ADMS Test Bed: AMI Data-based Grid Controls

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ADMS Test Bed Webinar Series

Advanced Distribution Management System (ADMS) Test Bed

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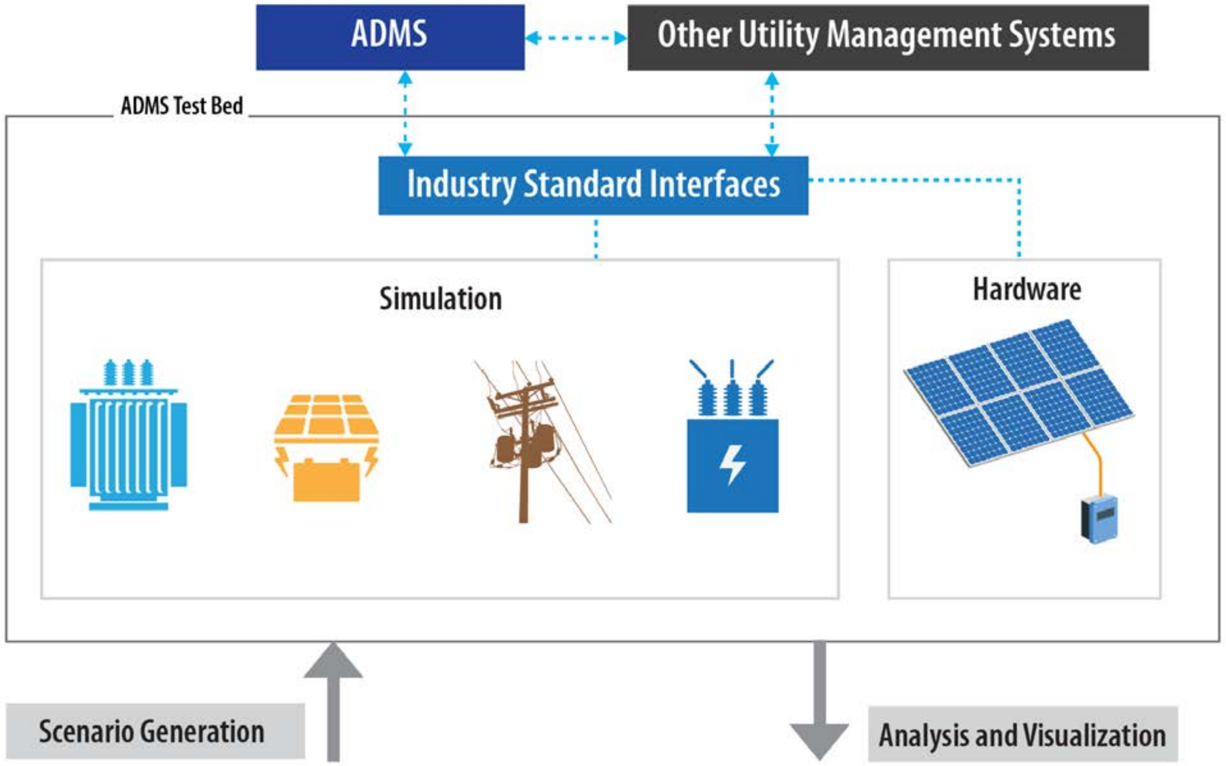
Goal: Accelerate industry adoption of ADMS to:

- Improve normal operations with high DERs
- Improve resilience and reliability.

Approach: Partner with utilities and vendors to evaluate specific use cases and applications.

- Set up a realistic laboratory environment:
  - Simulate real distribution systems
  - Integrate distribution system hardware
  - Use industry-standard communications
  - Create advanced visualization capability.

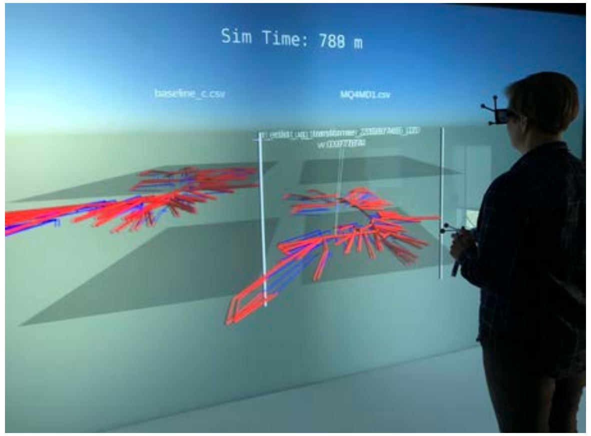


https://www.nrel.gov/grid/advanced-distribution-management.html

ADMS Test Bed

Expected outcomes: Increased industry confidence in ADMS technology through:

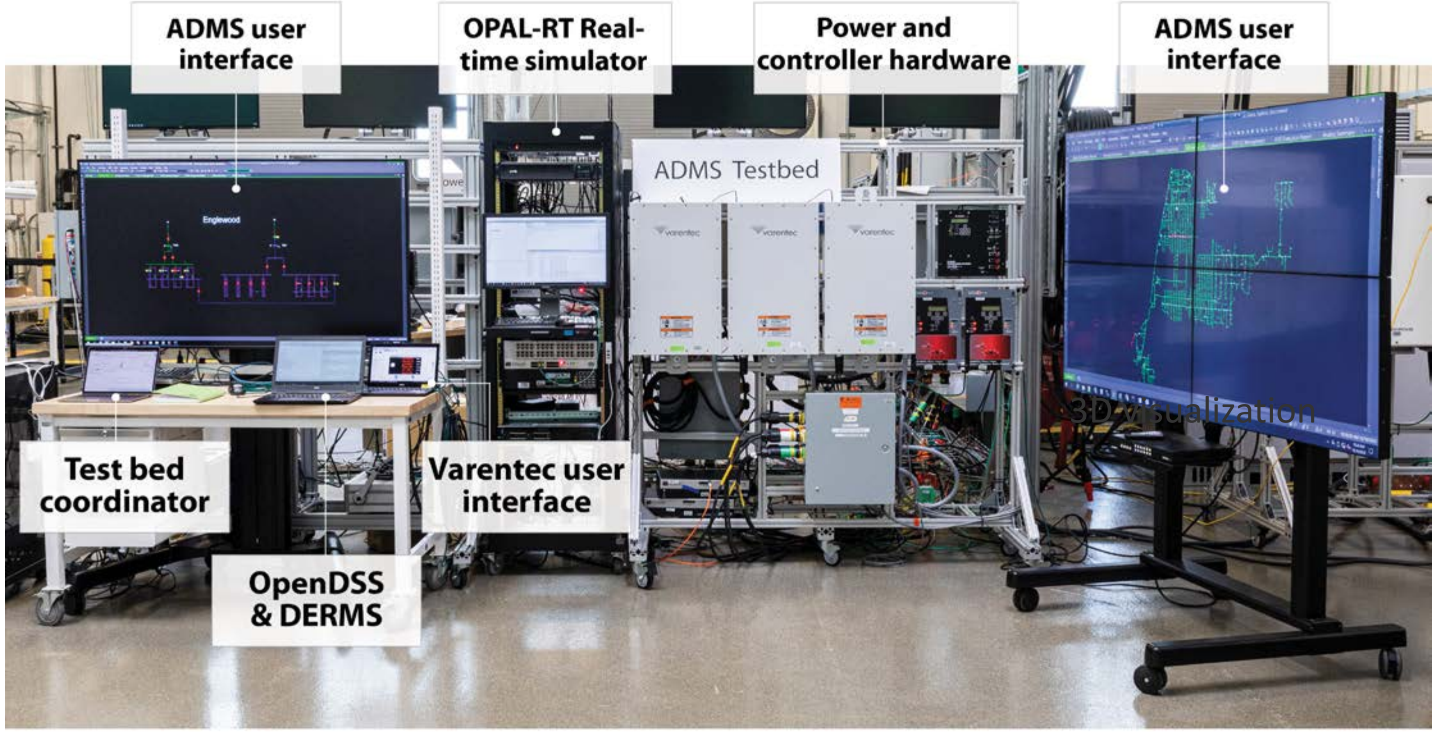
- Laboratory demonstration of applications for specific use cases
- Analysis and potential application to other utilities.



3D visualization

Photos by NREL

2D real-time visualization



ADMS Test Bed Use Cases & Projects

Completed ADMS Test Bed use cases

- Peak load management with ADMS and DERMS
  - Holy Cross Energy/Survalent (May 2021)
- ADMS network model quality impact on VVO
  - Xcel Energy/Schneider Electric (June 2021)
- **AMI-based, data-centric grid operations**
  - SDG&E + GridAPPS-D (May 2021)

In-progress ADMS Test Bed use cases

- FLISR in the presence of DERs
  - Central Georgia EMC/Survalent → Feb. 2022
- Federated DERMS for high PV system
  - Southern Company/Oracle + GridAPPS-D → Apr. 2022
- T&D co-optimization for enabling ADN to support bulk grid
  - Xcel Energy + GridAPPS-D → Mar. 2022

Other projects leveraging the ADMS Test Bed Capabilities

- Non-wires alternatives (done)
- ECO-IDEA (done)
- GO-SOLAR (done)
- SolarExpert (done)
- FAST-DERMS
- Resilient Operation of Networked Microgrids (RONM)
- Resilience and Stability Oriented Cellular Grid Formation and Optimizations for Communities with Solar PVs and Mobile Energy Storage (REORG)
- PV Integration using a Virtual Airgap (PIVA)
- Grid-edge intelligent distribution automation system for self-healing distribution grids (TCF)

AMI for Planning & Operations

Project Overview

Develop algorithms for leveraging existing AMI infrastructure to provide a foundational, pervasive secondary voltage monitoring network solution

- Identify network model discrepancies
- AMI data-based insights
- Novel visualization tools
- AMI-based controls
- Role in CEC EPIC Project

Technologies

Project Partners

SDGE

A Sempra Energy utility

Developing and demonstrating a data-driven paradigm for grid operations

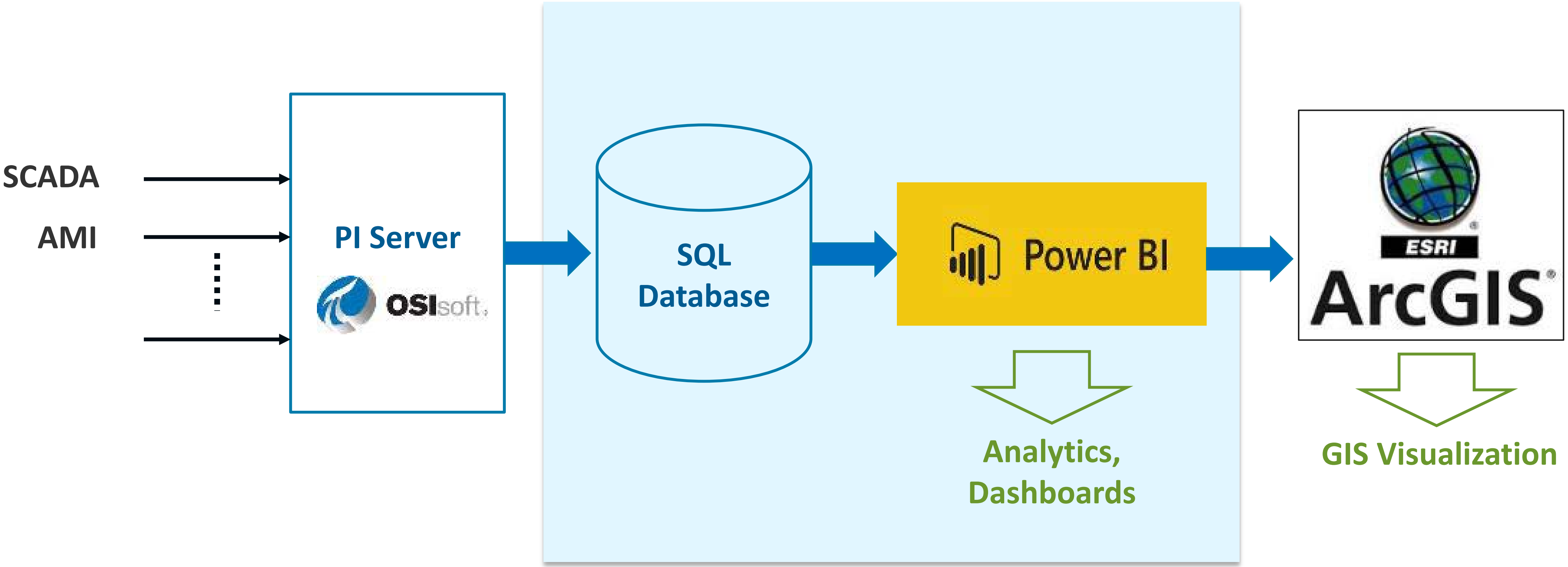
AMI for Planning & Operations

	ESIF HIP/SDG&E	ADMS test bed/SDG&E
Model Validation Transferring voltages to primary Identification of model discrepancies	Proof of concept, Development/testing and tool validation, integration with SDG&E platform	Evaluation on a new circuit, field verification
Model Estimation Phase Identification	Proof of concept	Field verification, integration with SDG&E platform
Data Analytics EV location/charging levels Likelihood of voltage exceedances	Proof of concept Development/testing	Test bed demonstration
Visualization 3D/2D tools	Proof of concept Development/testing	Integration with test bed
Data-driven controls Voltage regulation	Proof of concept	Test bed demonstration

Technical Achievements

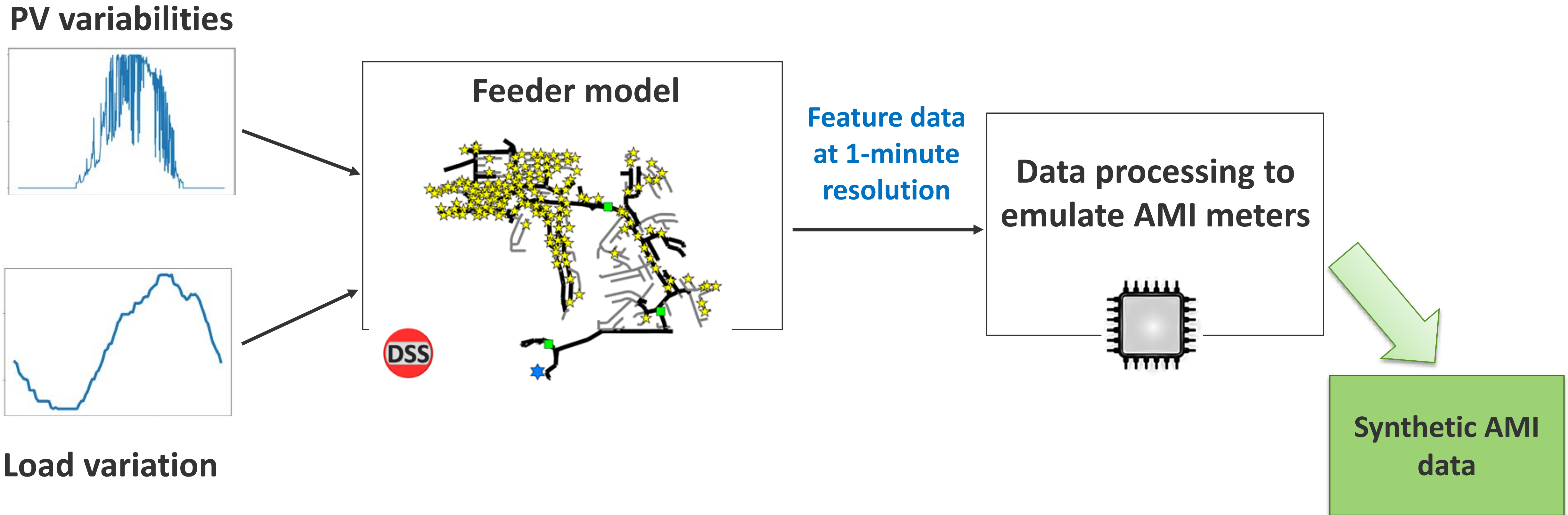
- Synthetic AMI generation framework for future PV adoptions
- Developed and validated method for identifying primary network model discrepancies & implemented in SDG&E control room
- Developed and field-validated robust method for phase identification & implemented in SDG&E control room
- Developed methods for analyzing AMI data and provide operational insights
- Developed techniques for visualizing large AMI datasets using 2D and 3D tools
- Demonstrated data-driven voltage controls on ADMS Testbed

Integration with SDG&E Platform

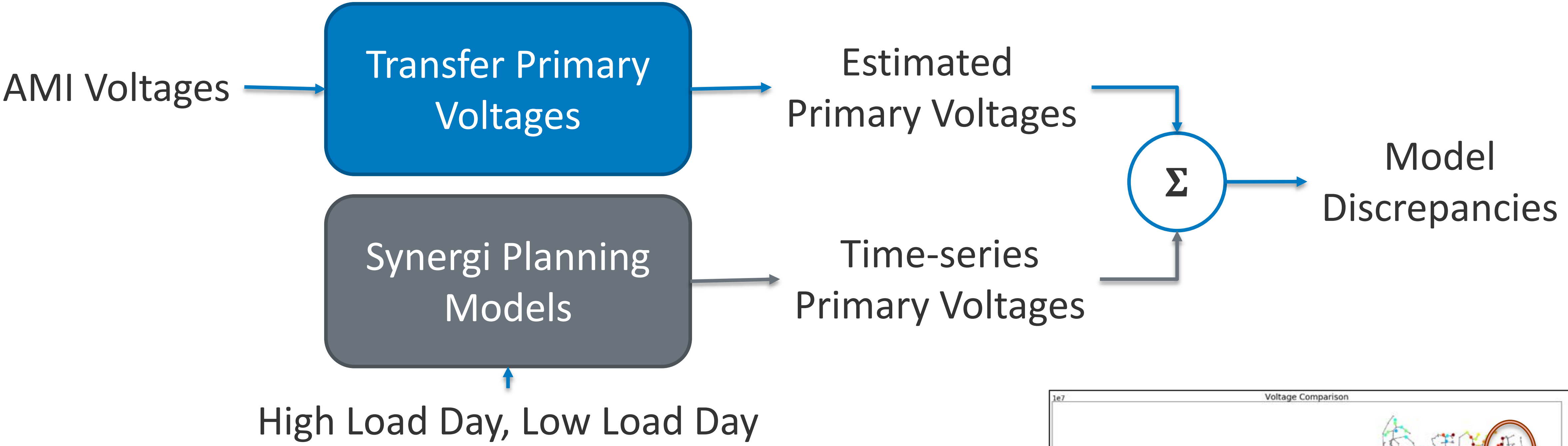


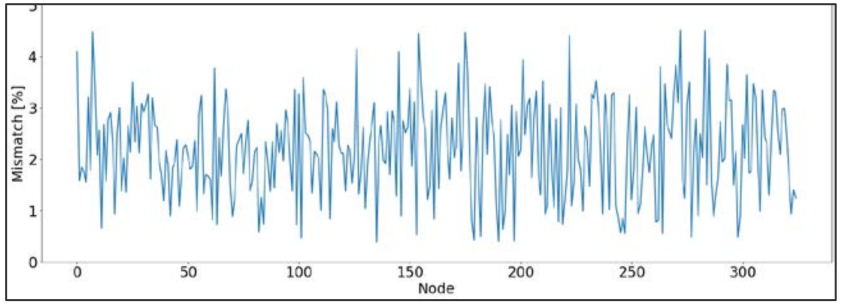
Framework for Synthetic AMI Generation

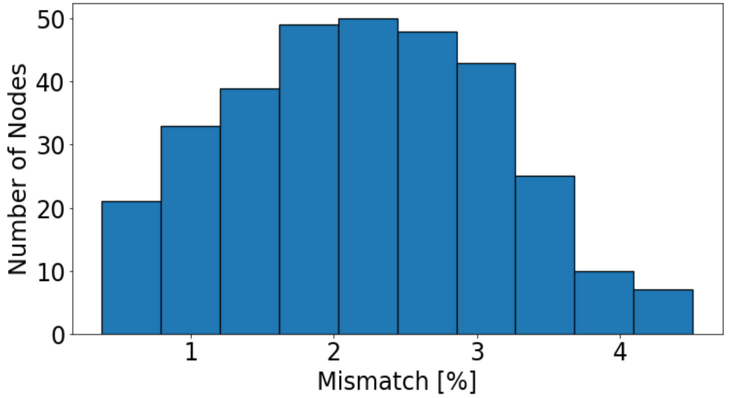
- QSTS simulations are performed with load and PV variations
- Feature data is extracted and processed to emulate AMI measurement data

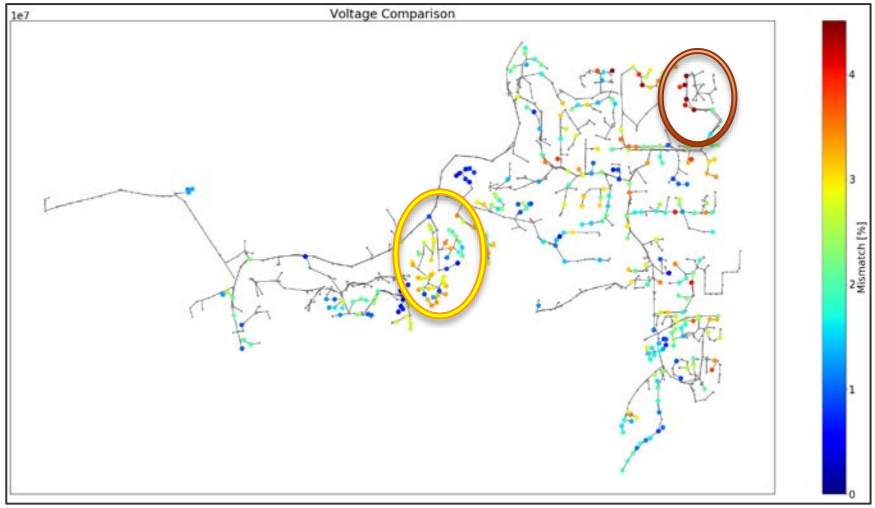


Primary Model Discrepancy

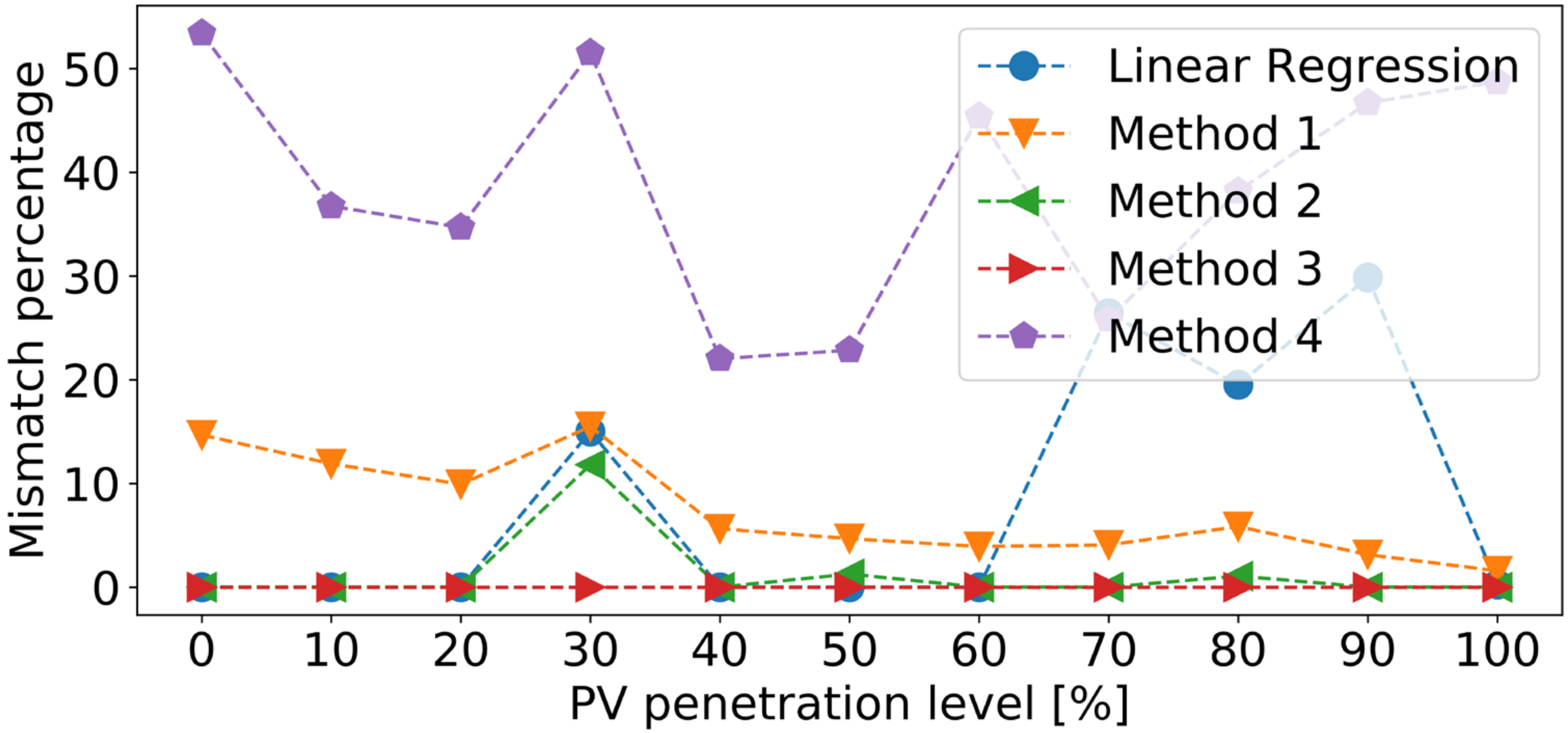








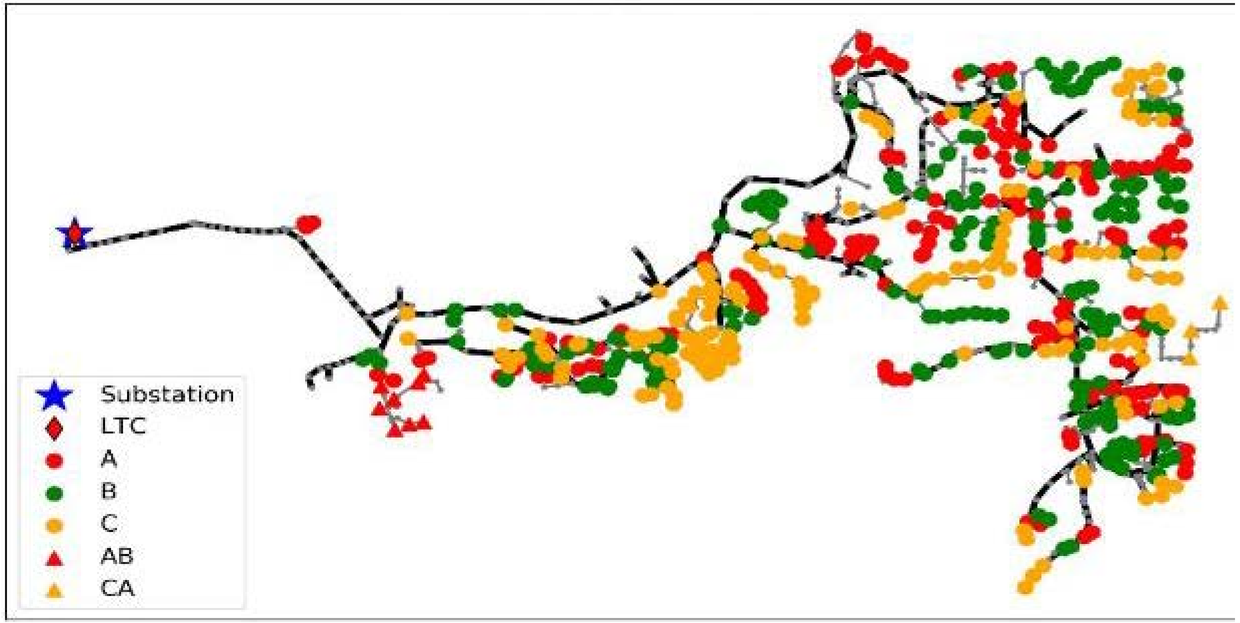
Impact of PV on Phase Identification



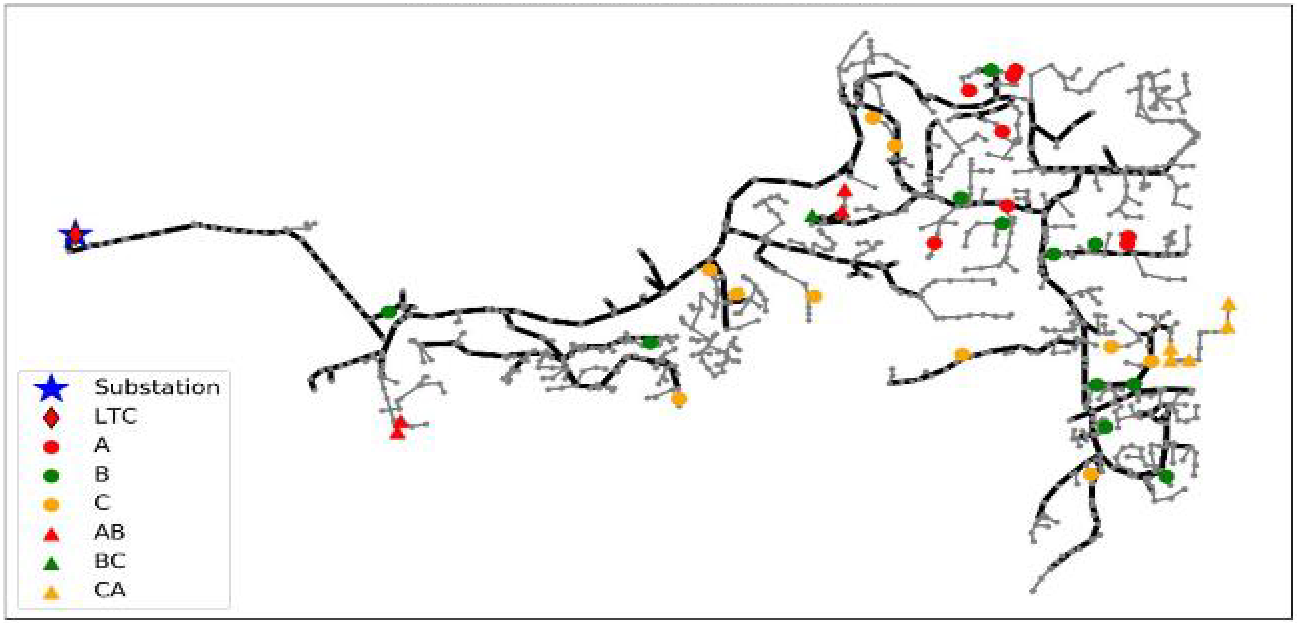
Presence of PV can create phase ID errors with existing methods

Phase Identification - Results

Correct Matches



Mismatches



Accuracy: Overall Accuracy 94.4%, Testing set - ~92%, Training set - 100%

Impact of high PV on AMI voltages

PV smart inverter settings	Secondary		Primary	
	Voltage exceedances hours per node	Number of voltage exceedances nodes	Voltage exceedances hours per node	Number of voltage exceedances nodes
Baseline	23.52	752	42.83	481
CA 21	0.55	16	0.61	0
HI 14	0.21	9	0.76	12
IEEE 1547	0.47	28	0.96	14
No Deadband	1.05	37	2.84	42
HS-no compensation	0.55	16	0.61	0
HS-deeper Q	0.09	3	0.91	12
Volt-Var-Watt	4.45	110	2.95	53

- Voltage Exceeding Thresholds
  - Out of range 0.95-1.06
  - Exceedance node: node has more than 12 hours of voltages exceeding the threshold

Data-driven controls demonstrated on ADMS Test Bed

Use Case 3: Data-centric grid operations

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Utility: San Diego Gas & Electric

"ADMS” Platform: GridAPPS-D

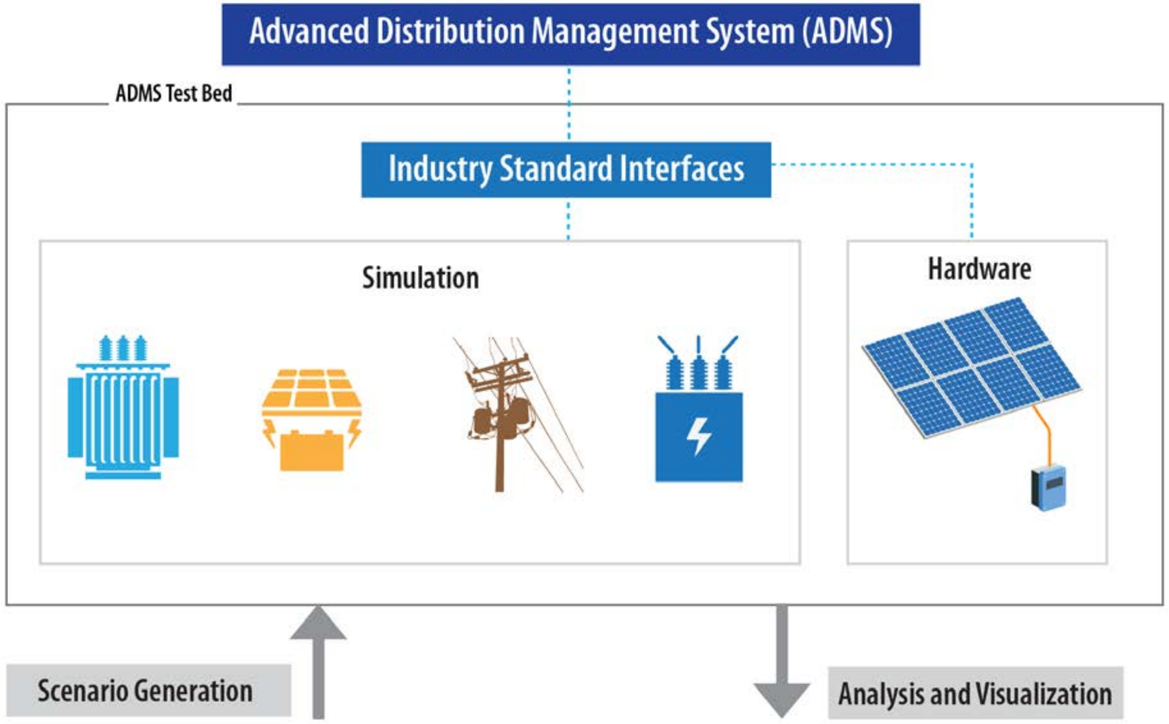
Advanced Algorithm: AMI-based voltage regulation

- Automated Metering Infrastructure (AMI) is a low-cost platform that provides a new paradigm for utility planning, operations & controls
- AMI enables real-time awareness at the grid-edge; utilities need tools to leverage this capability

Data-Centric Grid Operations

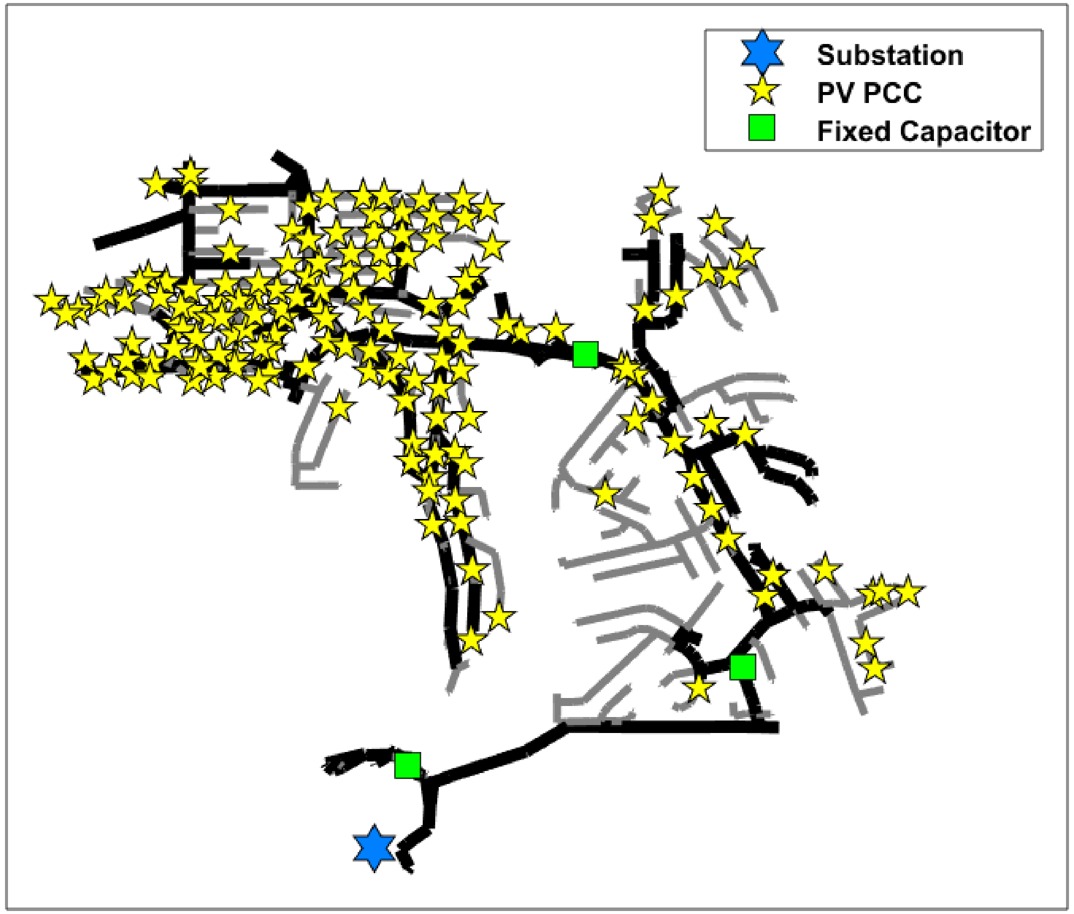
<u>Objective</u>: Evaluate and demonstrate advanced metering infrastructure (AMI)-based data-centric grid operations:

- Identify synergies with ADMS for grid operations
- Leverage AMI as a pervasive secondary voltage monitoring for next-generation planning/operations
- Demonstrate advanced data-driven voltage controls using GridAPPS-D platform.

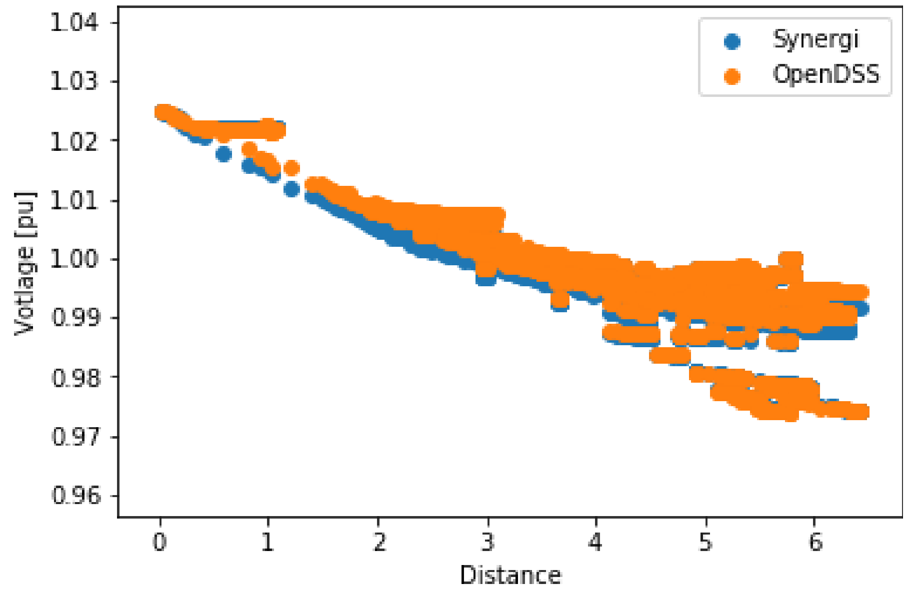


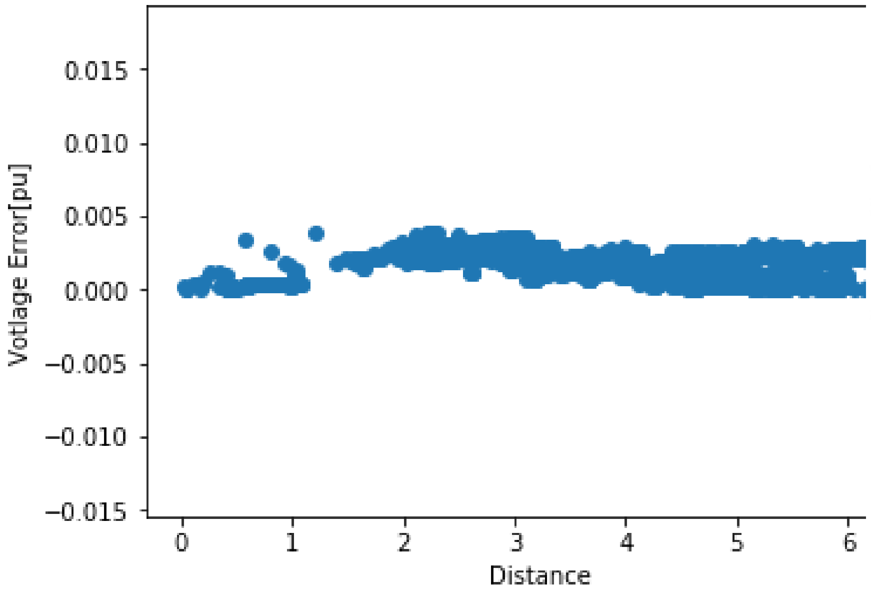
SDG&E Feeder Data

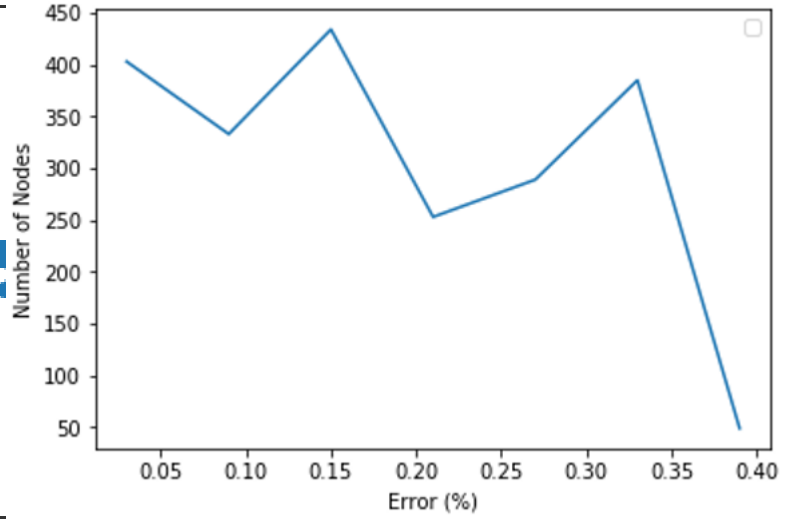
- Utility feeder:
  - Services ~4 sq. miles of geographic area
  - 4000+ nodes
  - Peak load - ~10 MW
  - Distributed PV generation – 33%
  - Substation LTC, cap banks



Model Validation







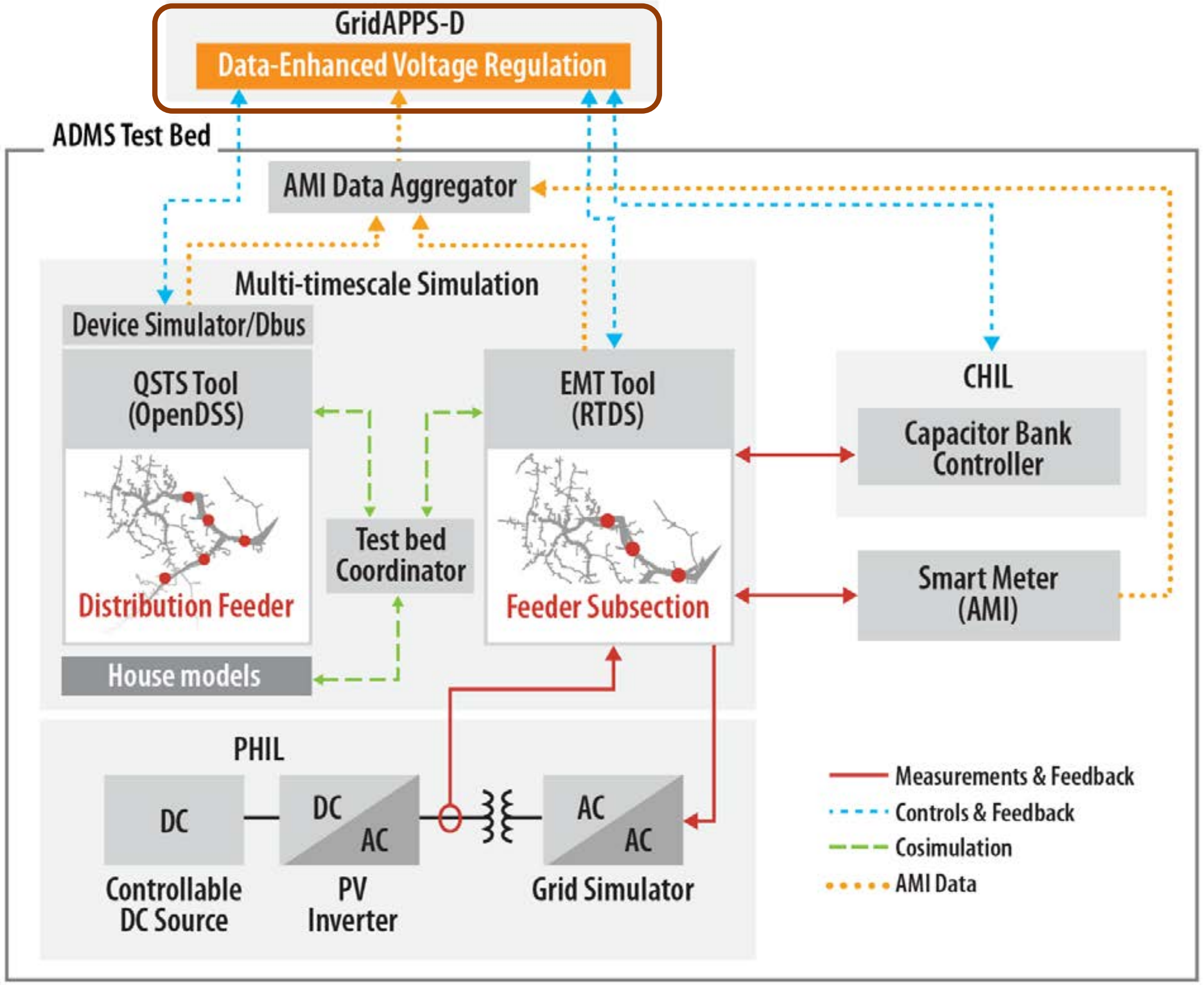
Error Distribution

	Synergi	OpenDSS
Phase A	3.514 MW	3.548 MW
Phase B	3.507 MW	3.449 MW
Phase C	3.507 MW	3.535 MW

An accurate validated model in OpenDSS for further Studies

ADMS Test bed Setup - Overview

- GridAPPS-D platform with the advanced algorithm, SDG&E feeder model, ability to talk DNP3*
- QSTS simulation with SDG&E feeder model, OCHRE-generated weather-dependent load profiles, OCHRE cosimulation
- DRTS simulation with SDG&E feeder model in RTDS
- Smart meter HIL, PV inverter PHIL and Cap bank CHIL implemented
- HELICS-based cosim engine to tie all the test bed components into a coherent distribution system simulation



Test Bed Set Up – GridAPPS-D

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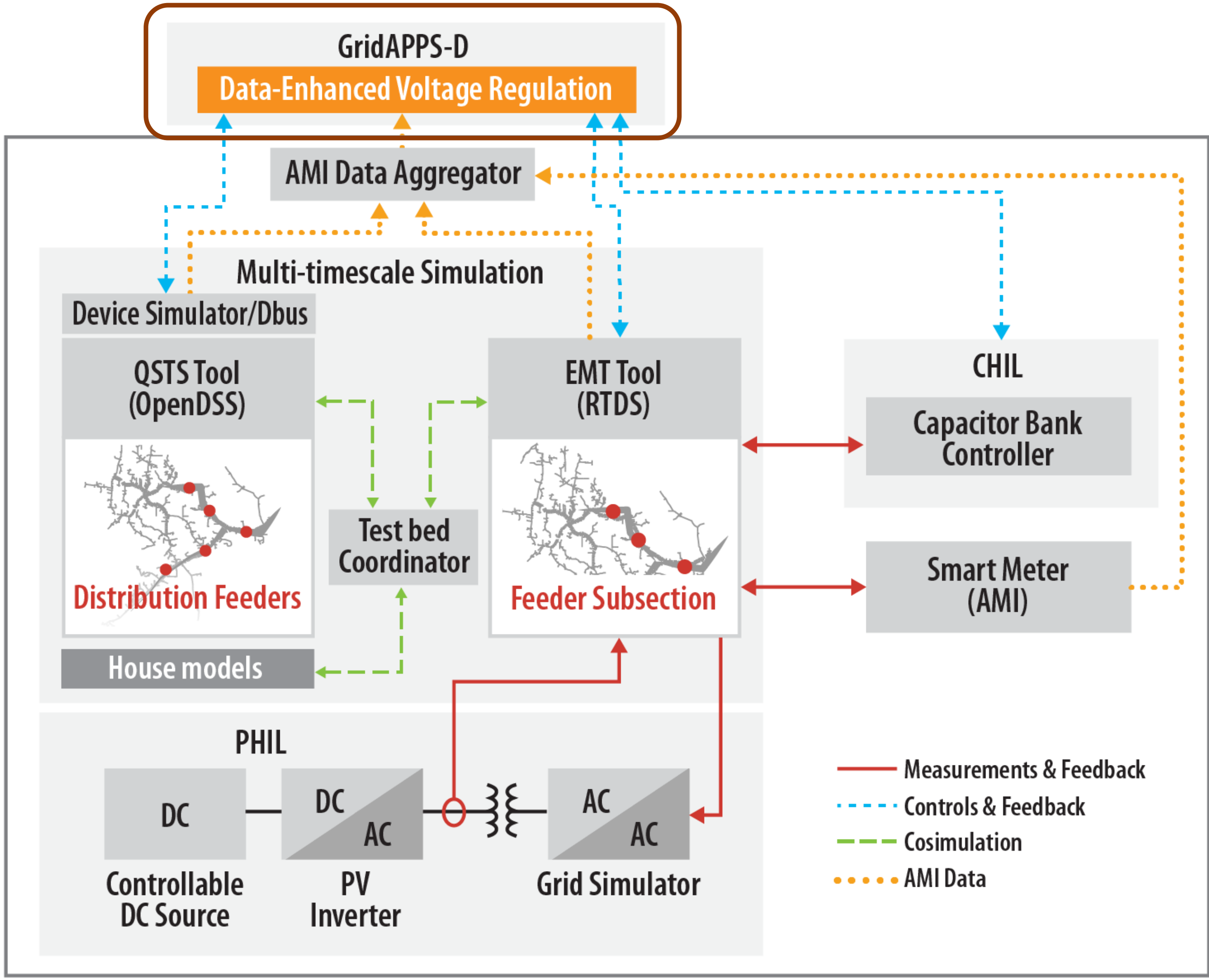
GridAPPS-D Platform

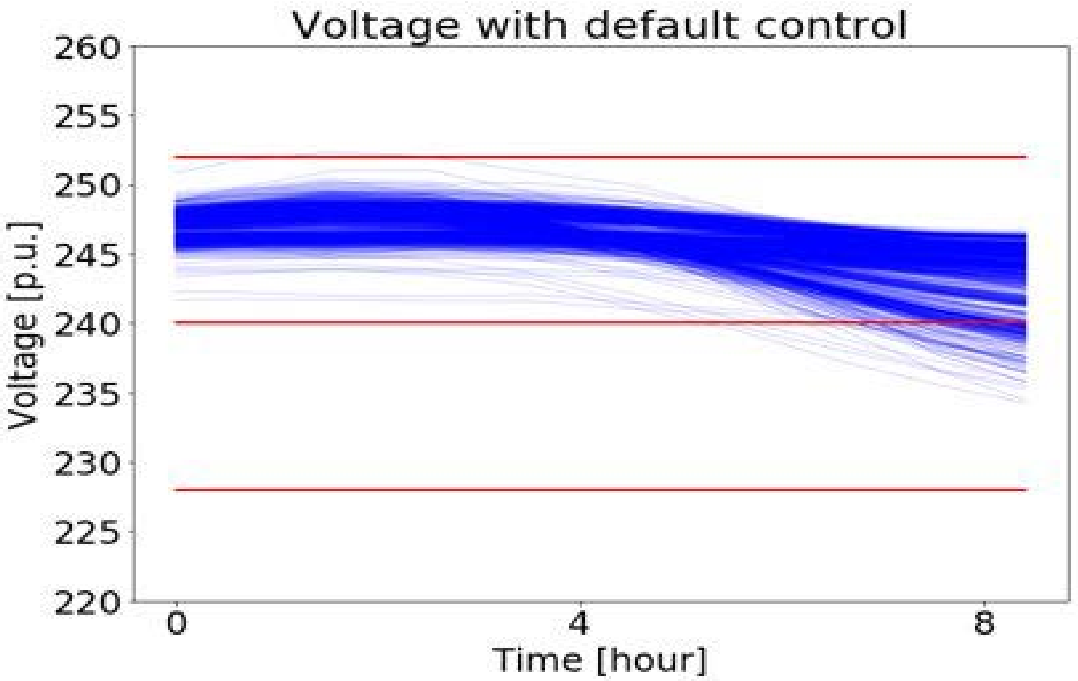
- Open-source platform that accelerates development of portable applications
- Enables standardization of data models, programming and data exchange interfaces

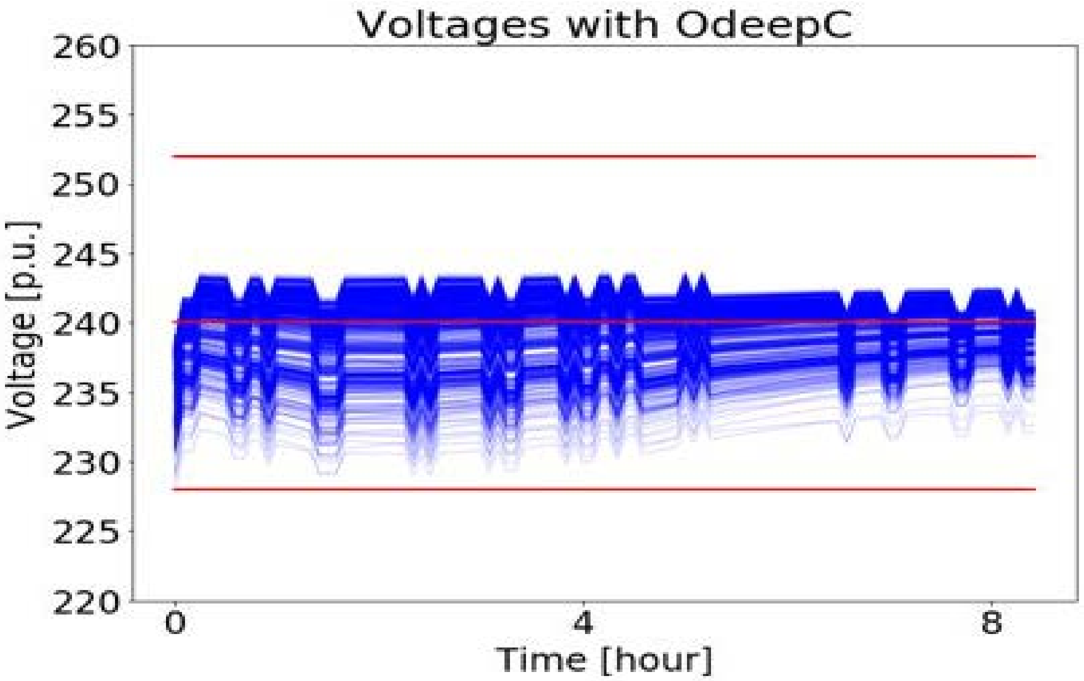


Test Bed Set Up - Algorithm

Online Data-enabled Predictive Control (ODeepC)

- Model-free model predictive control
- Uses AMI-data to control LTCs and CBs
- Full potential with other “control levers





Test Bed Set Up – Cosimulation

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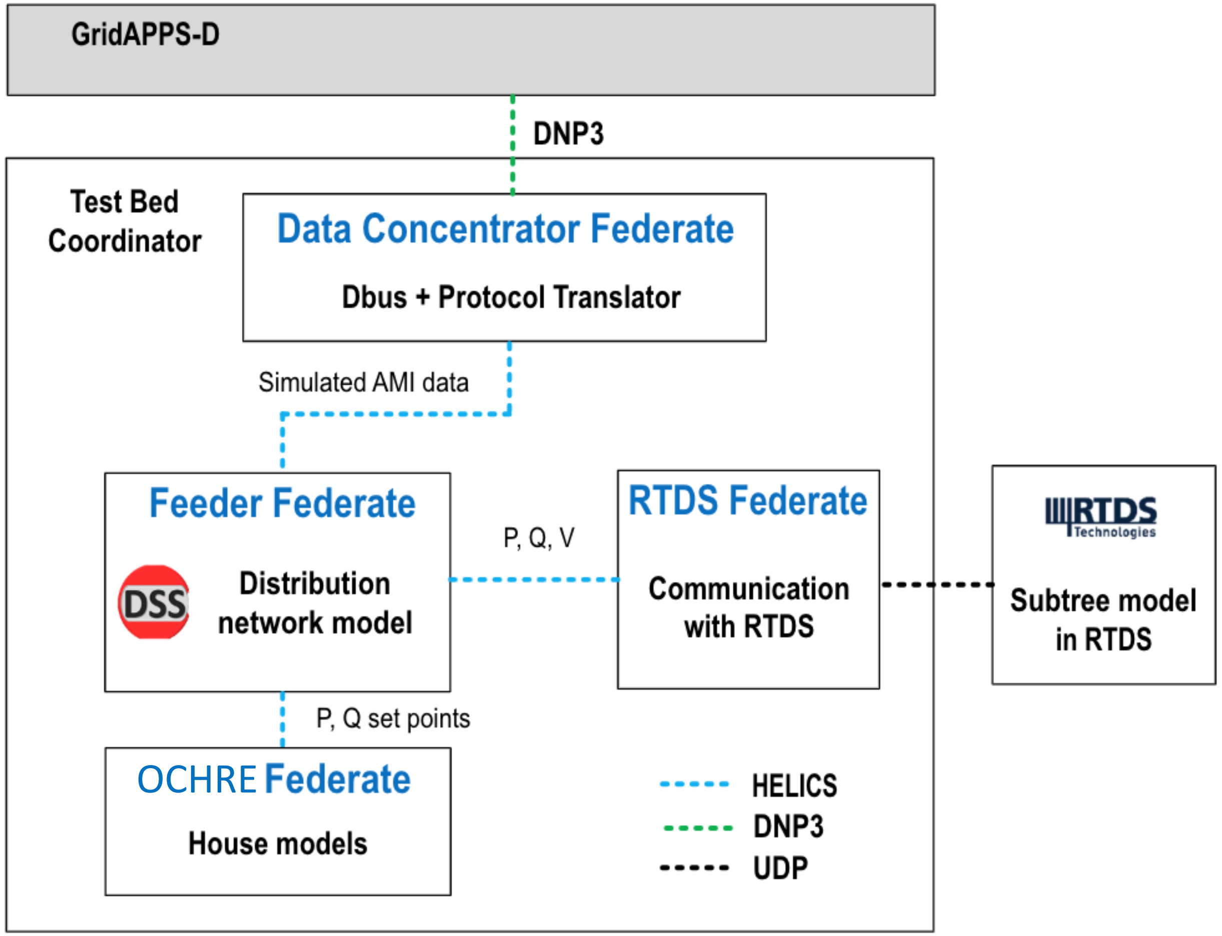
Test bed Coordinator provides HELICS-based Co-simulation

- OpenDSS Federate
- RTDS Federate
- AMI data concentrator federate
- OCHRE Federate



Test Bed Set Up – RTDS & HIL

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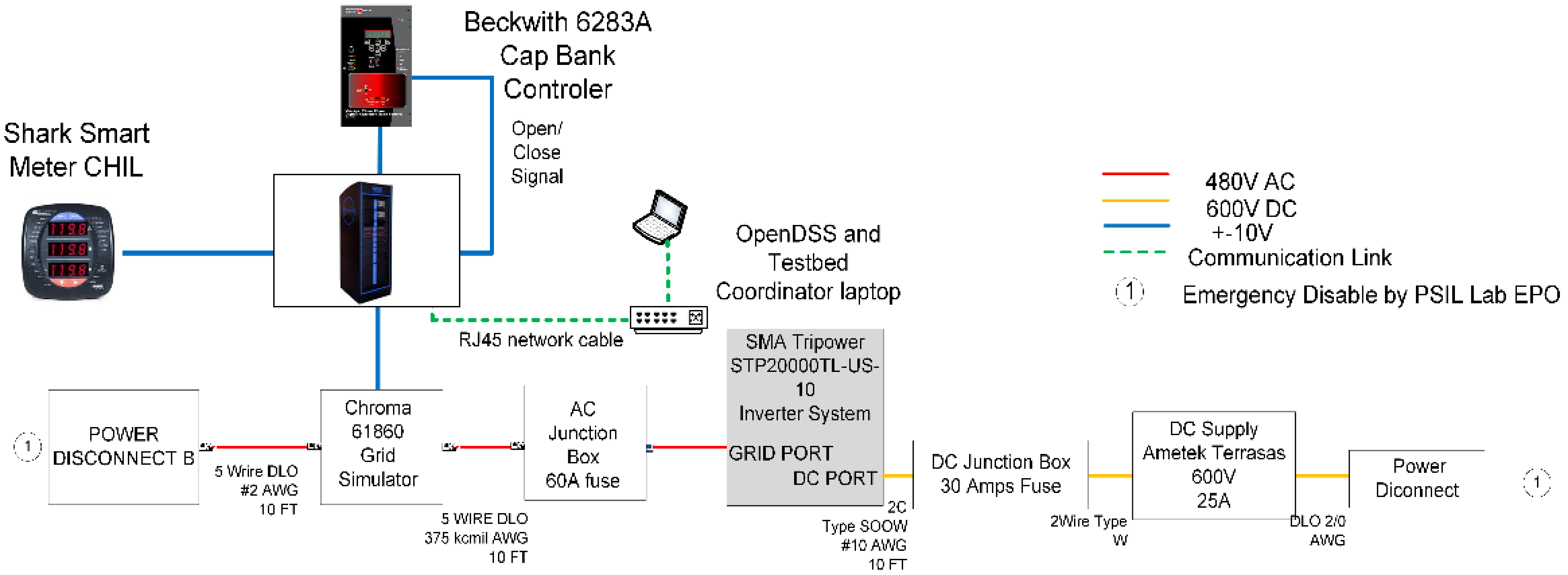
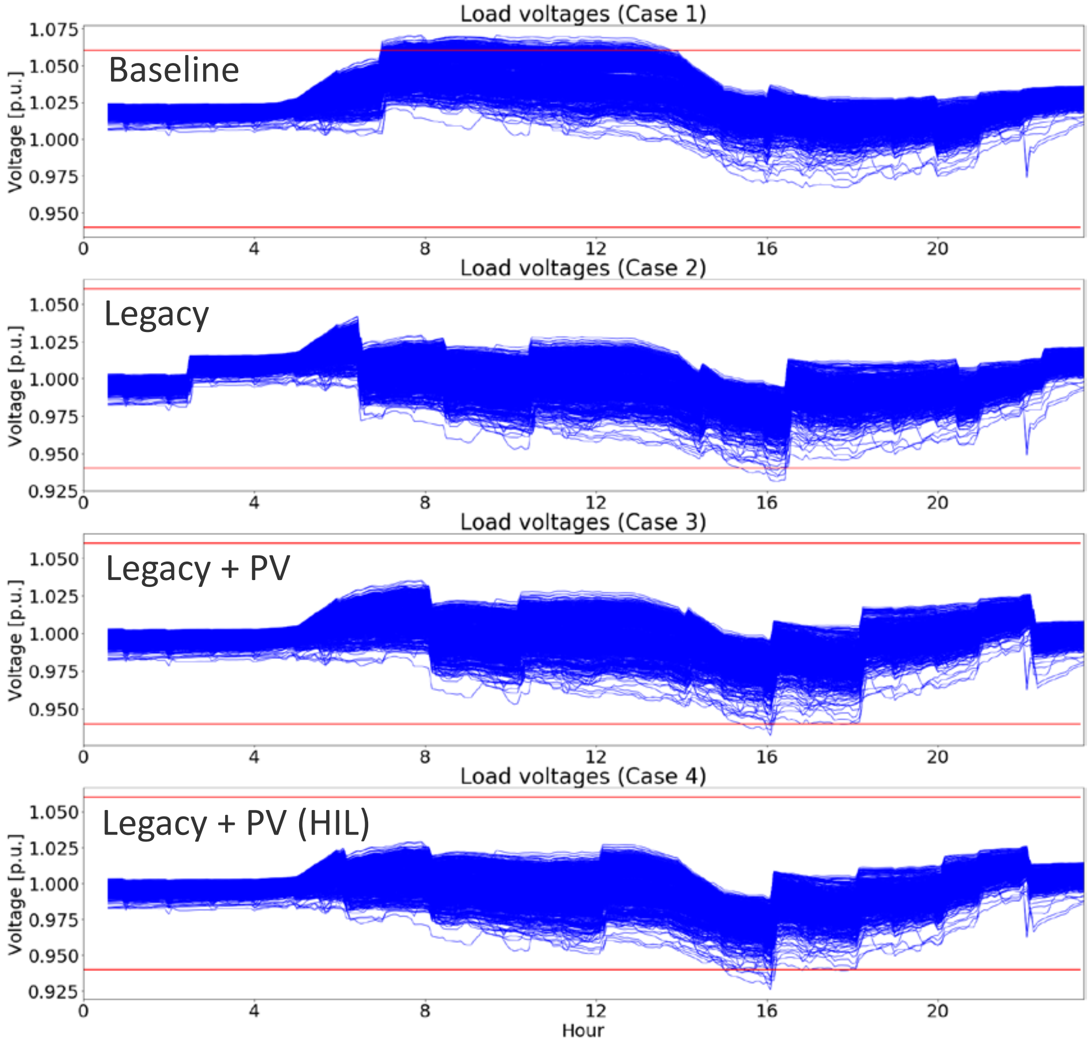
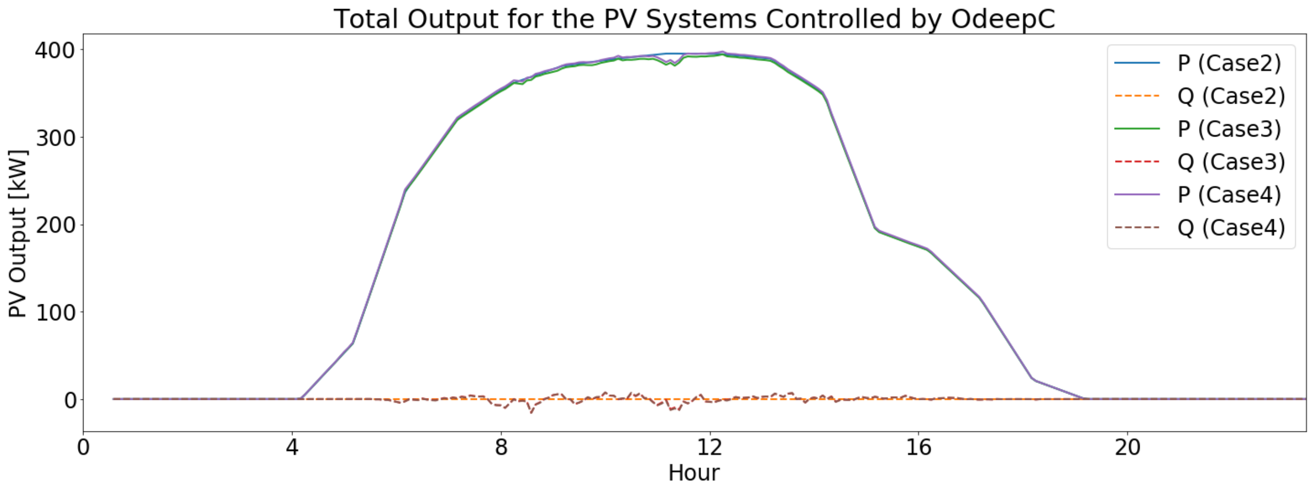


Test Scenarios

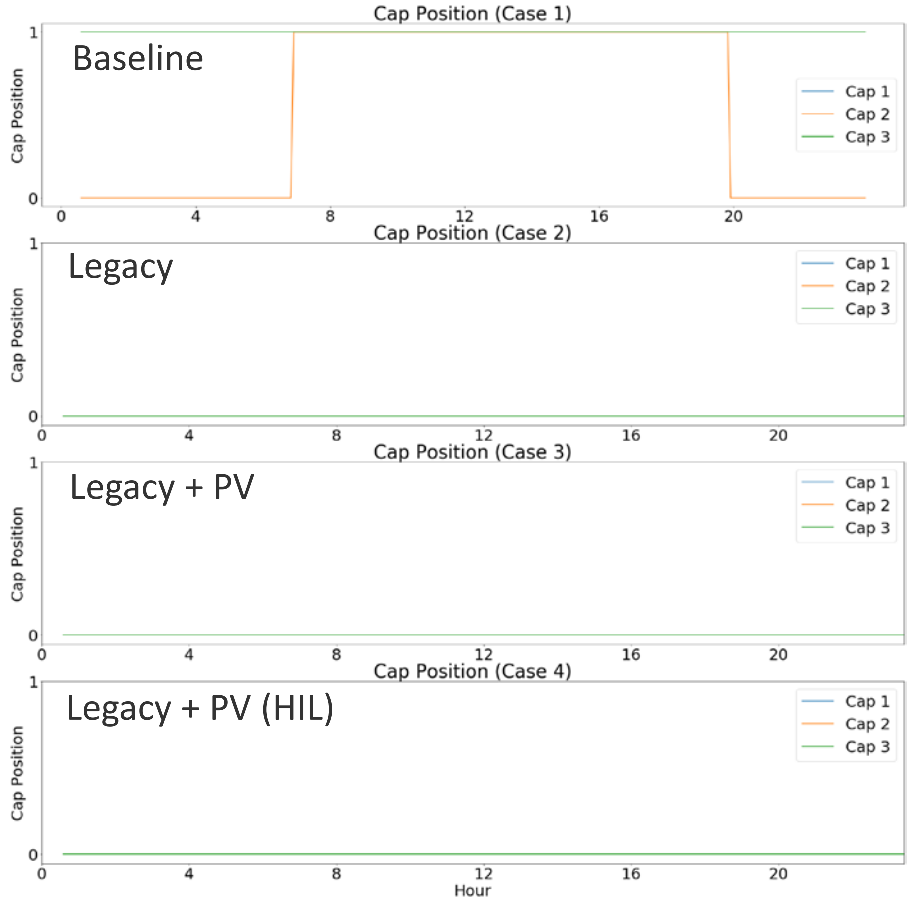
Test Case #	Description	Rationale
Test Case 1: Baseline	No centralized controls. LTC and capacitor banks are on local (default) controls.	This test case represents the current state in the field.
Test Case 2: Data-driven controls for legacy equipment	ODeePC algorithm (on GridAPPS-D) receives real-time data from the test bed and issues control set points to legacy voltage control devices (LTC and capacitor banks).	This test case represents a feasible next step to improve the voltage profile on the feeder through data-driven controls.
Test Case 3: Data-driven controls for PV inverters	ODeePC algorithm (on GridAPPS-D) receives real-time data from the test bed and issues control set points to legacy voltage control devices and 82 PV inverters.	This test case represents a future step wherein PV smart inverters support grid voltage control.
Test Case 4: Data-driven controls for PV inverters with HIL	Same as Test Case 3 plus AMI meter in HIL	

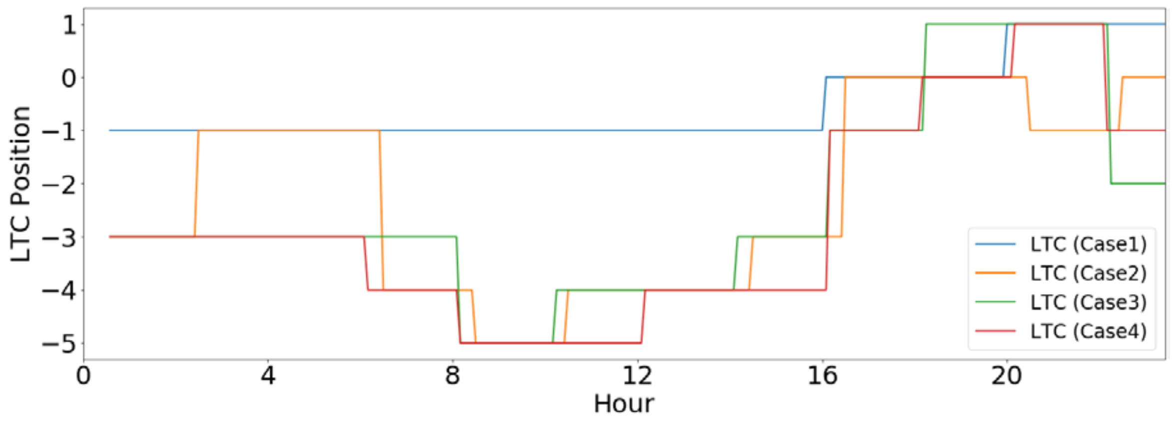
Voltage Results





Voltage Regulation Devices





Default control:
LTC set point: 123 V
Cap. 1: Decided by RTDS signal
Cap. 2 set point: Onsetting 119 V, offsetting 125 V, always on between 7 a.m.–8 p.m.
Cap. 3: Always on

Impact Analysis

1. Number of capacitor changes
2. Number of LTC changes
3. Average voltage
4. Voltage fluctuation index
5. Voltage unbalance index
6. Voltage exceedances

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Evaluation Metrics

Let the T stands for the total time steps in the simulation and N stands the total number of nodes in the feeder, the average voltage is calculated by:

$$V^{mean} = \frac{1}{N} \times (\frac{1}{T} \sum_{i=1}^{N} \sum_{t=1}^{T} V^{i}(t))$$

The voltage fluctuation index (VFI) is calculated by:

$$VFI = \frac{1}{N} \times (\frac{1}{T} \sum_{i=1}^{N} \sum_{t=1}^{T} \left| V^{i}(t+1) - V^{i}(t) \right|)$$

The voltage unbalance index (VUI) is calculated by:

$$VUI = \frac{1}{N} \times (\frac{1}{T} \sum_{i=1}^{N} \sum_{t=1}^{T} V_{imb}^{i}(t))$$

where $V_{imb}^{i}(t)$ is calculated by using the maximum deviation from average voltage over the average voltage .

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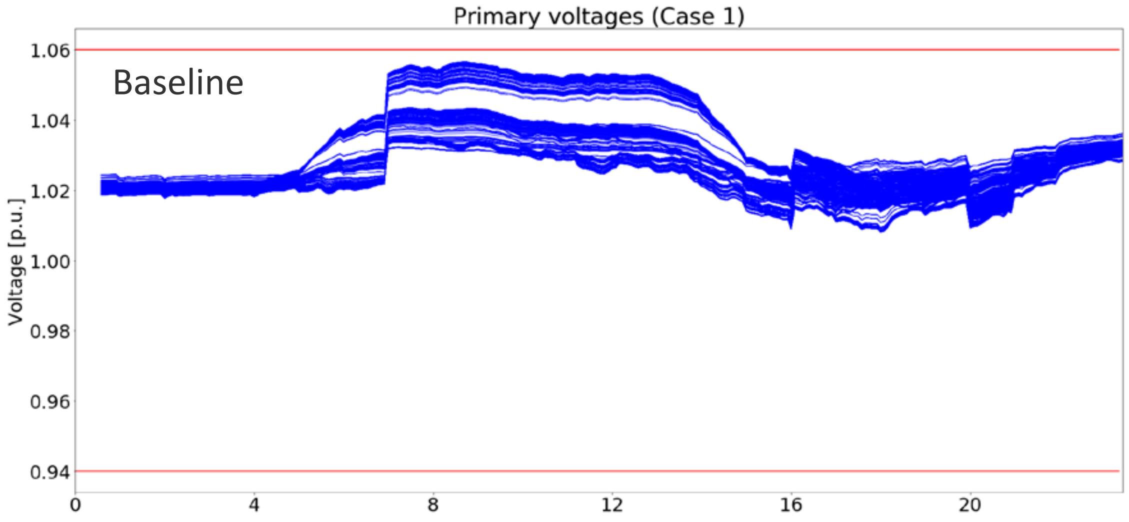
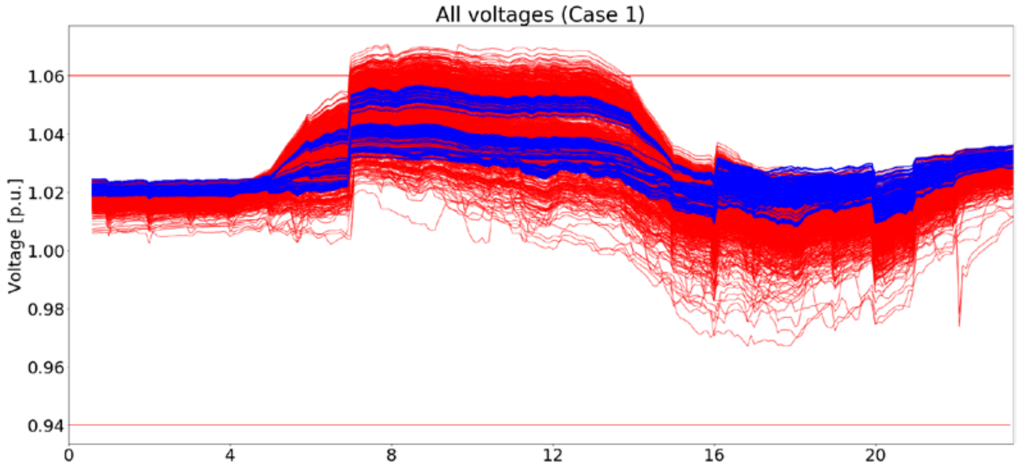
Load Voltage Results

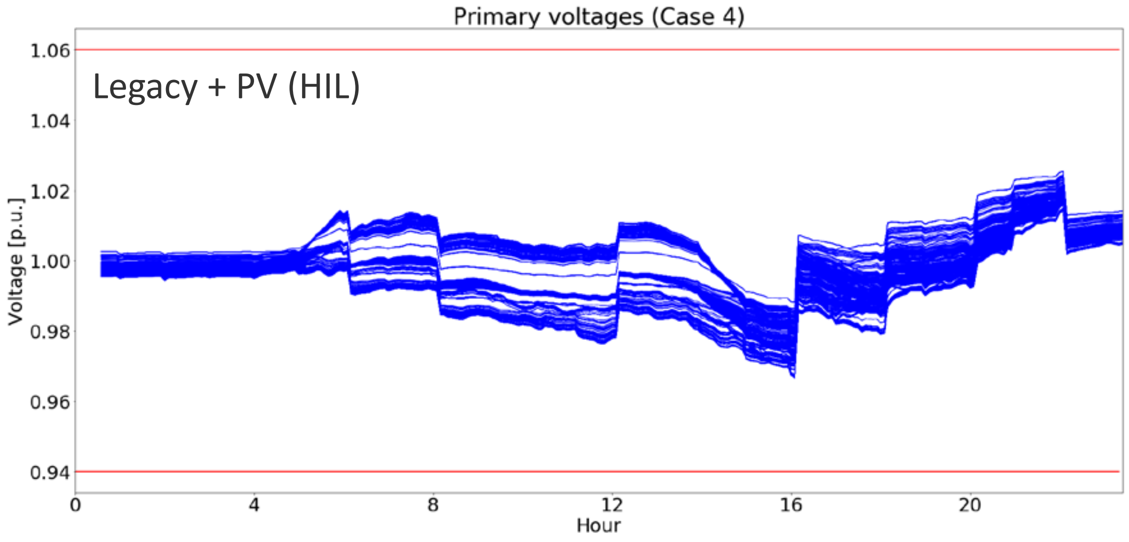
	Case 1	Case 2	Case 3	Case 4
Mean voltage	246.34	239.9 V	239.3 V	238.9
Variance	11.63	8.7 V	7.0 V	7.5 V
Mean absolute voltage deviation	6.34	0.37 V	0.68 V	1.09 V
Voltage fluctuation Index	8.34	8.28	8.28	8.28
Exceedance data points	5654	30	22	68
LTC actions	2	8	6	7
Capacitor actions	2	0	0	0

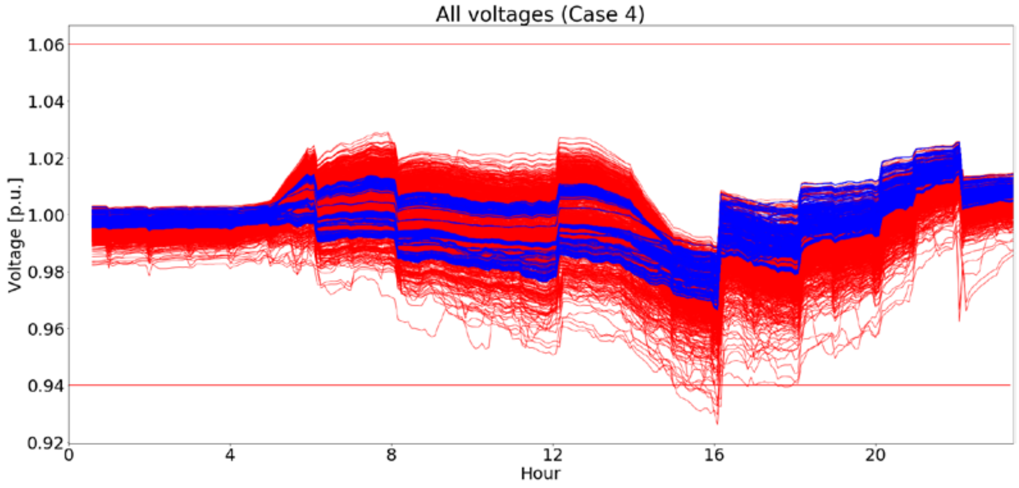
Primary Voltages

Blue: Primary voltages
Red: Secondary voltages









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