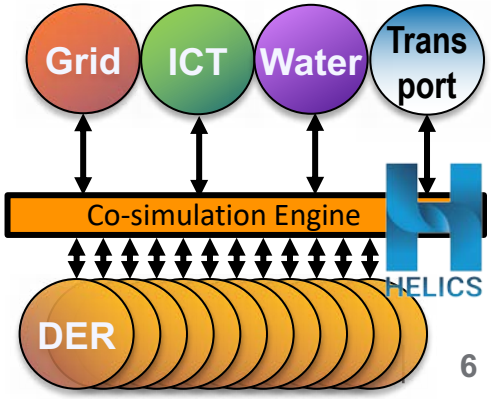
Scalable, High-performance co-simulation to combine best-in-class tools for breakthrough grid modernization simulation and analysis

Capabilities:

- **Scalable:** 2-100,000+ Federates
- **Cross-platform:** HPC (Linux), Cloud, Workstations, Laptops (Windows/OSX)
- **Modular:** mix and match tools
- **Minimally invasive:** easy to use lab/commercial/open tools
- **Open Source:** BSD-style.
- **Many Simulation Types:**
  - Discrete Event
  - QSTS
  - Dynamics
- **Co-iteration enabled:** "tight coupling"
- **APIs:** C++,. C, Python, Java, Matlab, Julia, FMI



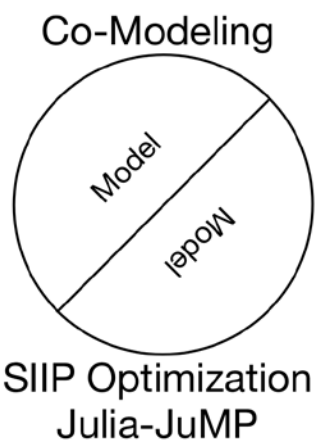
v2.0.0 available now at https://www.github.com/GMLC-TDC/HELICS-src

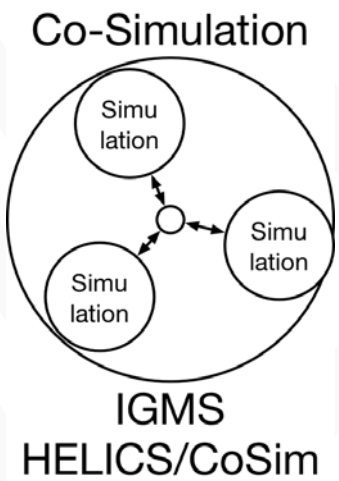


B. Palmintier, et al., "Design of the HELICS High-Performance Transmission-Distribution-Communication-Market Co-Simulation Framework," Workshop on Modeling and Simulation of Cyber-Physical Energy Systems, Pittsburgh, PA, 2017.

Computational Integration Workflows

Slide adapted from Dr. Wes Jones, NREL





Co-modelling is "w[h]ere **models are described in a unified language**, and then simulated."[1]

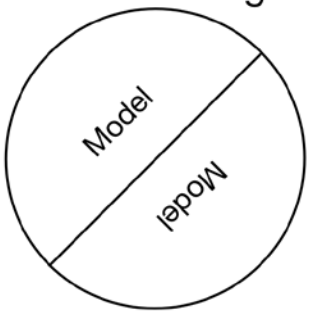
Co-simulation "consists of the theory and techniques to enable global simulation of a coupled system via the composition of simulators. **Each simulator is a black box** mock-up of a constituent system, developed and provided by the team that is responsible for that system."[1]

[1] Gomes, Cláudio et al. "Co-simulation: State of the art." CoRR abs/1702.00686 (2017): n. pag.
Figures: Gomes, Cláudio et al. "Co-Simulation: A Survey." ACM Comput. Surv. 51 (2018): 49:1-49:33.

Computational Integration Workflows

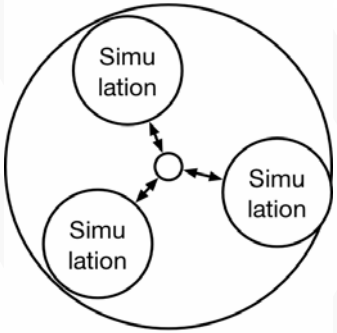
Slide adapted from Dr. Wes Jones, NREL

Co-Modeling



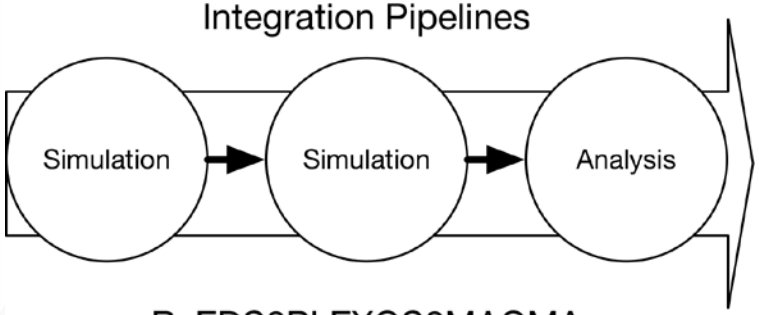
SIIP Optimization
Julia-JuMP

Co-Simulation



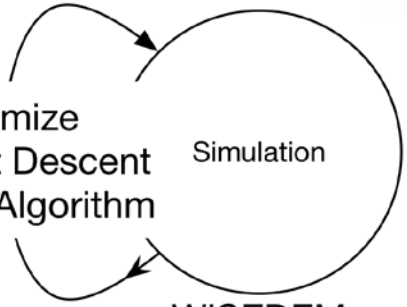
IGMS
HELICS/CoSim

Integration Pipelines



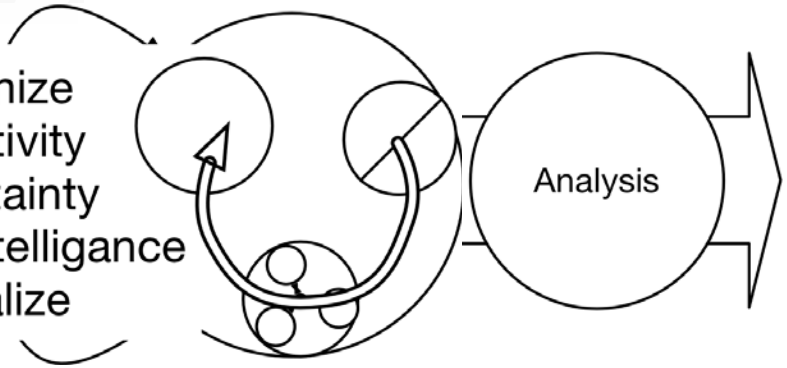
ReEDS2PLEXOS2MAGMA
Luigi

Simulation based Optimization



Optimize
Gradient Descent
Genetic Algorithm

WISEDEM
MDAO



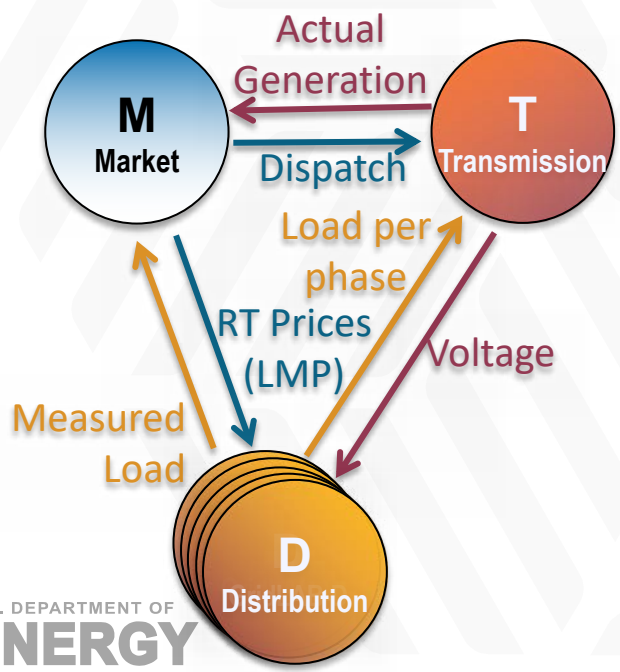
Optimize
Sensitivity
Uncertainty
Artificial Intelligence
Visualize

[1] Gomes, Cláudio et al. "Co-simulation: State of the art." CoRR abs/1702.00686 (2017): n. pag.
Figures: Gomes, Cláudio et al. "Co-Simulation: A Survey." ACM Comput. Surv. 51 (2018): 49:1-49:33.

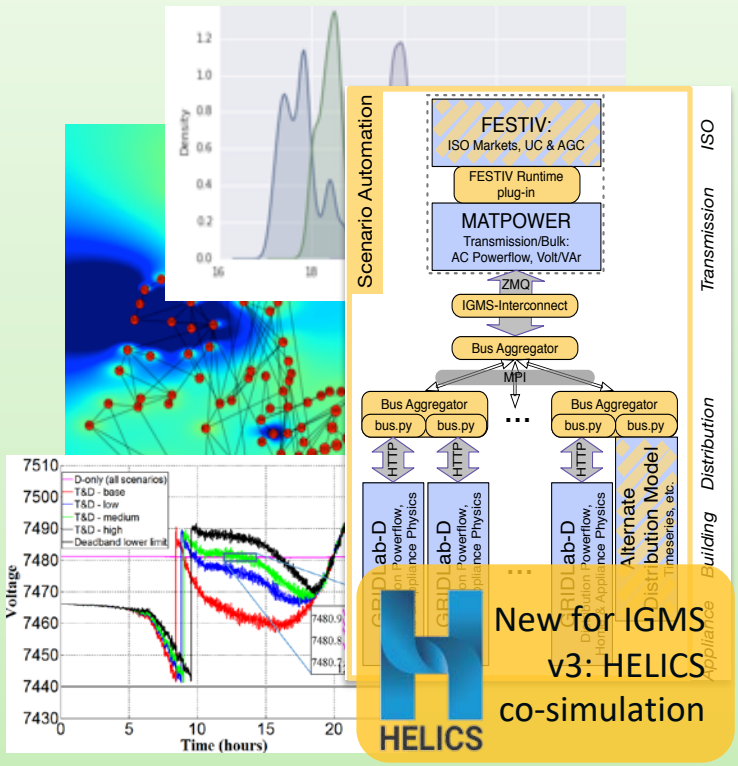
"Cyber"-Physical Simulation

e.g. Transmission-Distribution-Market

- Physical Data (Values)
  - Voltage, Frequency, Current
- Market Data (Messages)
  - Measured Load, LMPs



Large-scale DER-Market Interactions

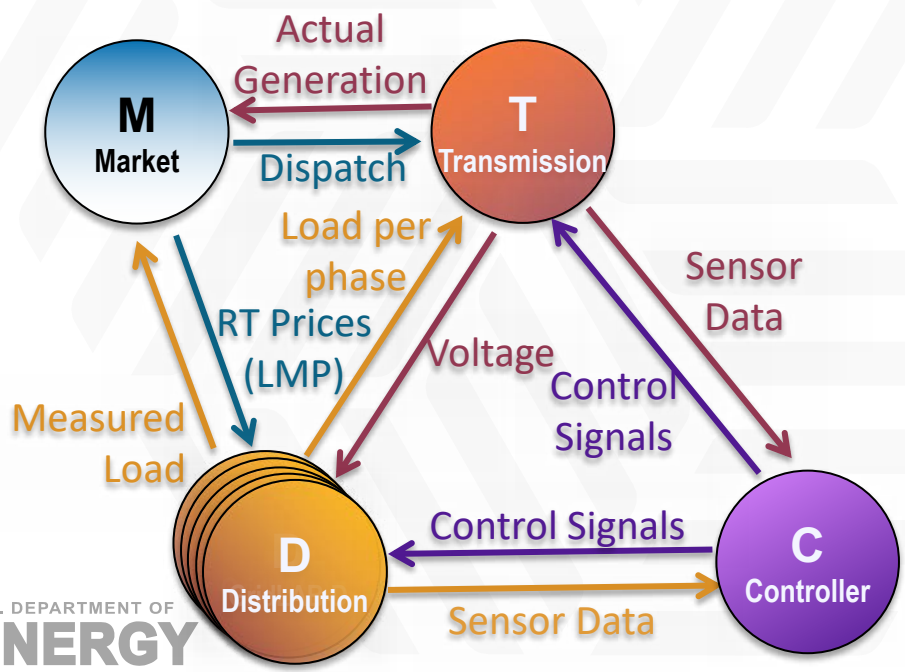


NREL's Integrated Grid Modeling System (IGMS) provides a full-scale co-simulation with transmission-level markets, 1000s of distribution feeders, and 1Ms of DERs

Adding Controllers…

e.g. Control Architecture Scaling & Performance

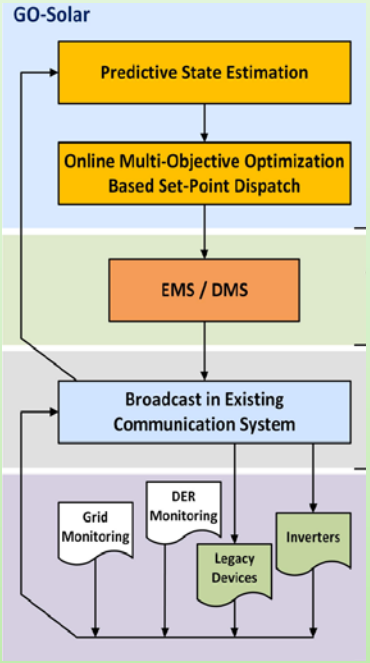
- Physical Data (Values)
  - Voltage, Frequency, Current
- Market Data (Messages)
  - Measured Load, LMPs
- Controller Data (Messages)
  - Sensor Readings, Control Signals



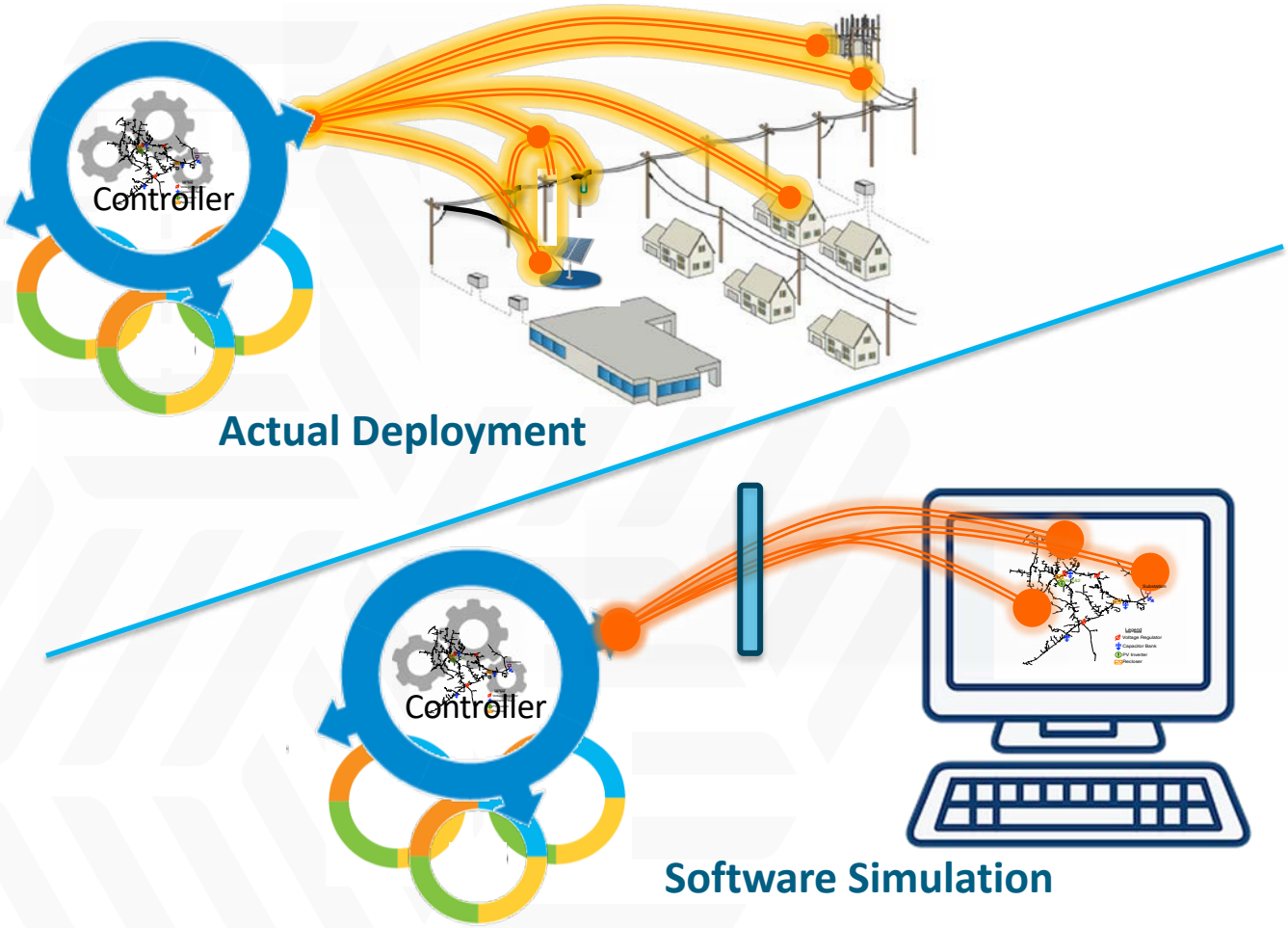
Novel T&D Control Architecture

Design: Predictive State Estimation & Machine Learning Control

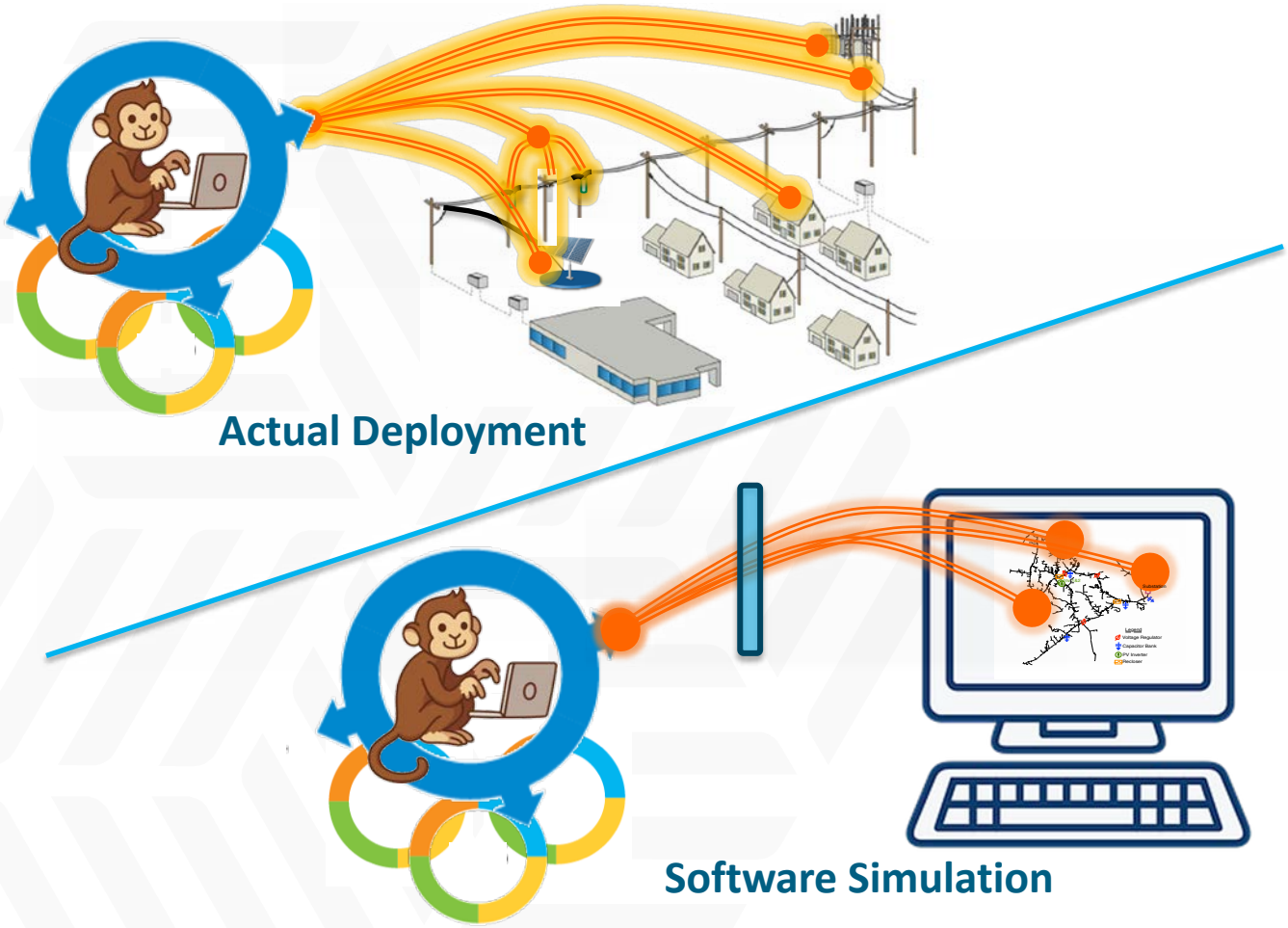
Grid Sim: Entire Island of Oahu, HI with >1M electric nodes.



Keeping the wires uncrossed



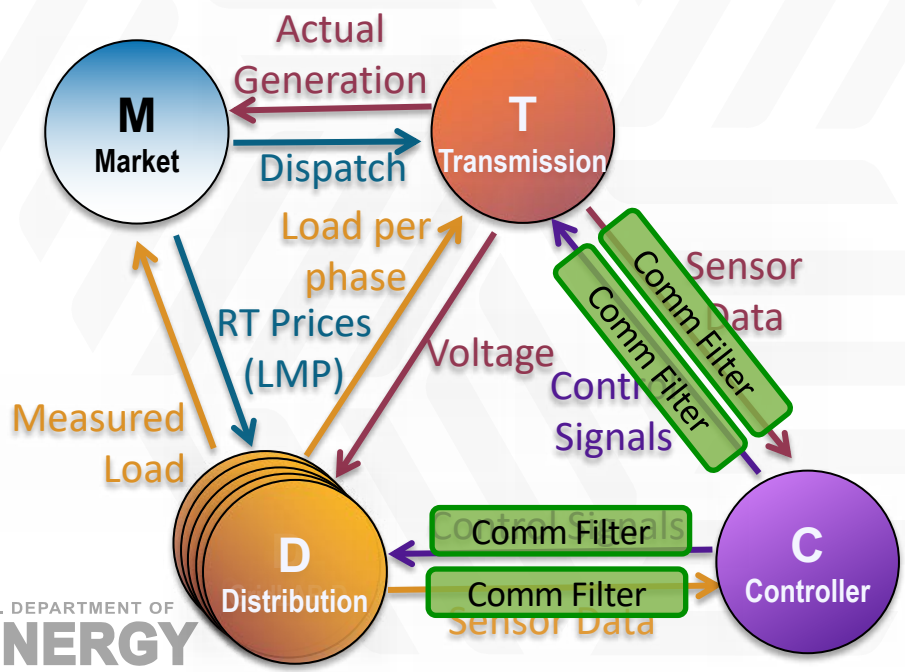
Keeping the wires uncrossed



… and Simple Communication

e.g. Design-stage Cybersecurity Evaluation

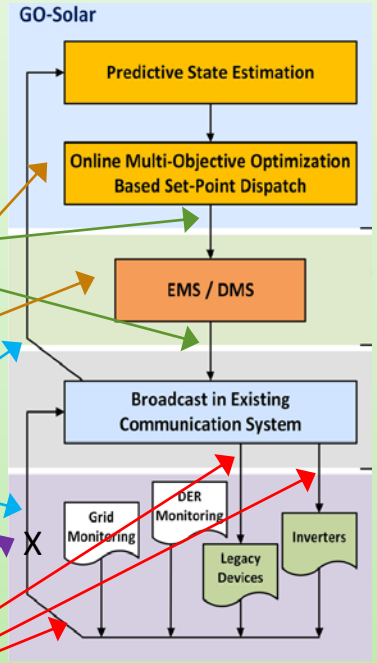
- Built in "Filters" for
  - Delays
  - Random drops
  - Other message effects (e.g. packetization)
  - And more
- No changes to domain models



Novel T&D Control Architecture

Design: Predictive State Estimation & Machine Learning Control

Grid Sim: Entire Island of Oahu, HI with >1M electric nodes.

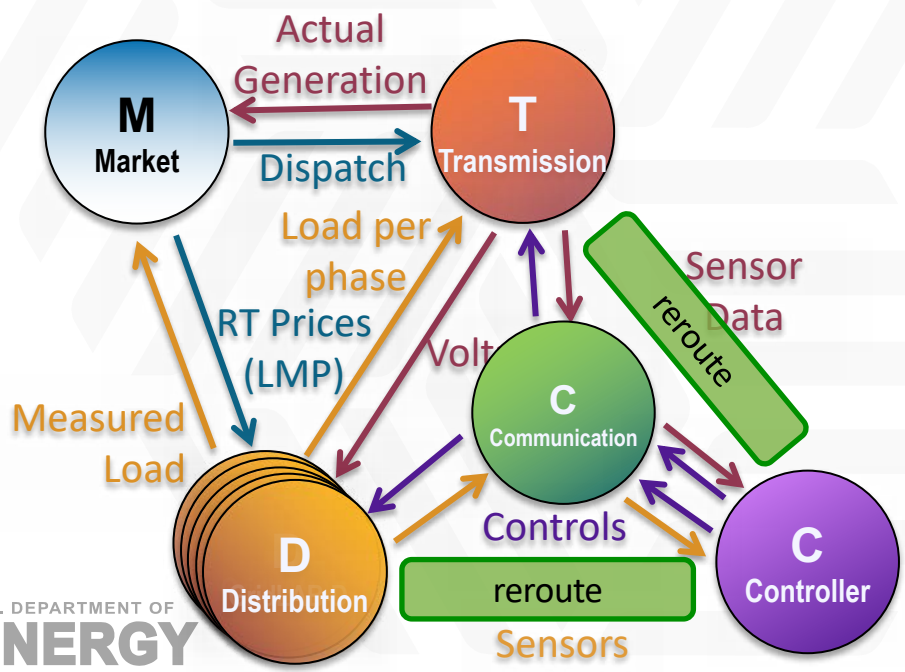


1. Control signal spoofing
2. Control node compromise
3. Sensor data spoofing
4. Communication Denial of Service
5. Communication Latency Margin

Or Detailed Communication

e.g. Protocol Comparison for Situational Awareness

- Full communication simulation:
  - Shared bandwidth
  - Network Specific Vulnerabilities
  - Potential Tools: ns-3, Opnet++, SCEPTRE, etc.
- No changes to domain models

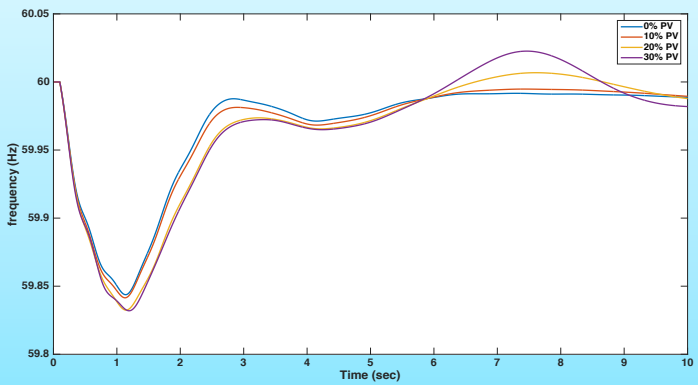


Protocol/Full-Stack Performance

t Ex: SuNLaMP Hybrid Comms

Ex: Power-Comm. Emulation

Some Other Use Cases



T&D frequency stability with high DER

ADMS Testbed and other PHIL

Large-scale DER-Market Sim

- 35k feeders
- WECC-240 trans.
- 25M homes
- Simplified CAISO-style Market

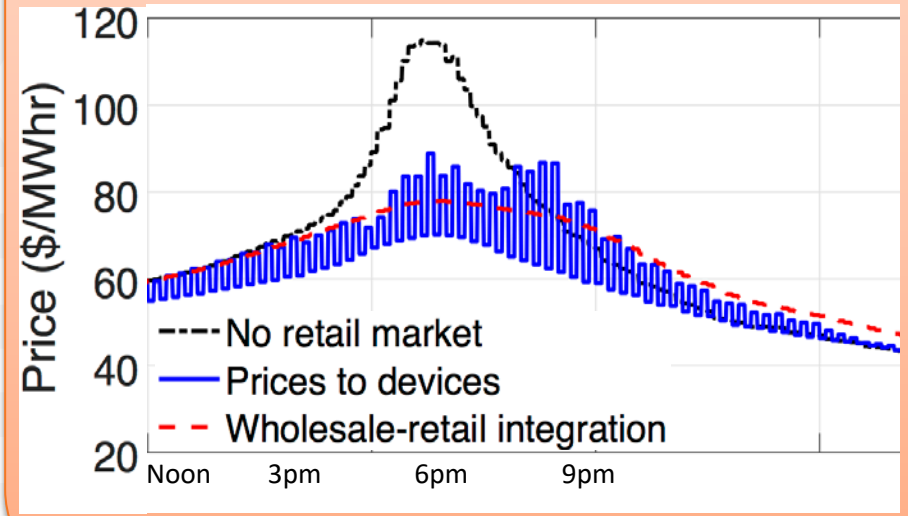
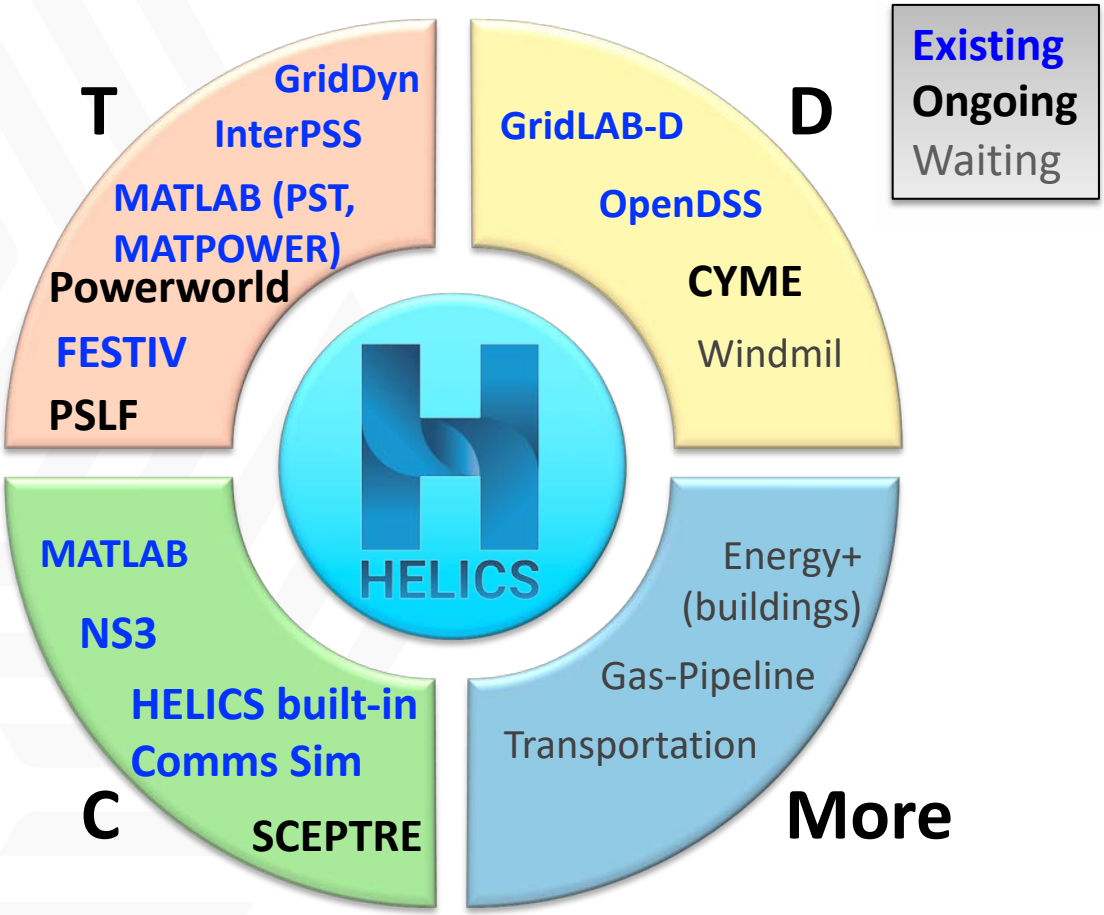


Figure from Trevor Hardy, PNNL

HELICS Interfaces to Domain Simulators

Not exhaustive lists.

- Growing mix of tools
- Enable large-scale interdependency all-hazards studies: scale to 100,000+ domain simulators
- Diverse simulation types:
  - Continuous, discrete event, time series
  - Steady-state/dynamic/transient
  - Any energy system
- Support standards: HLA, FMI, …
- **APIs:** C++,. C, Python, Java, Matlab, Julia, FMI



HELICS

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

HELICS v2.0.0 available at https://www.github.com/GMLC-TDC/HELICS-src

Thank You

Bryan Palmintier: bryan.palmintier@nrel.gov

NREL/PR-5D00-73977

Henry Huang, Liang Min, Jason Fuller, Philip Top, Dheepak Krishnamurthy, Shri Abhyankar, Manish Mohanpurkar, Kalyan Perumalla, David Schoenwald

Pacific Northwest NATIONAL LABORATORY
Lawrence Livermore National Laboratory
NREL
Argonne NATIONAL LABORATORY
OAK RIDGE National Laboratory
Sandia National Laboratories
INL Idaho National Laboratory

This work was authored in part by Alliance for Sustainable Energy, LLC, the manager and operator of the National Renewable Energy Laboratory for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by U.S. Department of Energy Offices of Electricity and of Energy Efficiency and Renewable Energy Solar Technologies Office through the Grid Modernization Initiative. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.