ENERGISE Program Kickoff

DOE Award #: DE-EE0008006

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Robust and resilient coordination of feeders with uncertain distributed energy resources: from real-time control to long-term planning

Lead: University of Vermont

October 11, 2017

The Energy Systems Laboratory at UVM (TESL@UVM)

TESL@UVM

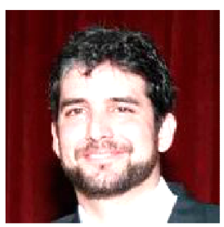
Six EE faculty working on grid and energy problems

Mads Almassalkhi

Jeff Frolik

Paul Hines

Hamid Ossareh



Luis Duffaut Espinosa

Pavan Racherla

Broad expertise

- Power systems
- Optimization
- Control theory
- Stochastic systems
- Weather/Climate
- Communications

Advising more than 10 graduate students in the area of power/energy (most PhD)

TESL@UVM is growing

Recent and ongoing industry-research projects with

Ongoing federal grants with

ENERGISE: How the Why?

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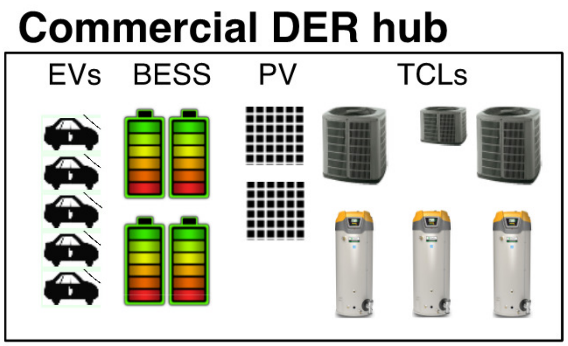
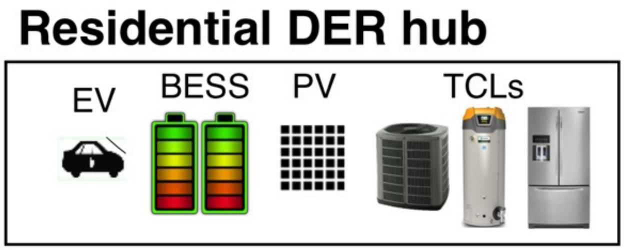
- Consider a 1000-feeder distribution system in Year 2030 with
  - >50% solar PV by energy and >100% solar PV by peak demand
  - Millions of "active nodes" (controllable net-load devices) have been installed





How do we leverage these uncertain/variable DERs optimally for <u>robust and resilient grid operations and future markets</u> while still giving customers what they need, when they need it?

Key idea: adapt wide-area control concepts to Dist. Ops.
➔ Primary, secondary, tertiary control becomes within- and between-feeder balancing, and DSO markets

Team

❖ **UVM** leads project (Almassalkhi, Ossareh, Racherla)

- power engineering, optimization, control theory, data analytics
- open-source software & HiL validation

Dr. Mads Almassalkhi

Dr. Hamid Ossareh

Dr. Pavan Racherla

Team

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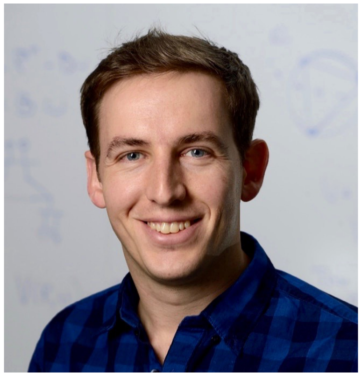
❖ **JHU:** optimization & markets (Gayme, Mallada)

- Optimization, dynamical systems, and energy market design

Dr. Dennice Gayme



Dr. Enrique Mallada

Team

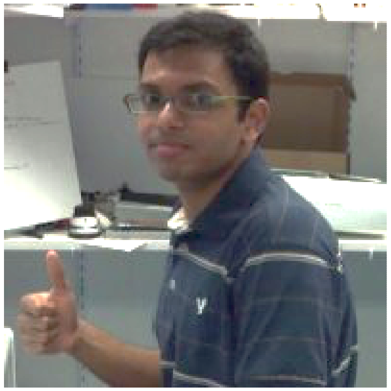
❖ **PNNL**: flexible load modeling (Kundu)

- Power systems, control, modeling, large-scale validation

Dr. Soumya Kundu

Team

❖ **NIST**: HiL, cyber, & interop considerations, smart grid



Dr. Dhananjay Anand

❖ **Con Edison** (**ORU**): utility partner, validation (data & models)

- Andrew Reid, Joe White, and Mike McGuire

Project Outcome

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- **Project outcome:** a technology that unleashes the flexibility of controllable grid assets and, in the process, reinvents the utility from a volt/VAR-focused loss-minimizer into **a full-service energy coordinator**.
  - Aligns well with New York state's REV's notion of Distributed System Platform (DSP) and Distribution System Operator (DSO)
    - *Report of the Market Design and Platform Technology Working Group (2015)*

- **Technical objectives:**
  1. **Technology development:** extend optimization and control tools and algorithms to facilitate integrated management of grid constraint and heterogeneous end-use resources
  2. **Full-scale hardware validation:** implement and validate technology at NIST's Smart-Grid Test Bed using hardware-in-the-loop simulation for normal and contingency operation for >100 physical active nodes
  3. **Large-scale software validation:** implement technology and validate technology with PNNL's GridLab-D with >1,000,000 active nodes over a one-year representative period
  4. **Benefit assessment**: Assess the financial and reliability benefits for various levels of variable renewable generation, flexible load, and energy resources.

Summary of Approach

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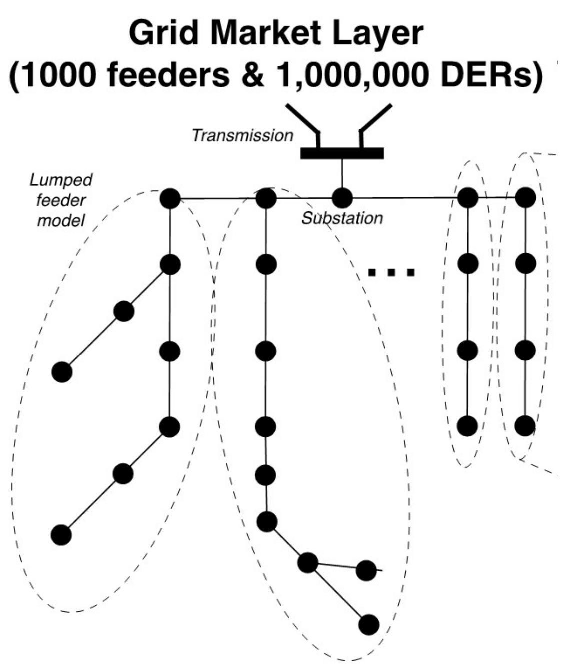
- Decompose operation across spatio-temporal scales and use corrective control to manage uncertainty



Manage resources economically

Manage network optimally

Manage resources dynamically

Summary of Approach

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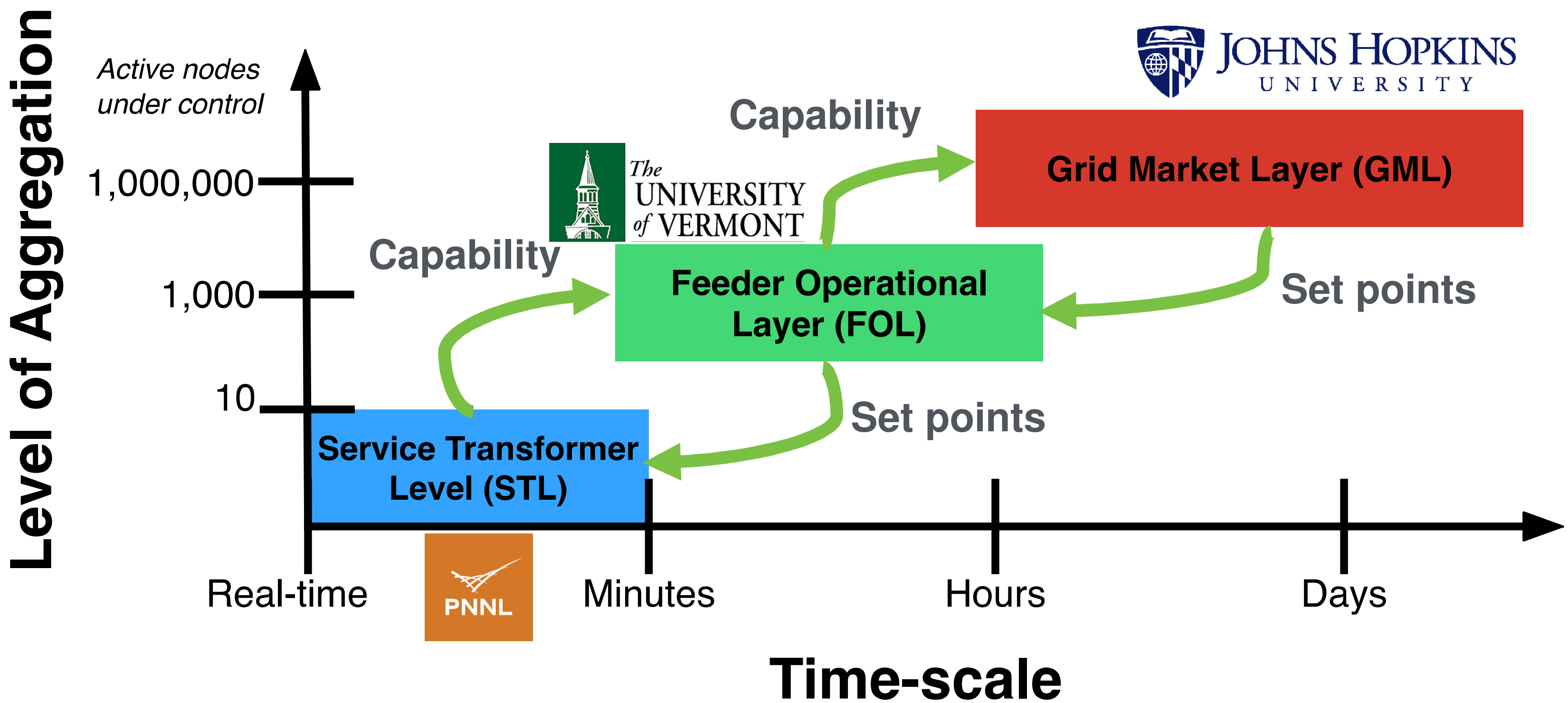

Need to study different time-scale separations and levels of aggregation

Service Transformer Layer (STL)

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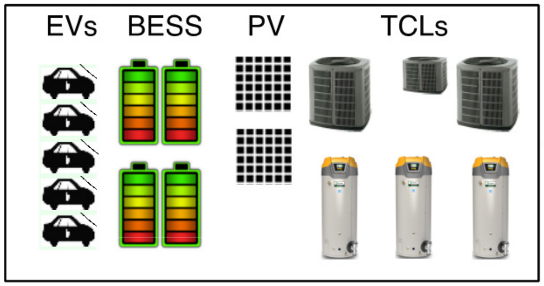
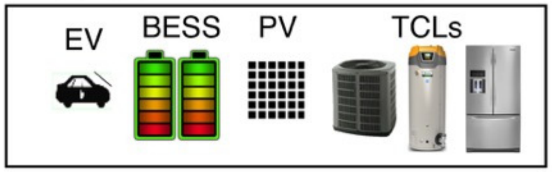
- Each STL element represents 10-50 flexible devices at service level transformer
- **Goal**: characterize & model dynamical aggregated resources at service transformer and quantify modeling uncertainty
  - Aggregate modeling constructs an uncertain but dispatchable flexible energy resource
    - Leverage existing expertise at PNNL
    - **Uncertainty quantification**, dynamic aggregate models, constraint-aware controller design

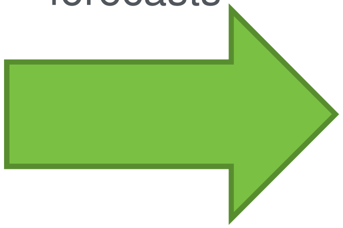
Commercial DER hub



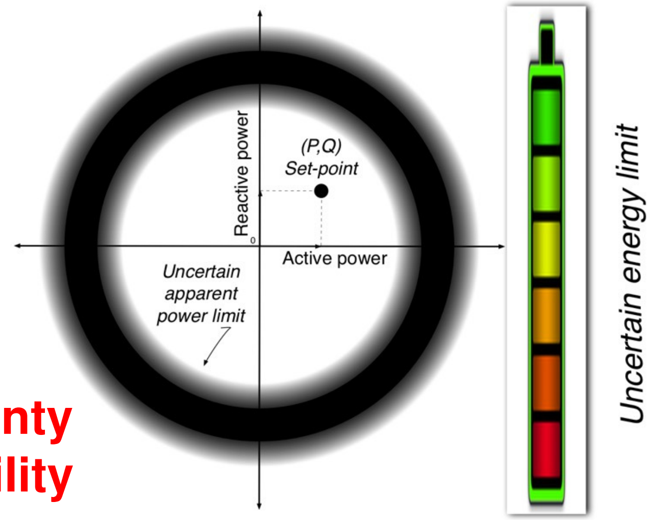
Residential DER hub



+ Solar/weather forecasts



Aggregated controllable load



Uncertainty in flexibility

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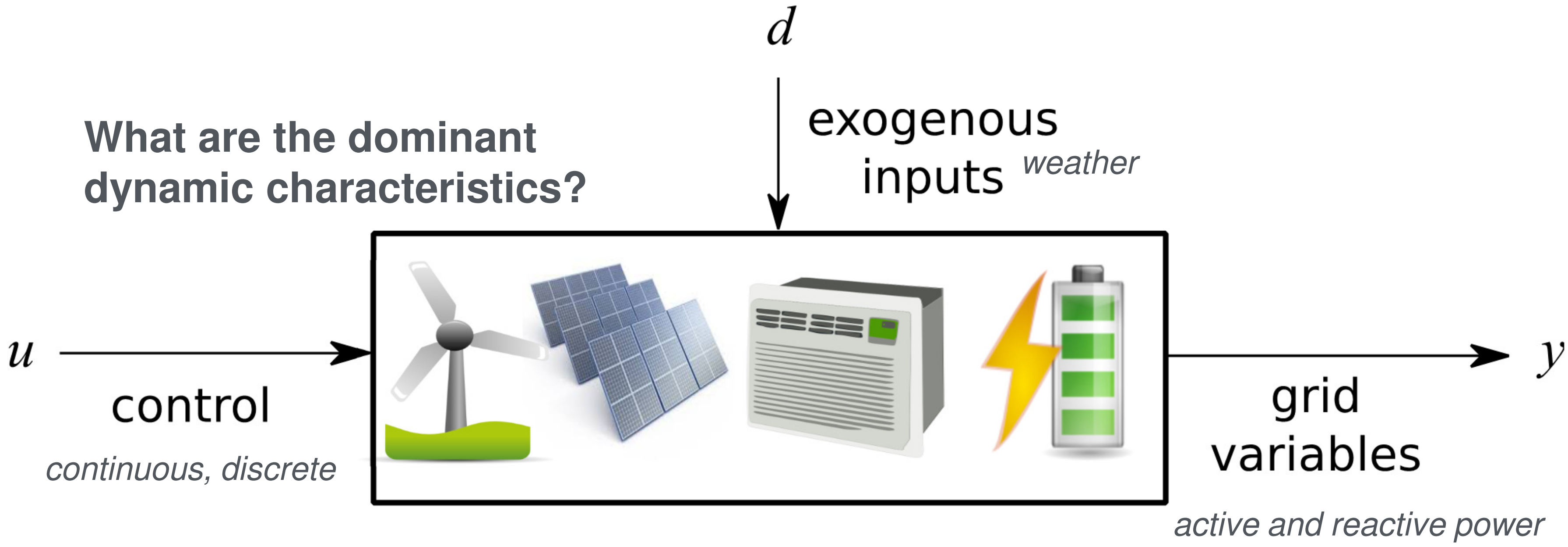

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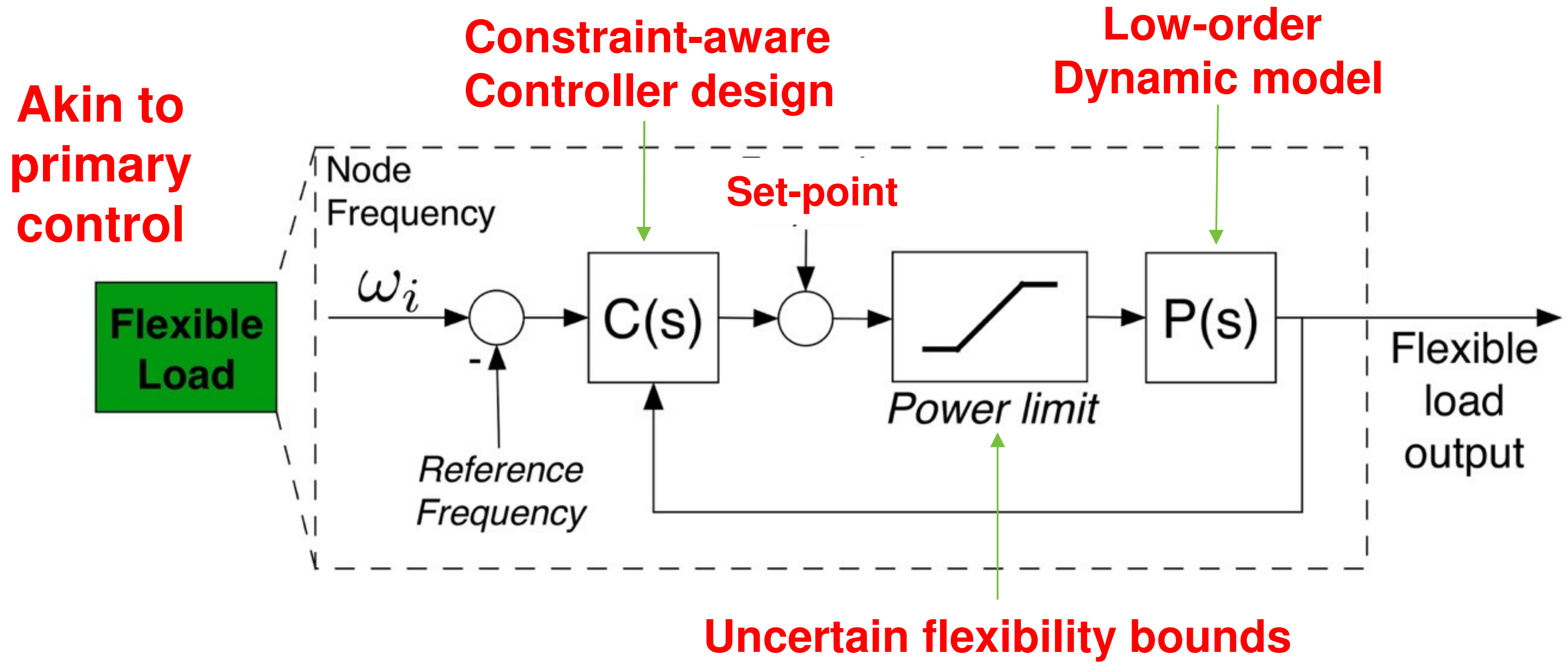

Feeder Operational Layer (FOL)

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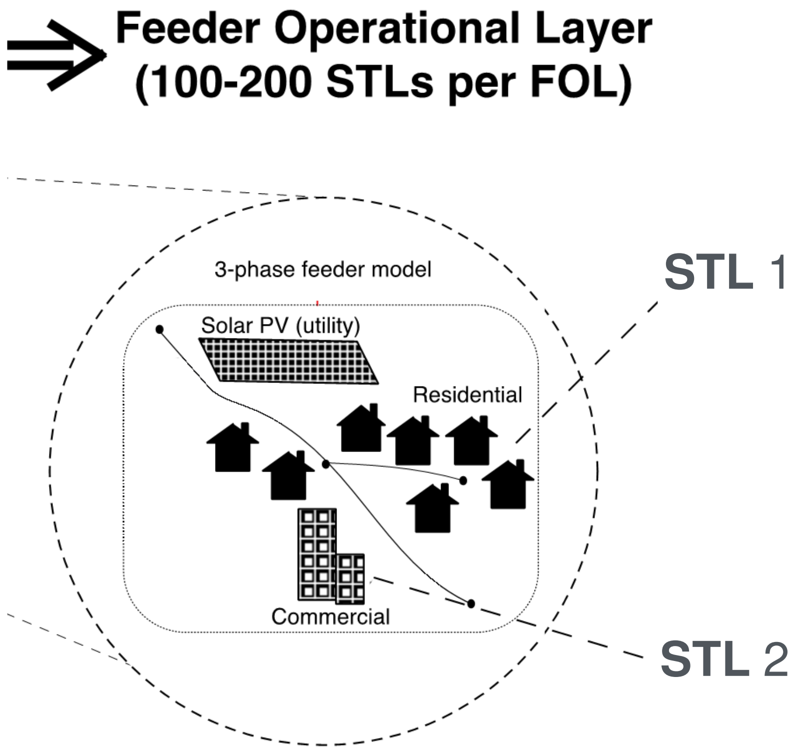
2. **Optimize feeder asset schedules to regulate bidirectional unbalanced power flows and voltages under net-load uncertainty**

- Distribution System State Estimator (DSSE)
  - Robustly estimate nodal voltages and topology changes in near real-time
- Full unbalanced grid optimization
  - Considers mechanical switching (legacy) devices and flexible STL elements on different time-scales
    - Ensure robust voltage profiles under uncertainty of available net-load resources
  - Optimize fast flexible STL elements for corrective control
    - Techno-economic optimization: balance operational roles (volt/VAr/losses) with market incentives (revenue)



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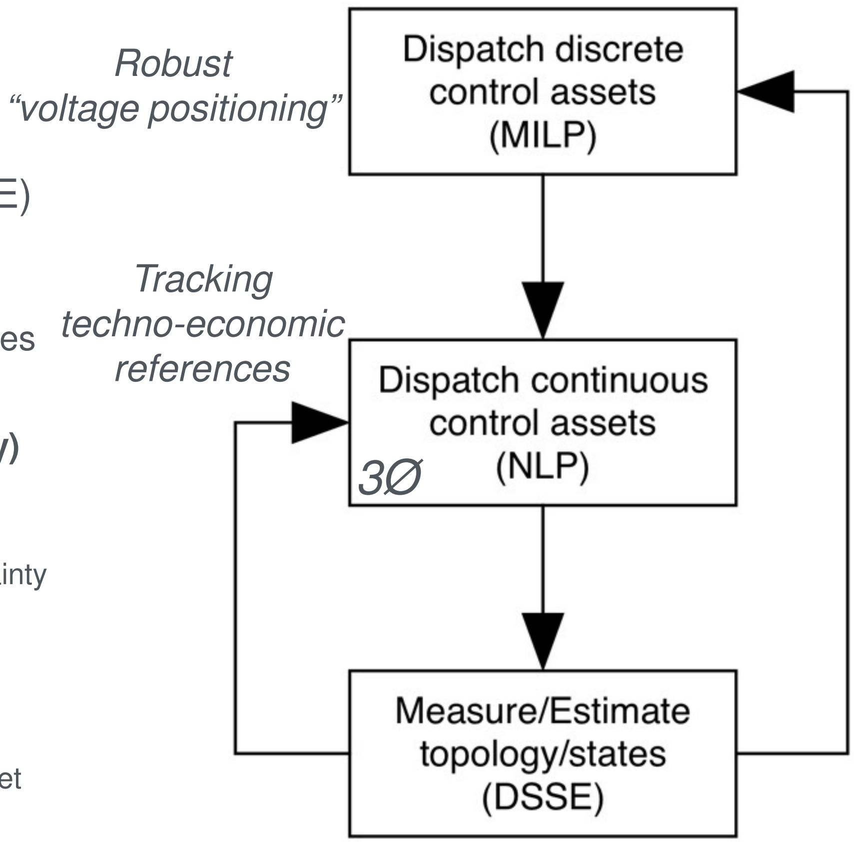

Considers STL flexibility and very-short-term solar forecasts

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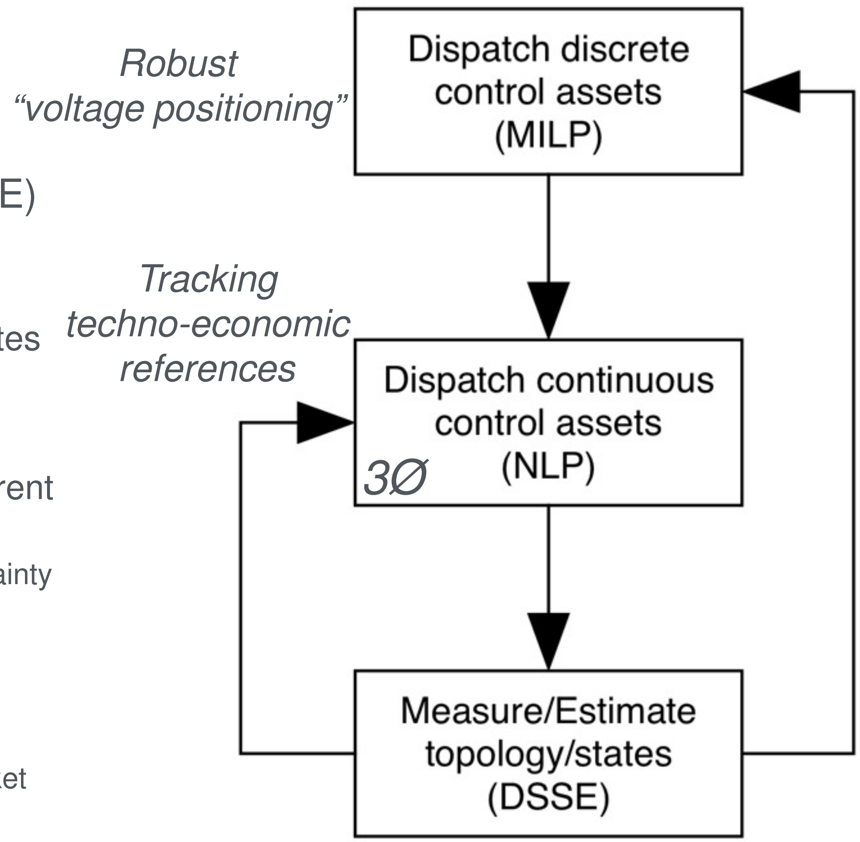

Considers STL flexibility and very-short-term solar forecasts

Grid Market Layer (GML)

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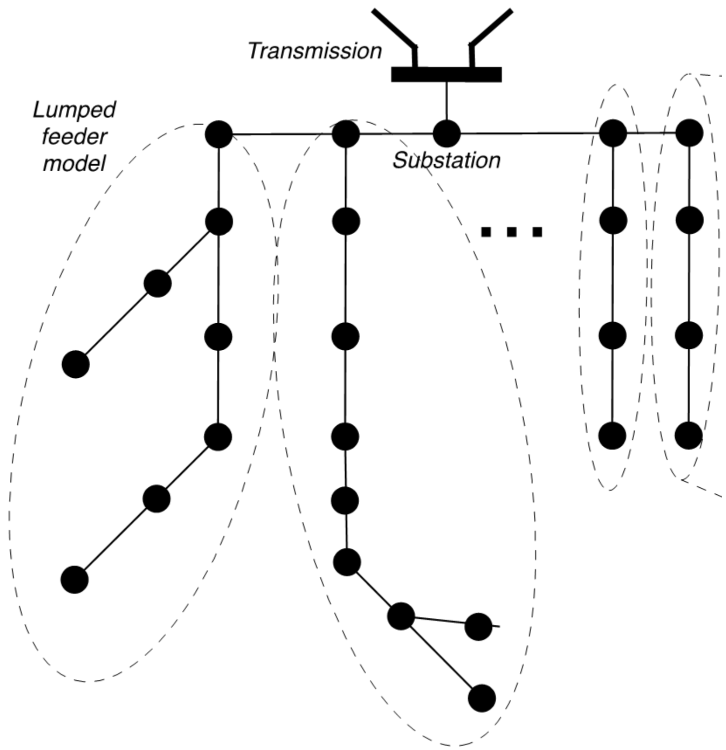
3. **Coordinate 100s of feeders via grid market layer (GML) to consider optimal economic dispatch of net-load resources**

- Must consider
  - A. physical inter-feeder coupling constraints
  - B. different time-scales of (slower) market dispatch and (faster) feeder balancing operations/regulation needs.
    - Focuses on coordinating energy exchanges

❖ Contingency mode updates feeder dispatch when triggered by any feeder that is unable to self-regulate and provide expected resources

Grid Market Layer
(1000 feeders & 1,000,000 DERs)



Optimally coordinate feeder resources

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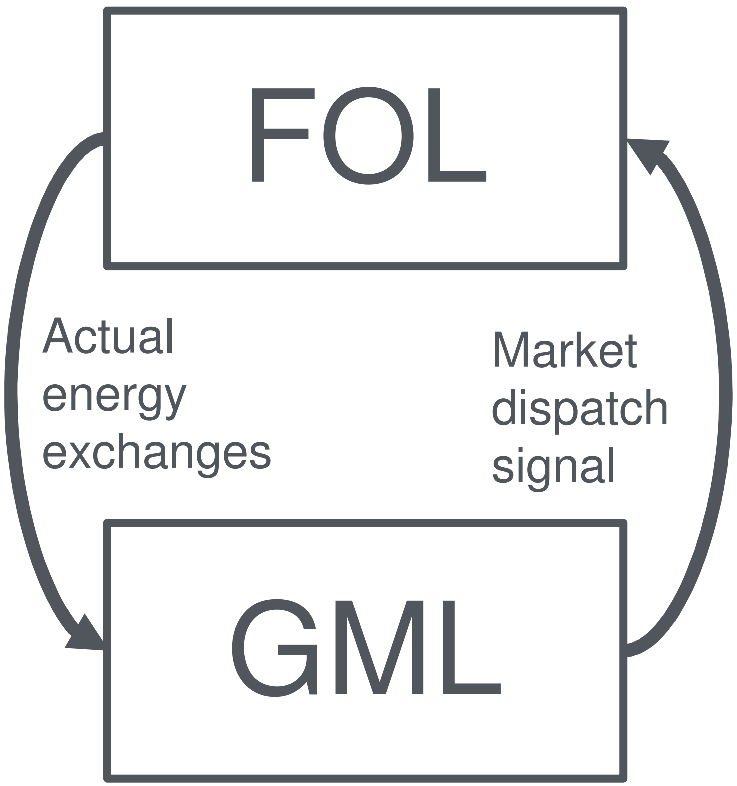

Multi-timescale Decomposition in GML

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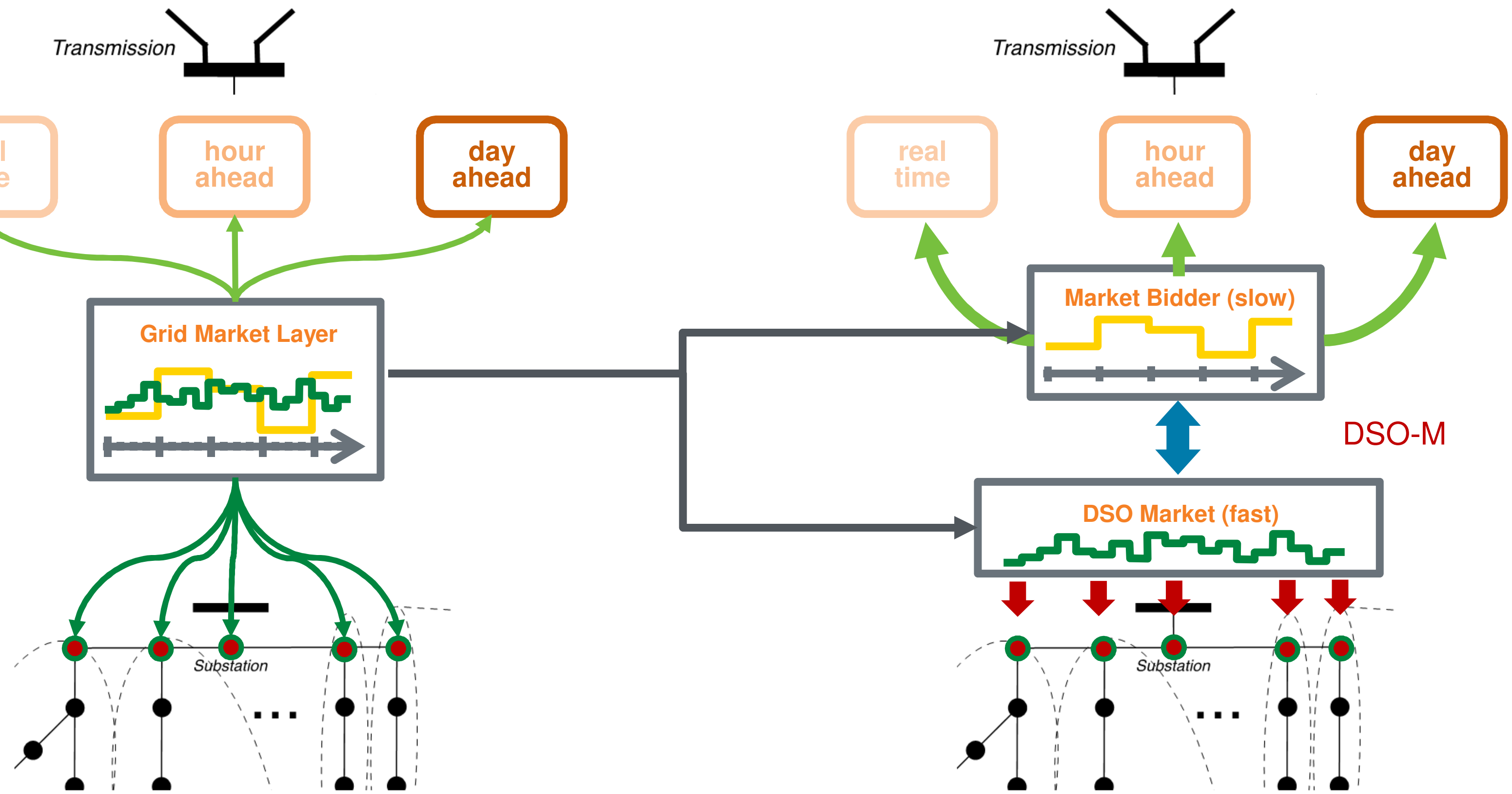

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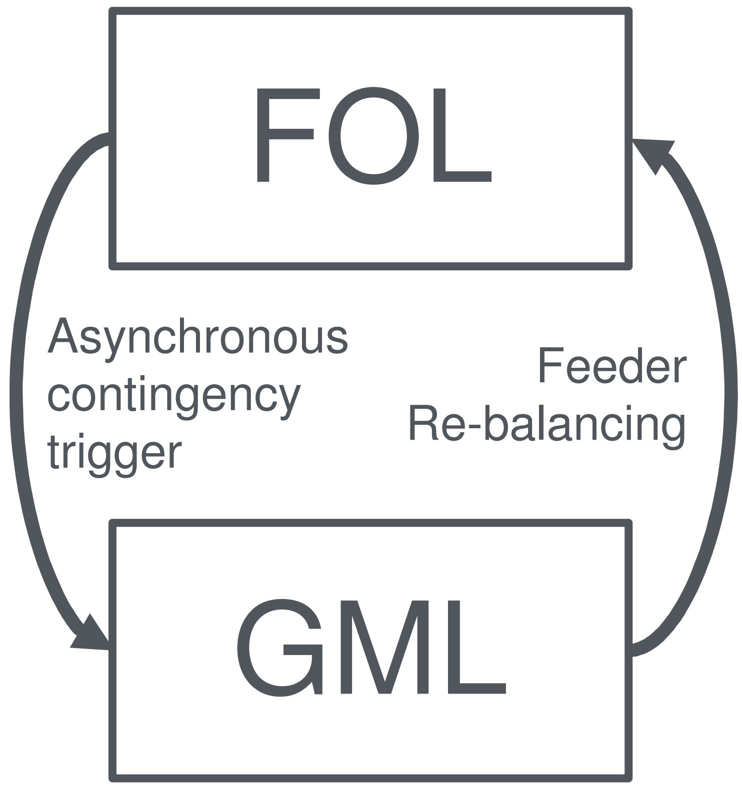

Technical Development Plan

Year 1
Dynamic Modeling UQ
Robust DSSE
Deterministic Opti Dispatch
Deterministic Decomposition

Year 2
Dynamic controller design
Stochastic Opti Dispatch
Stochastic Decomposition

Year 3
Quantify flexibility tradeoffs
Market benefit analysis

Validation & Demonstration Plan

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The University of Vermont | Pacific Northwest National Laboratory | Johns Hopkins University | NIST | conEdison

- **UVM** leads project (Almassalkhi, Ossareh, Racherla)
  - power engineering, optimization, control theory, data analytics
  - **open-source software & HiL validation**
- **JHU:** optimization & markets (Gayme, Mallada)
  - Optimization, dynamical systems, and energy market design
- **PNNL**: flexible load modeling (Kundu)
  - Power engineering, control, modeling, **HiL & large-scale validation**
- **NIST**: **HiL & cyber validation**, dynamical systems
- **Con Edison** (**ORU**): utility partner, **validation** (data+models)

Validation & Demonstration Plan

End of Year 1

Build “Year 2030” grid scenarios with real data and input from ConEd (ORU)

Simulate each level separately

Early Year 2

Small-scale coupled software validation (GridLab-D @ UVM)

Late Year 2

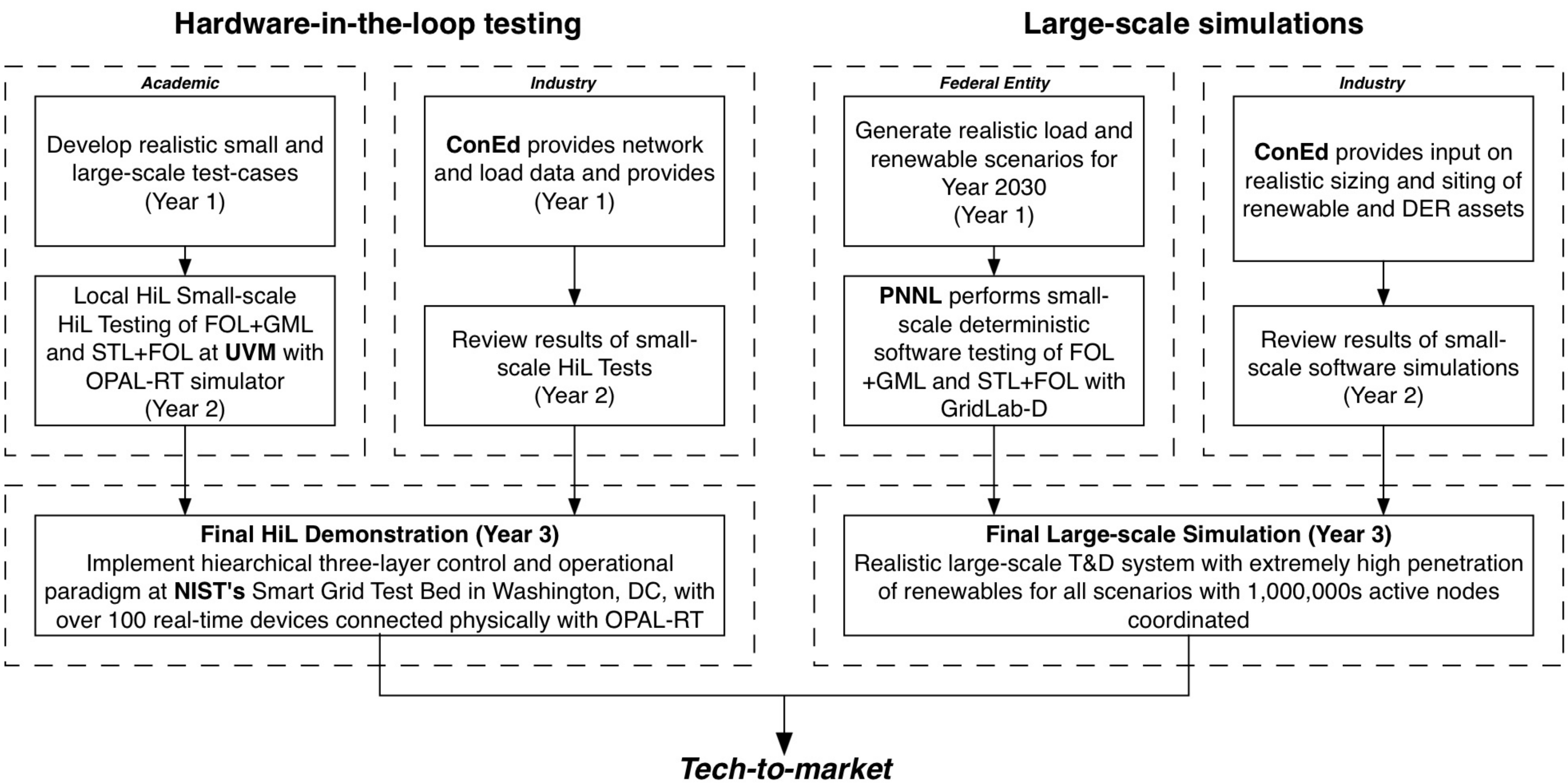
Small-scale coupled HiL validation (OPAL-RT @ UVM/NIST)

OPAL-RT TECHNOLOGIES

End of Year 3

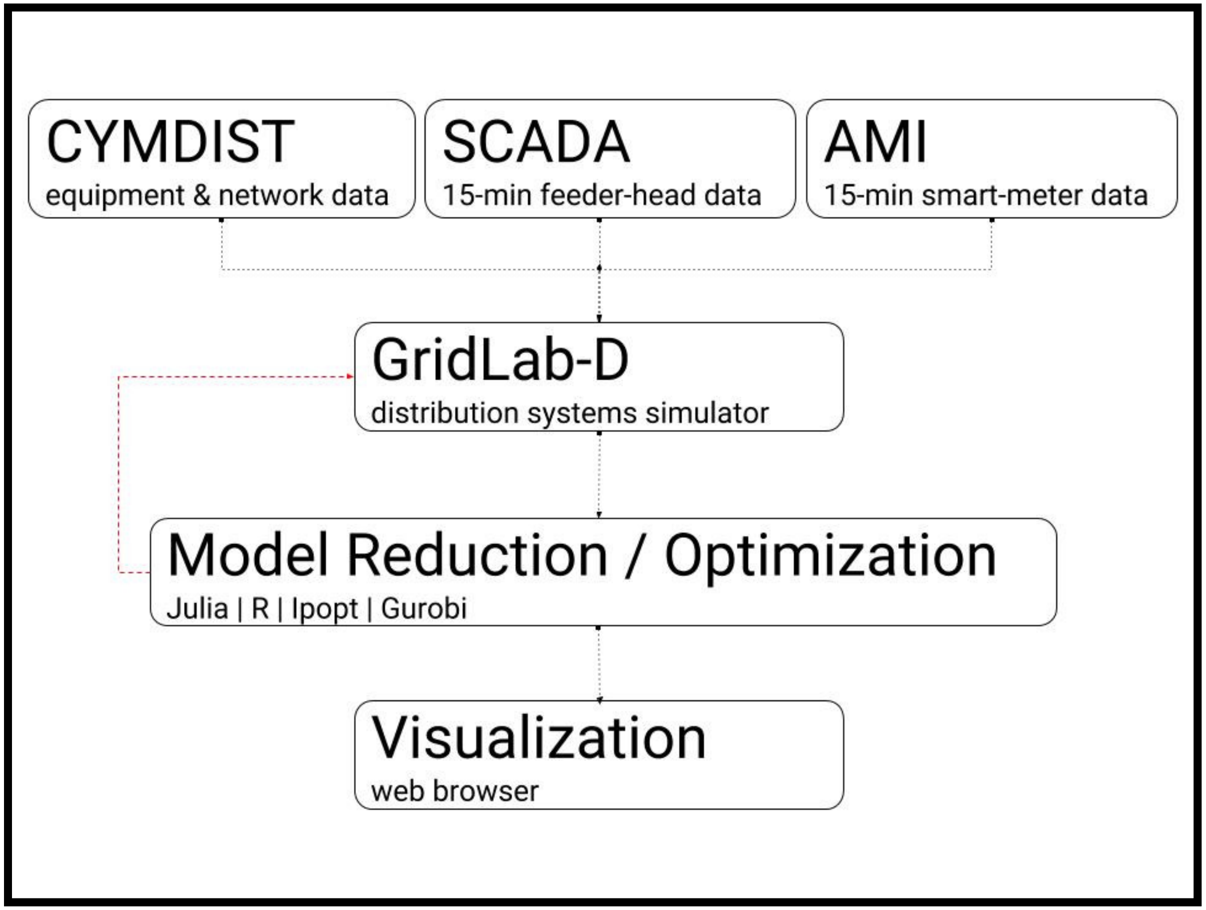
Full-scale HIL and large-scale software validations

Validation & Demonstration Plan



Validation & Demonstration Plan

UVM's interactive distributed grid analytics (iDGA) platform



UVM's interactive distributed grid analytics (iDGA) platform

In-browser 3Ø load flows with SCADA/AMI data

Comparison with FOA Objectives

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Computation cycles & device time res

- FOL is main challenge but < 1 minute
- SOCP-hot start solution → secs on Gurobi
- NLP 3Ø solver from hot-start → secs on IPOPT for good feasible solution
- Leverage feedback to speed up solve time

Response time

- STL responds to small imbalances in RT
- STL responds to set-point changes < 10s
- FOL responds to set-point changes < 1m
    - These are all within specs

Cyber security standards

- *Inf-TESLA* multicast auth @ *NIST*
    - Can bake into simulation environment
- Leverage PNNL projects on cyber-secure integration of DERs (e.g., B2G test-bed)

DER sensing and control standards

- PNNL's VOLTTRON allows energy mngt
    - EV, HVAC, building loads, DERs
- NIST Testbed set up for DER compliance tests
    - Well-suited for P-Q control algos
    - Helpful for STL and FOL (incl. dynamics tests)

Comparison with FOA objectives

Performance Metric	FOA Metric	Proposed Target
Solution components	Subset of layers	Device & Enhanced layers
HiL Validation	$> 10^2$ physical nodes	$> 10^2$ with OPAL-RT
Software Validation	$> 10^6$ virtual nodes	$> 10^6$ with GridLab-D
Scalability (Feeders)	1000	>1000
Scalability (Active nodes)	1,000,000	>1,000,000
Computation cycle (Real-time)	1 minute	< 1 minute
Computation cycle (Planning)	5 minutes	< 5 minutes
Device Time resolution (Real-time)	1 second	1 seconds
Device Time resolution (Planning)	1 minutes	1 minutes
Response time (local: STL)	< 10 seconds	Real-time
Response time (network: FOL)	< 30 seconds	< 30 seconds
Response time (system: GML)	< 1 minute	< 1 minutes
DSSE Observability	>99%	100%
Power Flows	Multiple substations	Multiple substations
OPF Objectives	Techno-economic	Techno-economic
Predictive Control	Real-time planning	Real-time planning
Prescriptive Control	Operational planning	Operational planning

Thank you! Questions? Comments?

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Fall in Vermont, Groton, VT

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