Federated Architecture for Secure and Transactive Distributed Energy Resource Management Solutions (FAST-DERMS)

Annabelle Pratt, Chief Engineer, NREL (PI)
Jason MacDonald, Principal Scientific Engineering Associate, LBNL (PI+1)

December 12, 2024. For ADMS Test Bed and FAST-DERMS Workshop

FAST-DERMS Project

Supported by the Department of Energy under the Grid Modernization Laboratory Consortium

Objectives:

- *Develop and demonstrate a control architecture* for heterogeneous distributed energy resources (DER) to provide grid services to the bulk power system at scale and support aggregation and transactive management.
- *Enable DER contribution to bulk services* at scale by simplifying transmission and distribution (T&D) interaction and increasing reliability of aggregated resource response.

- Three key project activities:
  - Architecture development
  - Reference controls development
  - Laboratory demonstration

Project Team

PI: Annabelle Pratt, Chief Engineer, NREL

Co-PI: Jason MacDonald, Principal Scientific Engineering Associate, LBNL

National Laboratories:
- National Renewable Energy Laboratory
- Lawrence Berkeley National Laboratory
- Pacific Northwest National Laboratory
- Oak Ridge National Laboratory

Utilities:
- San Diego Gas and Electric (SDG&E)
- Southern Company
- ComEd – An Exelon Company
- New York Power Authority (NYPA)

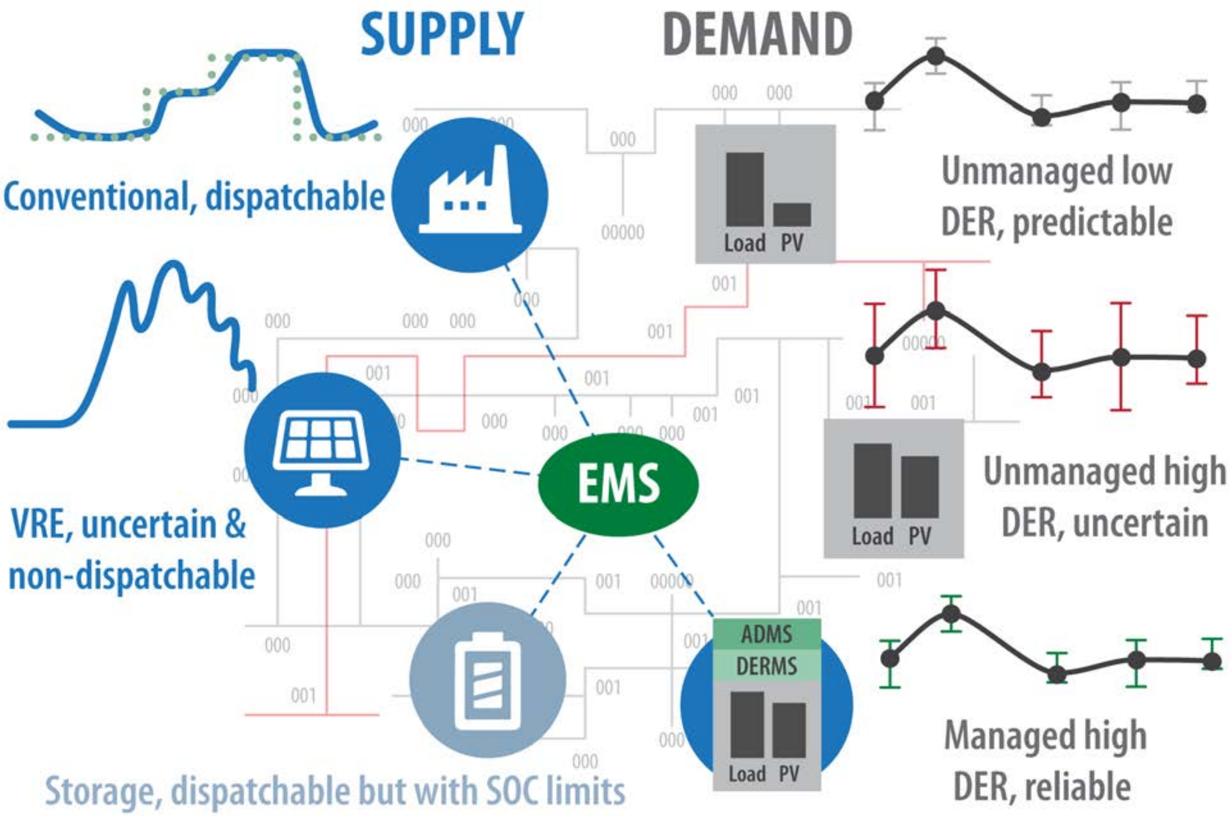
Universities:
- Iowa State University
- University of North Carolina - Charlotte

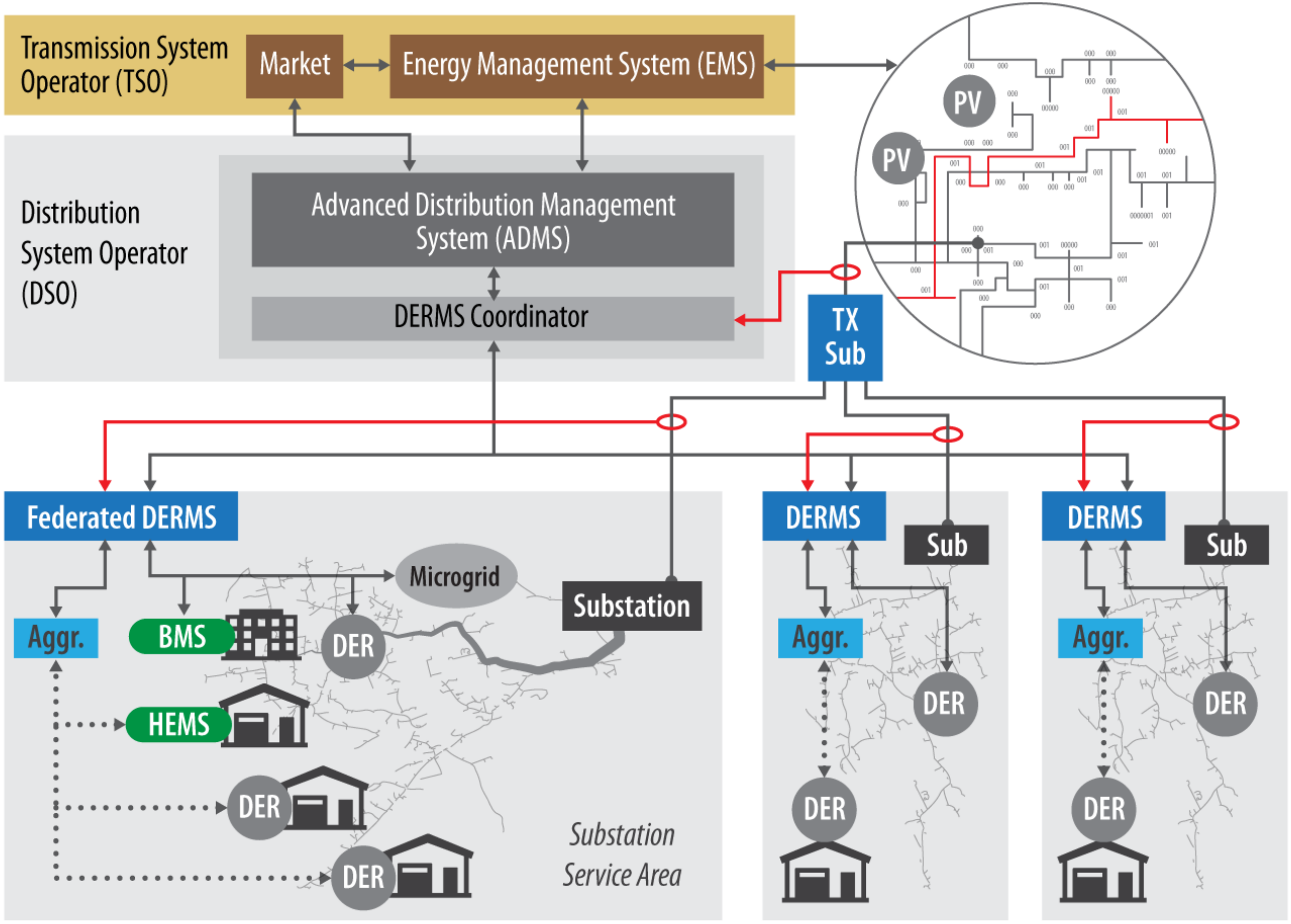
Industry Partners:
- Electric Power Research Institute (EPRI)
- Oracle
- GridBright, Inc

Architecture Development

Annabelle Pratt

The Big Picture





BMS = Building Management System HEMS = Home Energy Management System Sub = Substation Aggr. = Aggregator

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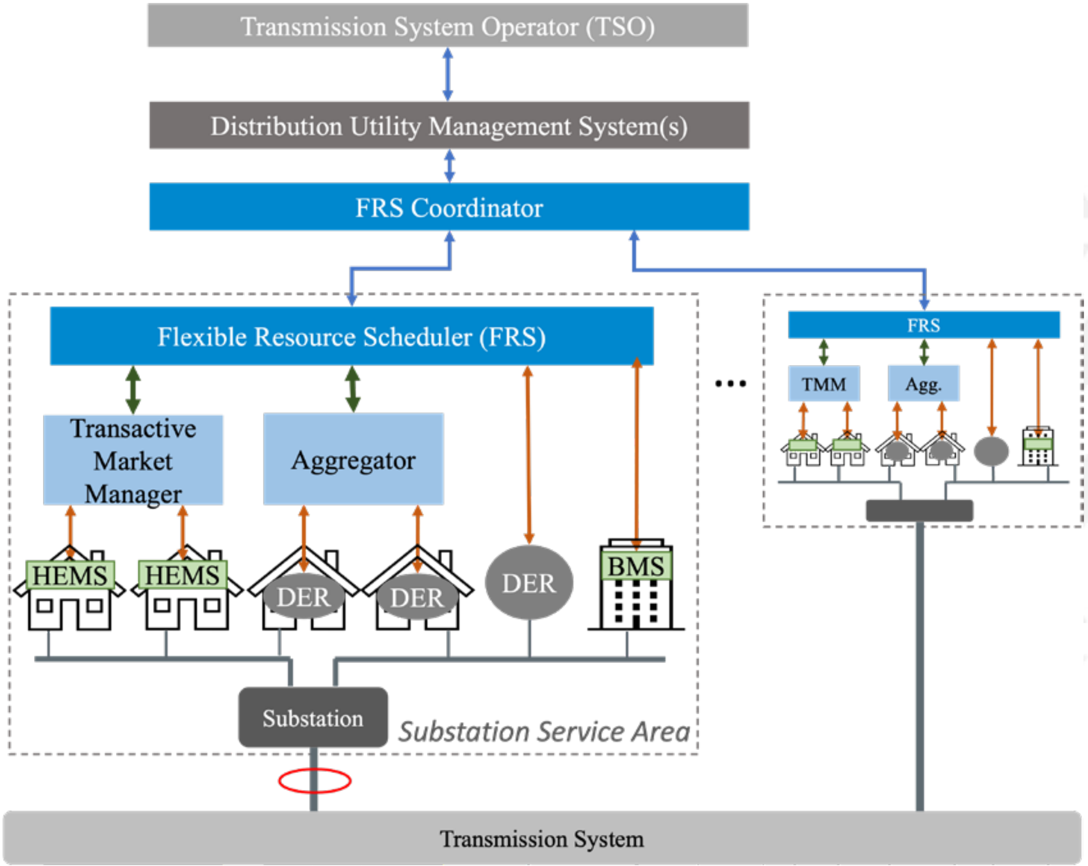
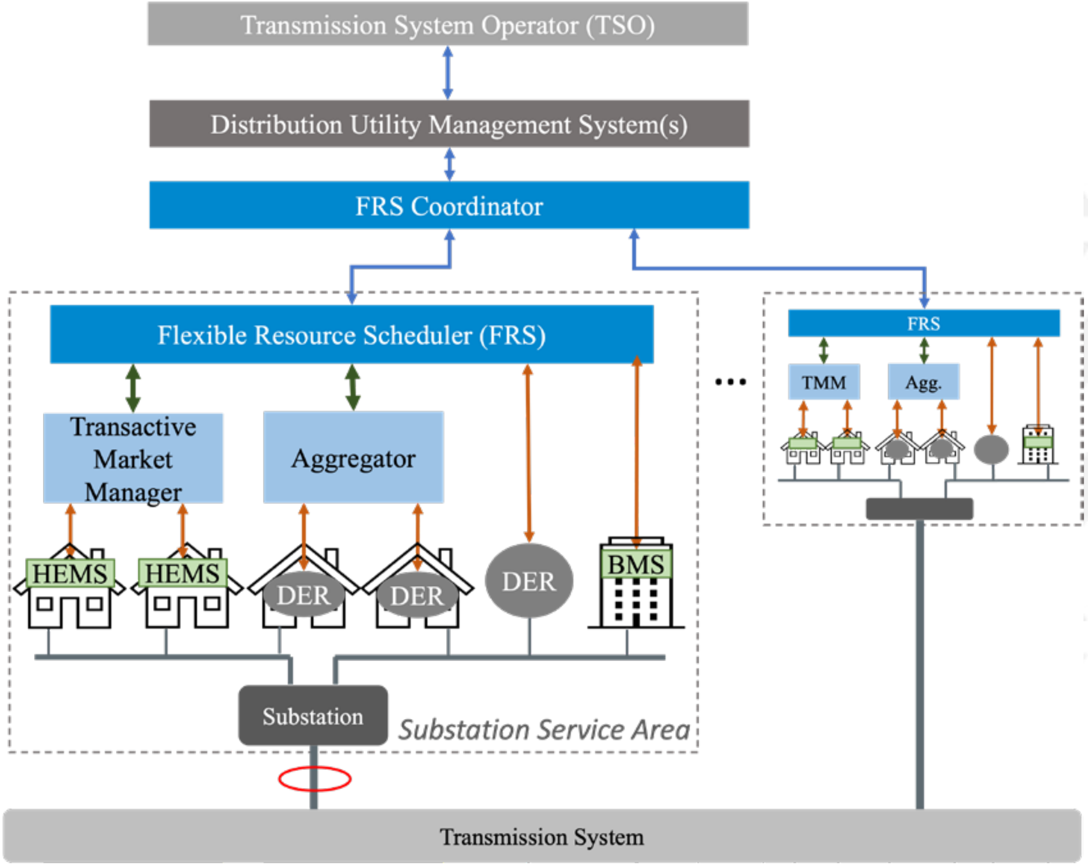


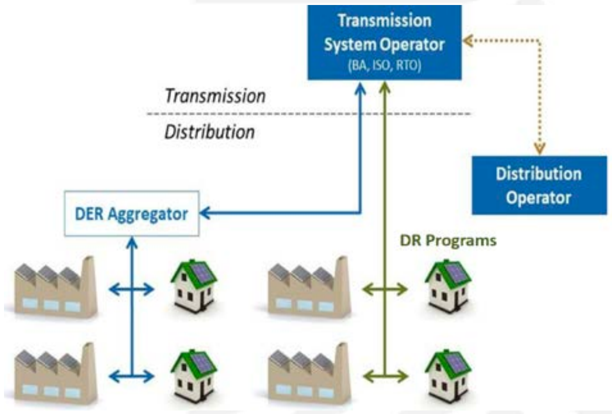
FAST-DERMS Architectural Features



- **Simplify T&D interaction** by defining and measuring transmission services provided at the distribution substation.
- Demonstrate **distributed intelligence** by managing aggregations at the distribution substation through our Flexible Resource Scheduler (FRS).
- Perform **network-aware optimization** to maintain distribution health while simultaneously providing bulk service.
- Employ **"Total DSO" architecture** model such that the DSO represents the aggregated resource response in the bulk transmission system.

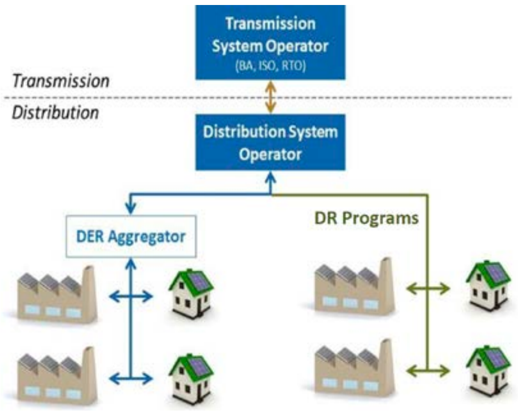
Architectures for Future Grid Interaction

Total TSO



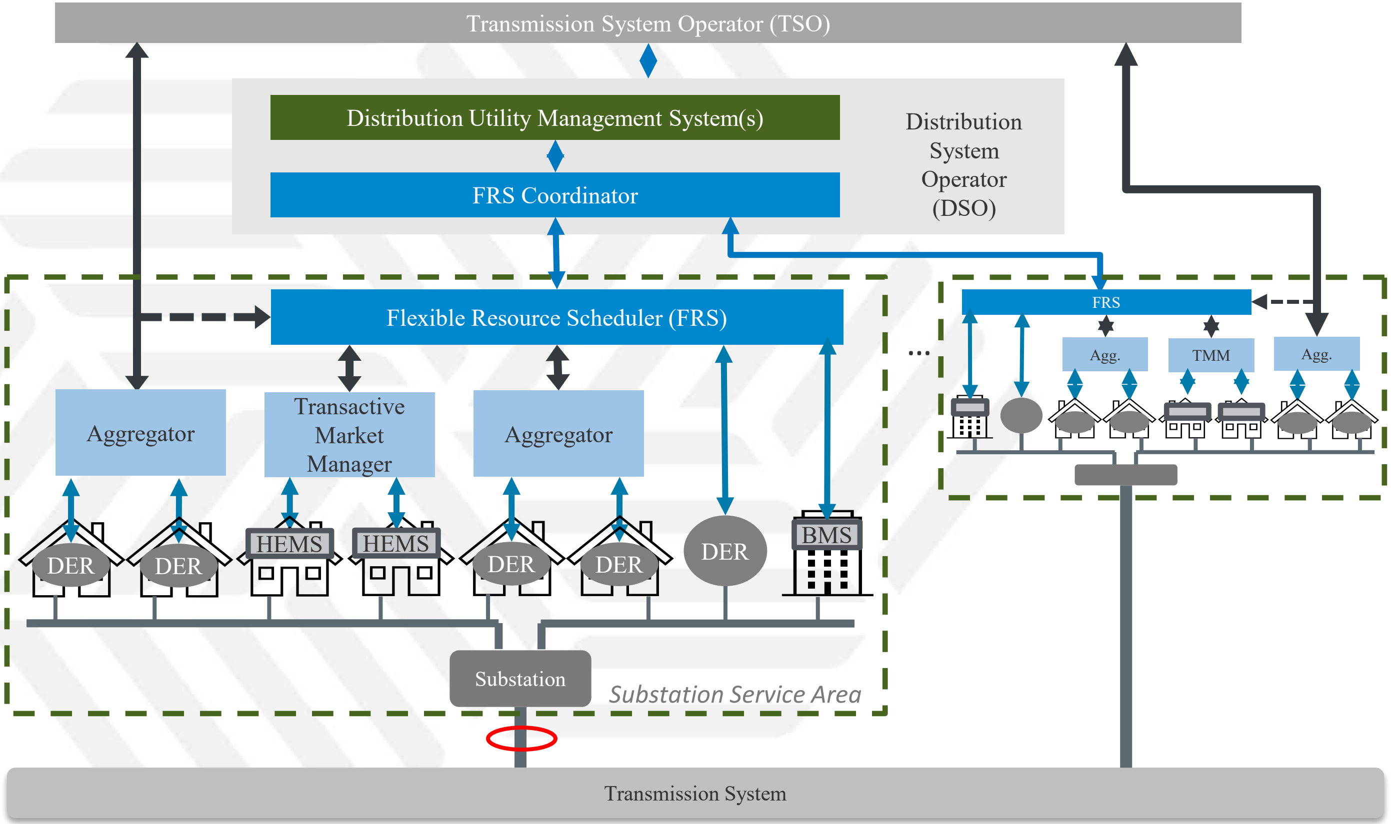
Hybrid

Total DSO



Source: Paul De Martini, "T-D Operational Coordination", Newport Consulting, December 9, 2020 (Presentation to National Council on Electricity Policy)

FAST-DERMS Extension to Hybrid Architecture



FAST-DERMS Project

- Three key project activities:
  - Architecture development
  - Reference controls development
  - Laboratory demonstration

- Architecture:
  - Developed and published System Architecture and Reference Implementation (Jan 2022)
  - Defines system-level principles and objectives, concepts, specifications for FAST-DERMS
  - https://www.nrel.gov/docs/fy22osti/81566.pdf

Federated Architecture for Secure and Transactive Distributed Energy Resource Management Solutions (FAST-DERMS)

System Architecture and Reference Implementation

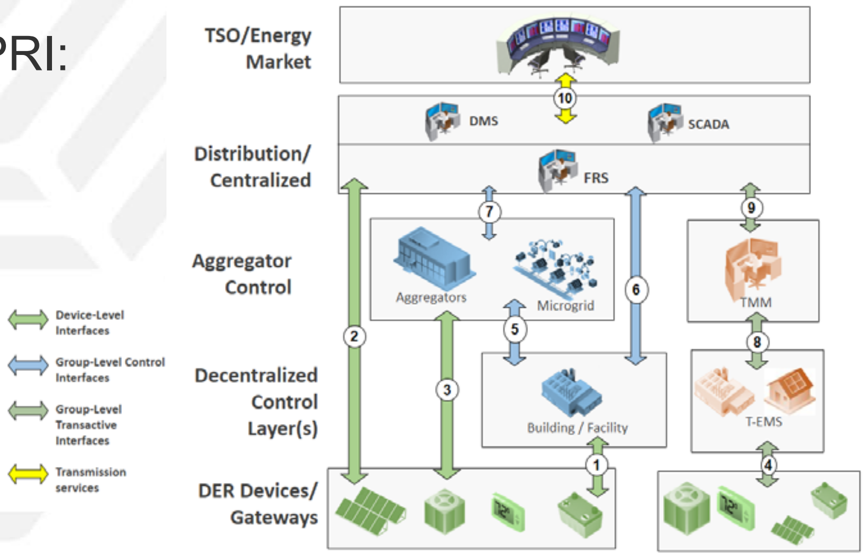
January 2022

Fei Ding
Weijia Liu
Jason MacDonald
James Ogle
Annabelle Pratt
Avijit Saha
Joe Hagerman
Murali Baggu

FAST-DERMS Progress: Architecture

- Architecture:
  - PNNL Grid Architecture team developed and published a companion document
  - "Grid Architecture Guidance Specification for FAST-DERMS" (April 2021)
  - https://gridarchitecture.pnnl.gov/media/Grid_Arch_Guidance_for_FAST%20DERMS.pdf

- Communications architecture, led by EPRI:
  - Complex communication landscape
  - Extends across multiple layers
  - Standards-based
  - Interoperable



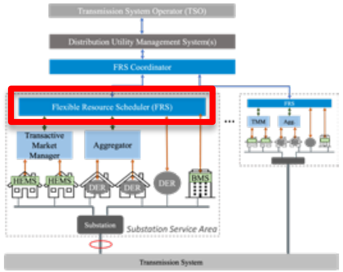
Summary and Takeaways

- We need DER—including BTM DER—to contribute to grid services to ensure reliable grid operations.
- BTM DER need to be aggregated to participate meaningfully.
- Need a scalable solution that can aggregate small resources that are not under direct control of distribution system operators into a reliable service provider.
- FAST-DERMS addresses this need through a federated architecture approach.
- We are developing a reference controls solution and will demonstrate it in a realistic laboratory environment on a real utility feeder.
- Reference controls will be made available open-source at the end of the project.

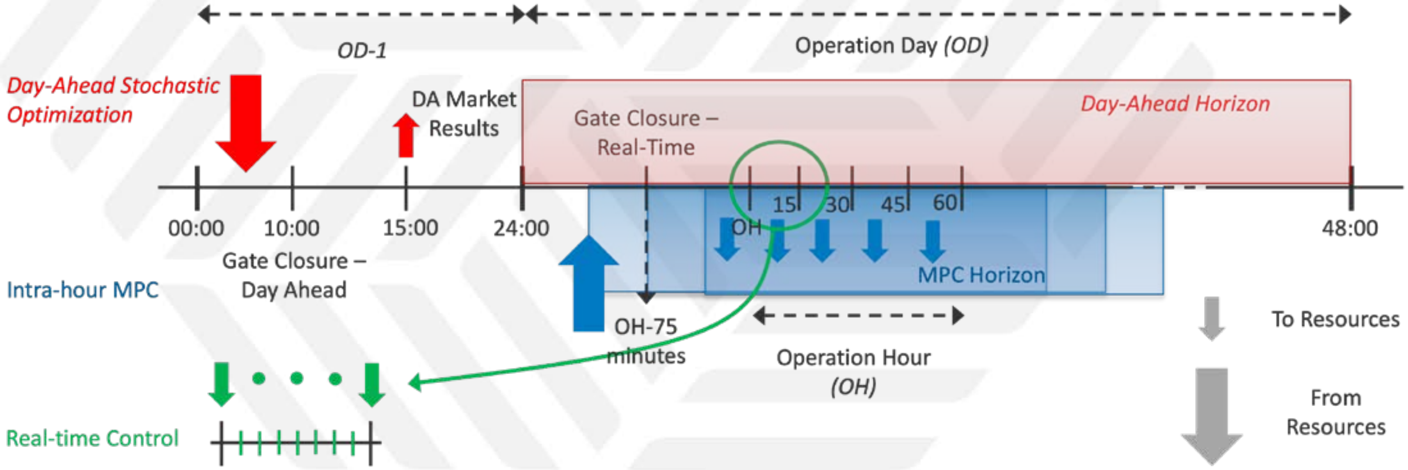
Reference controls development

Jason MacDonald

Controllers: Flexible Resource Scheduler



- Temporal hierarchy of coordination and control via the FRS:
  - **Day-ahead stochastic optimization** for wholesale market bidding
  - **Intra-hour model predictive control** for DER management and response allocation
  - **Real-time PID control** for dispatch error correction.



- Simultaneous distribution management & transmission service provision

Controllers: FRS Day Ahead Optim.

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U.S. Department of Energy

- **Network-aware, Scenario-based Stochastic Optimization** determines <u>substation power and reserve</u> offers consistent across most any possible uncertainty scenario, at <u>minimum total cost</u>.
  - Thousands of random variables makes scenario selection critical.

$$\min_{u(t)} E\left[\text{Total Cost}\right]$$

$$\text{subject to: } \forall d \in N_{scenarios}$$

$$\left[\text{DER Power (P \& Q) and Energy Constraints}\right]_d$$

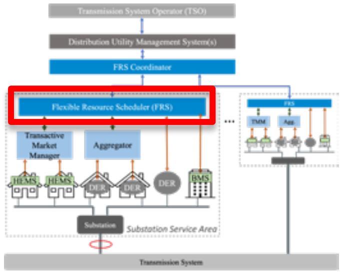
$$\left[\text{Linearized AC Power Flow}\right]_d$$

$$\left[\text{Power System Constraints (Voltage and Thermal)}\right]_d$$

$$\left[\text{Constant Substation Energy and Reserve Offers}\right]_d$$

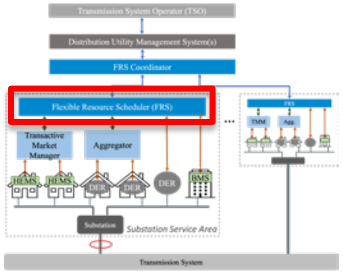
$$\left[\text{Minimum distribution system cost recovery}\right]_d$$

  - Decision variables: power and reserve schedules for DER and aggregators, and price fore transactive market managers.



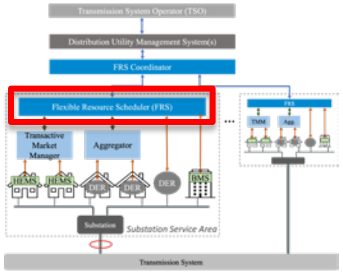
Controllers: FRS Intra-Day MPC

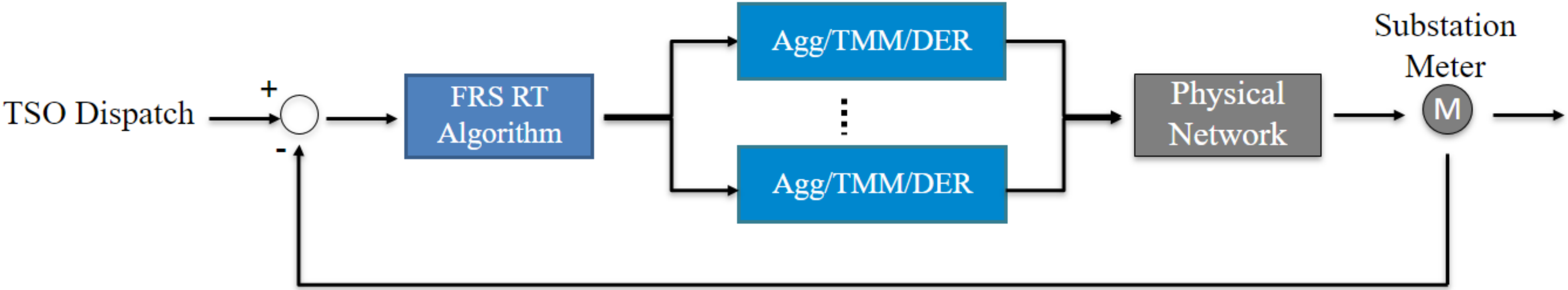
- **Rolling horizon, deterministic optimization** that chooses DER power setpoints and reserve allocations to minimize the deviation between substation power and available TSO reserves with the Day Ahead market awards.
  - 15-minute granularity, 4-hour rolling horizon
  - Requires communication of state of charge from DER/Aggregators.
  - Constraint structure remains the same as the Day Ahead.
  - A distribution operating reserve requirement calculated based on the uncertainty in the forecasts is added to the TSO market reserves.



Controllers: Real-Time Controller

- Simple Proportional-Integral-Derivative (PID) controller drives the error between the substation power and ISO dispatch to zero.
  - Simplicity is key: FRS provides one-way communications in real time to DERs and aggregations, no telemetry required.
  - Dispatch signal disaggregated every 1-minute according to reserve allocations from the MPC.





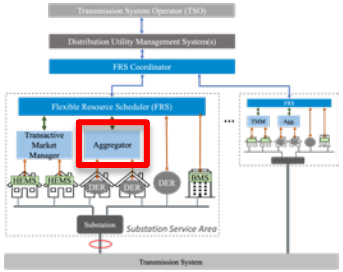
Controllers: Battery Aggregator

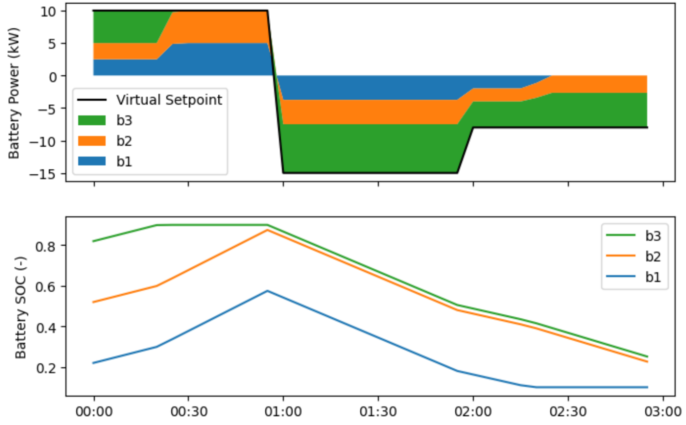
- Merges batteries into a single virtual battery model
  - Linearizes models before aggregating
  - Virtual battery capacity = sum of capacities
  - SOC and efficiency uses a weighted average

$$P_i = P_i^+ - P_i^-$$

$$SOC_i(k+1) = SOC_i(k) + \frac{\eta^+ \Delta t}{E_i} P_i^+ - \frac{\Delta t}{\eta^- E_i} P_i^-$$

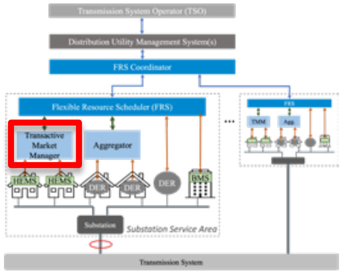
- Aggregator Objective:
  - Distribute virtual battery power setpoint equally to individual batteries based on battery capacity

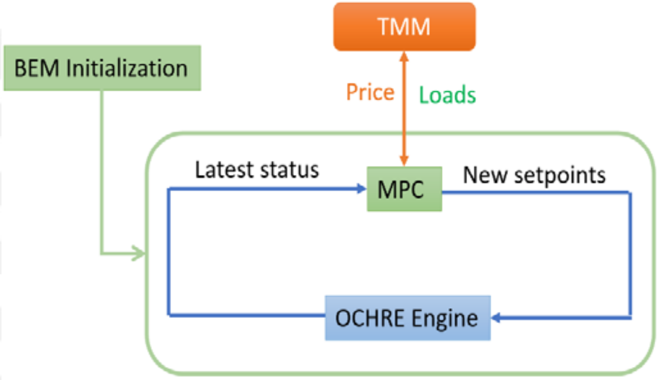




Controllers: Transactive Market Manager

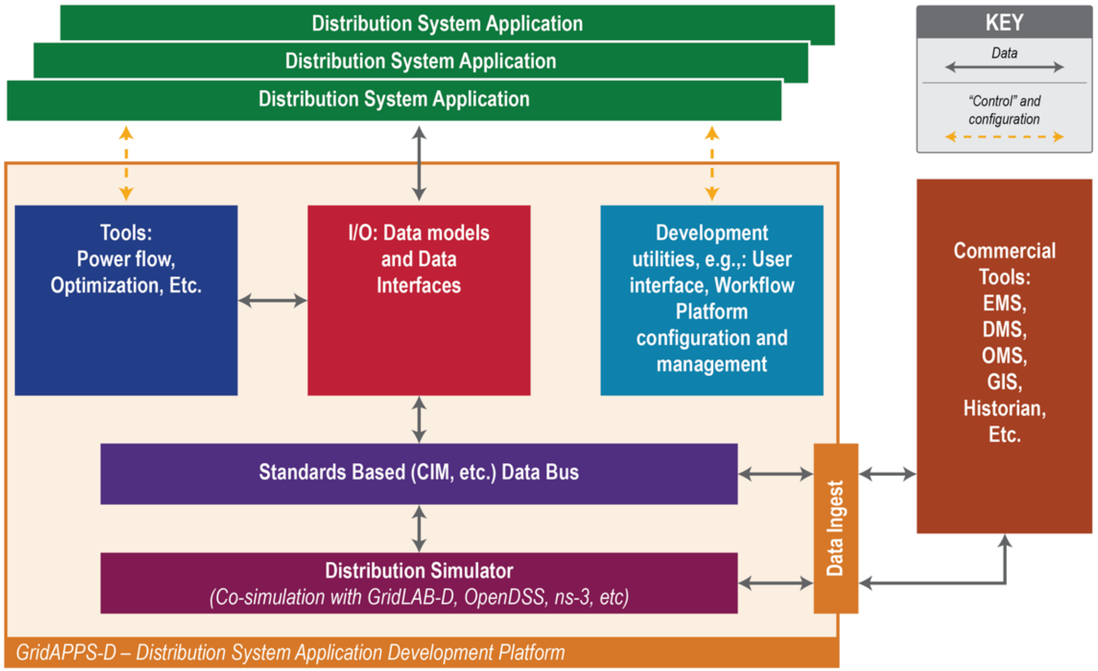
- ORNL's TMM design is both an aggregator and a collection of Transactive Home Energy Managers (T.HEMs) based on Model Predictive Control
  - TMM recieves price forecast / signals from FRS and passes to house-level MPCs
  - MPCs determine optimal control actions and compose house level bids / compute house level control actions to send to OCHRE house models.
  - TMM aggregates bids for FRS optimization.





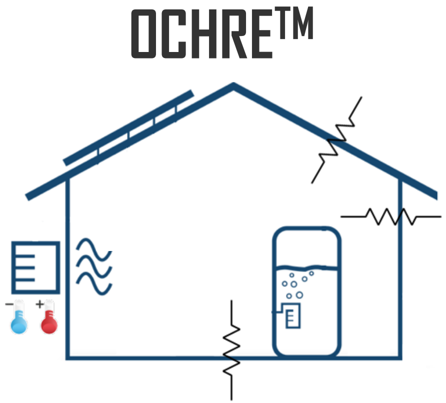
Platform: GridAPPS-D

- Overview:
  - An open-source platform for advanced distribution management system (ADMS) application development
  - Built-in distribution simulator, cosimulation, and common services for developers and applications
  - Can integrate with external software systems using standard communications (e.g., IEEE Std. 2030.5, DNP3).
- FAST-DERMS leverages data bus, simulation, co-simulation, and communication interfaces.



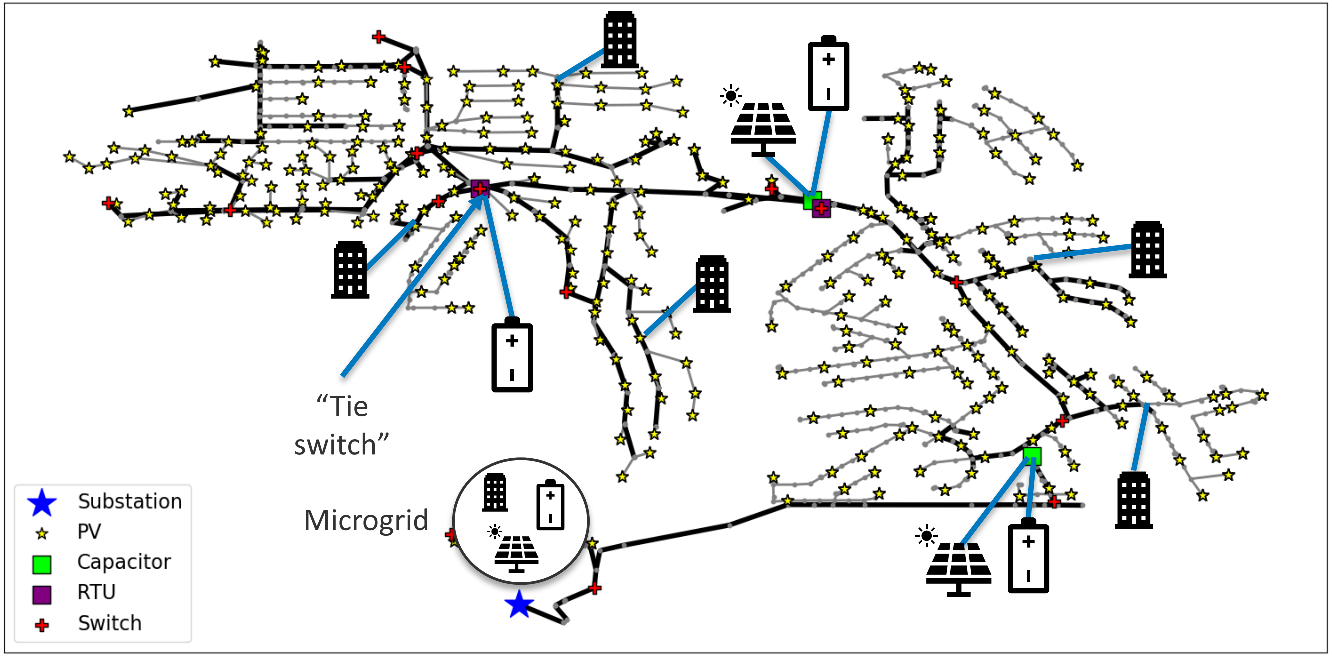
Co-Simulation: OCHRE

- OCHRE™:
  - Object-Oriented Controllable High-Resolution Residential Energy Model (open source)
  - Residential building simulation suitable for cosimulation with power systems
  - Implementation on high-performance computing for many homes.
  - https://ochre-docs-final.readthedocs.io/en/latest/.



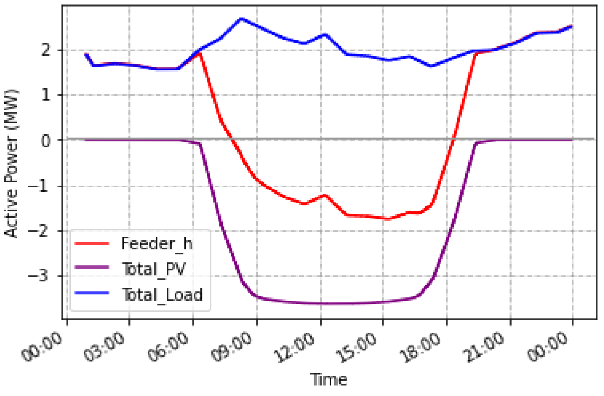
Modified SDG&E feeder

- Model augmented with Utility Scale PV and Batteries, responsive commercial buildings, Current modeling PV and Batteries
- Replace some load with 100 homes modeled in OCHRE, and responsive to either battery aggregator or TMM



Simulation Results: Battery Aggregator + PV

- Day-Ahead Results

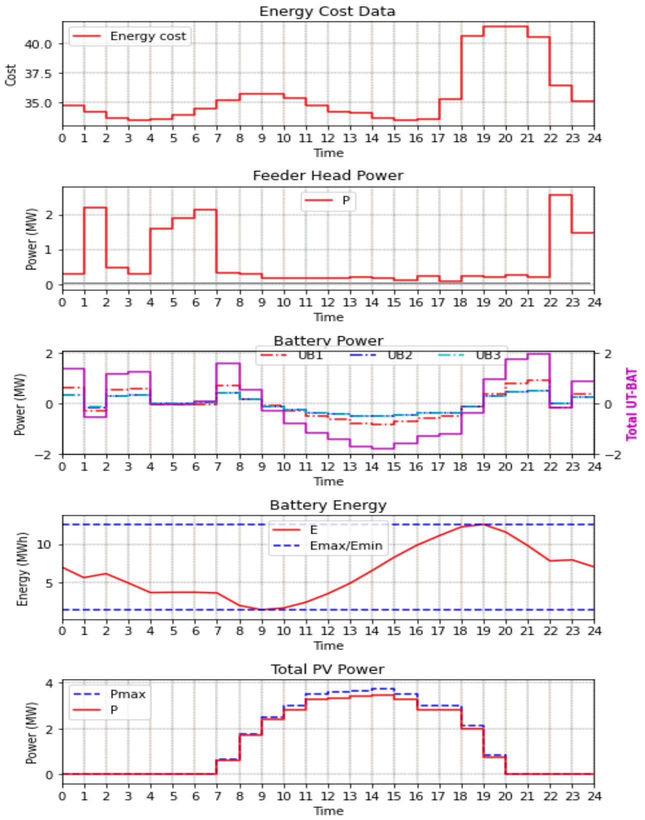


► Southern Company feeder: light load and high PV day—baseline:

Lorem Ipsum Added utility-scale battery systems to model to address reverse power flow.

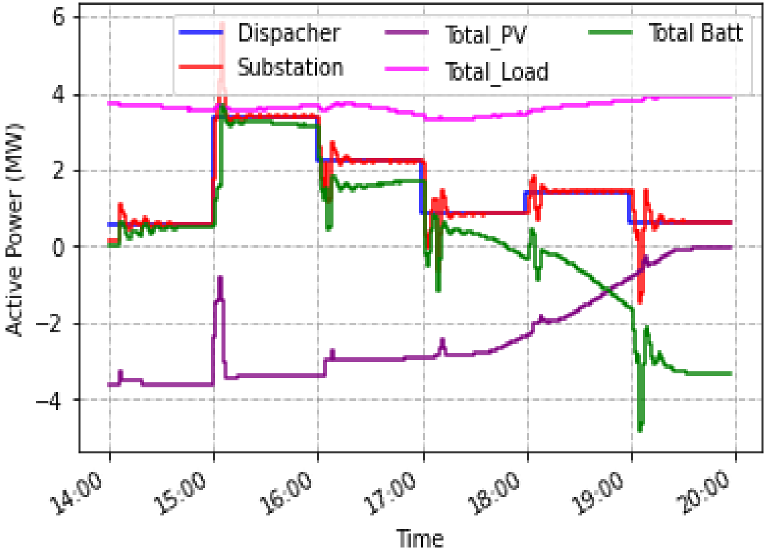
Day-ahead FRS stochastic optimization:

- Objective is to minimize cost, subject to network constraints
- No reverse power flow allowed (per use case)
- Performs energy arbitrage using battery
- Limited PV curtailment.



Simulation Results: Battery Aggregator + PV

- Real-Time Results
  - Model predictive control:
    - Operates over 4-hour horizon
    - Updated every 15 minutes.
  - Real-time control:
    - PID controller
    - Time step of 1 minute.
  - Continuing work to reduce overshoot.



Simulation Results: ADMS Integration

- Real-Time Results
  - Model predictive control:
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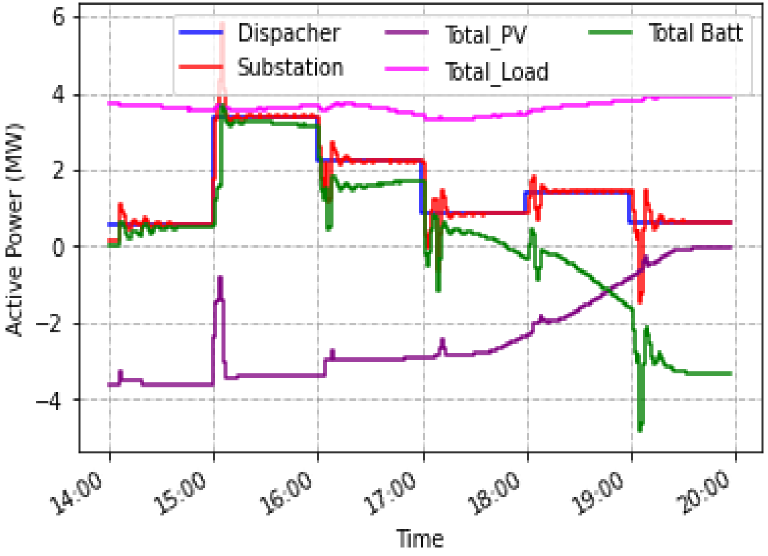

Simulation Results: ADMS Integration

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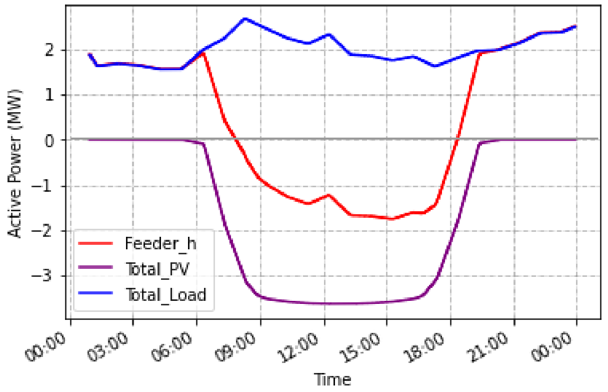
- Day-Ahead Results



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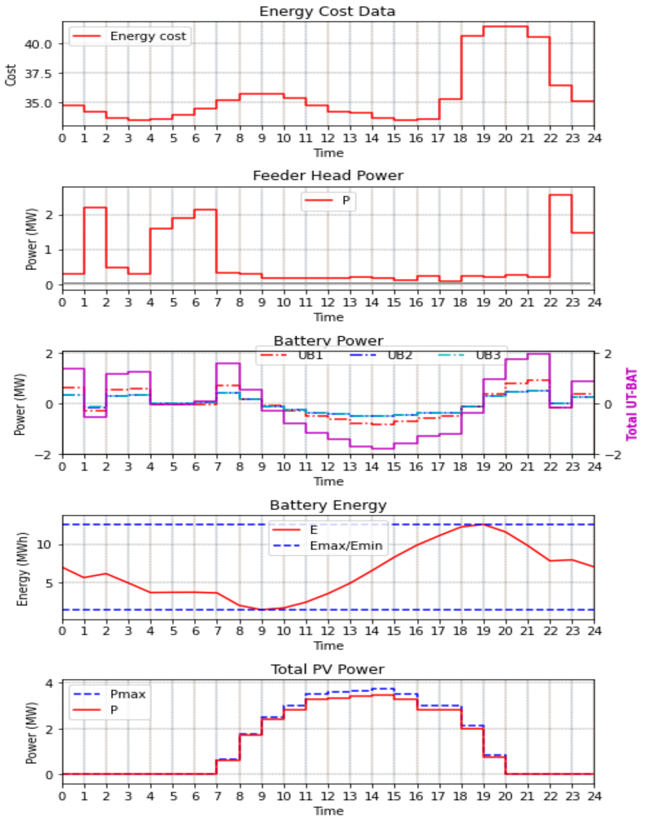
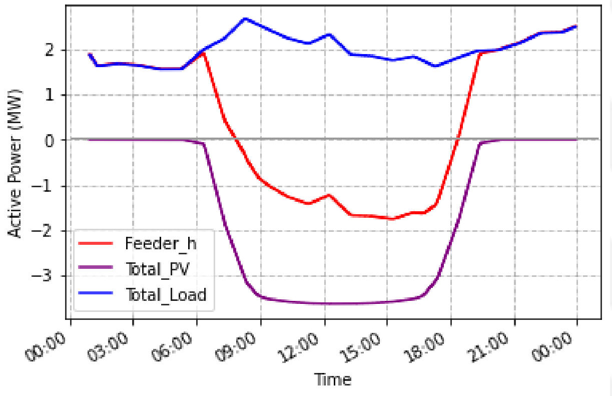


Simulation Results: TMM

- Day-Ahead Results



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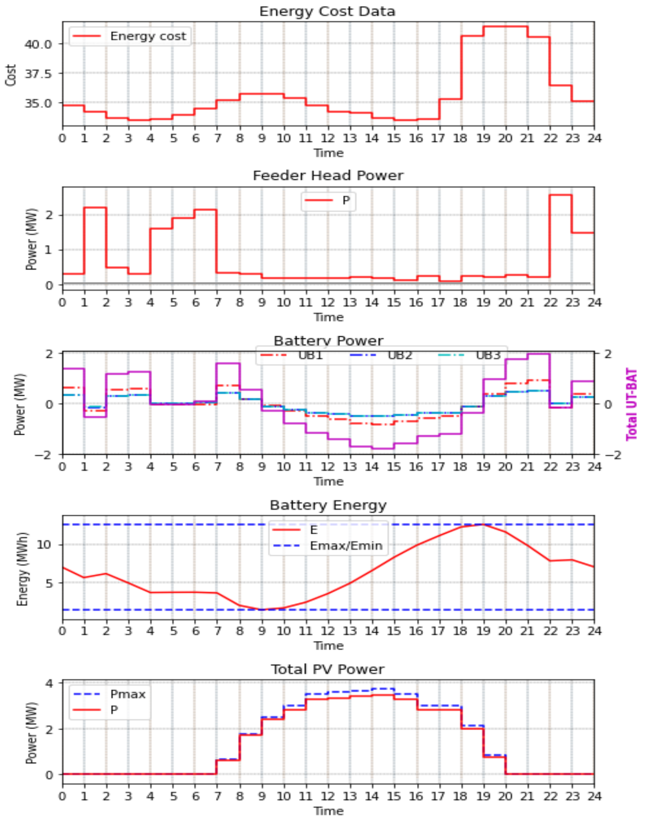

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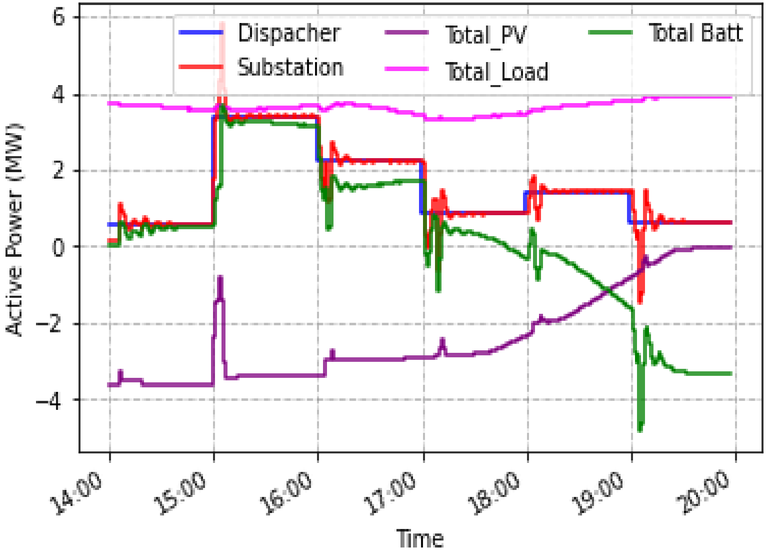


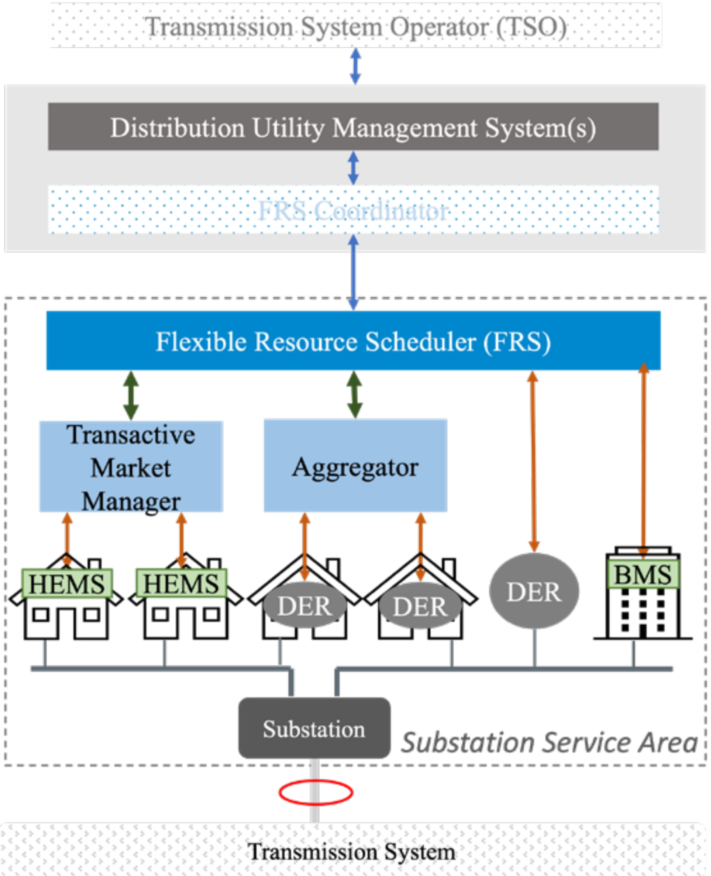
Laboratory Demonstration

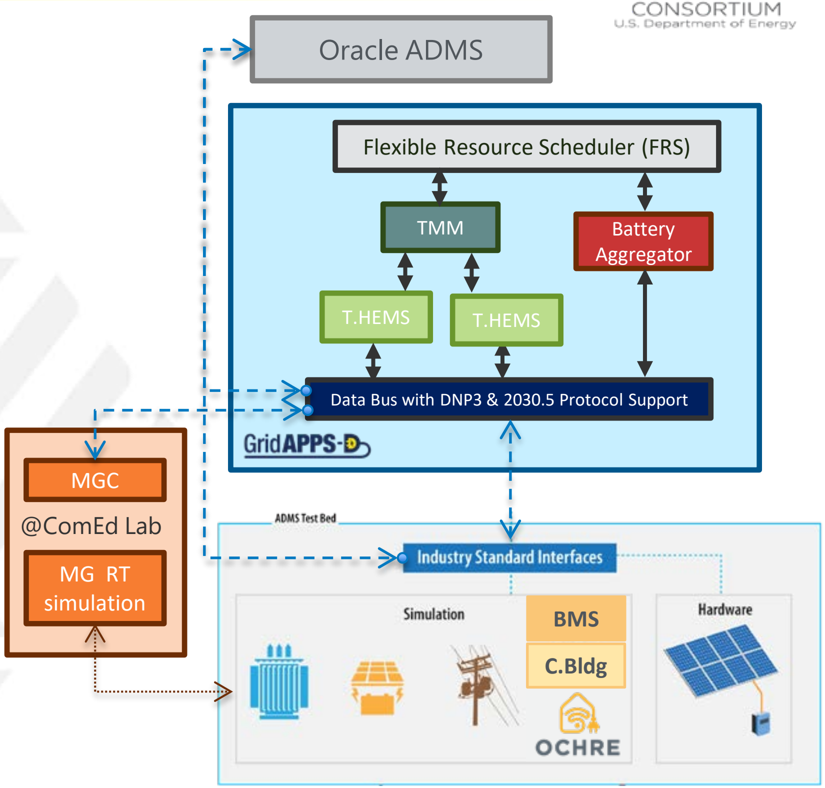
Annabelle Pratt

Laboratory Demonstration Features

- Real-time simulation
- Interface with commercial controllers
- Industry-standard communications protocols

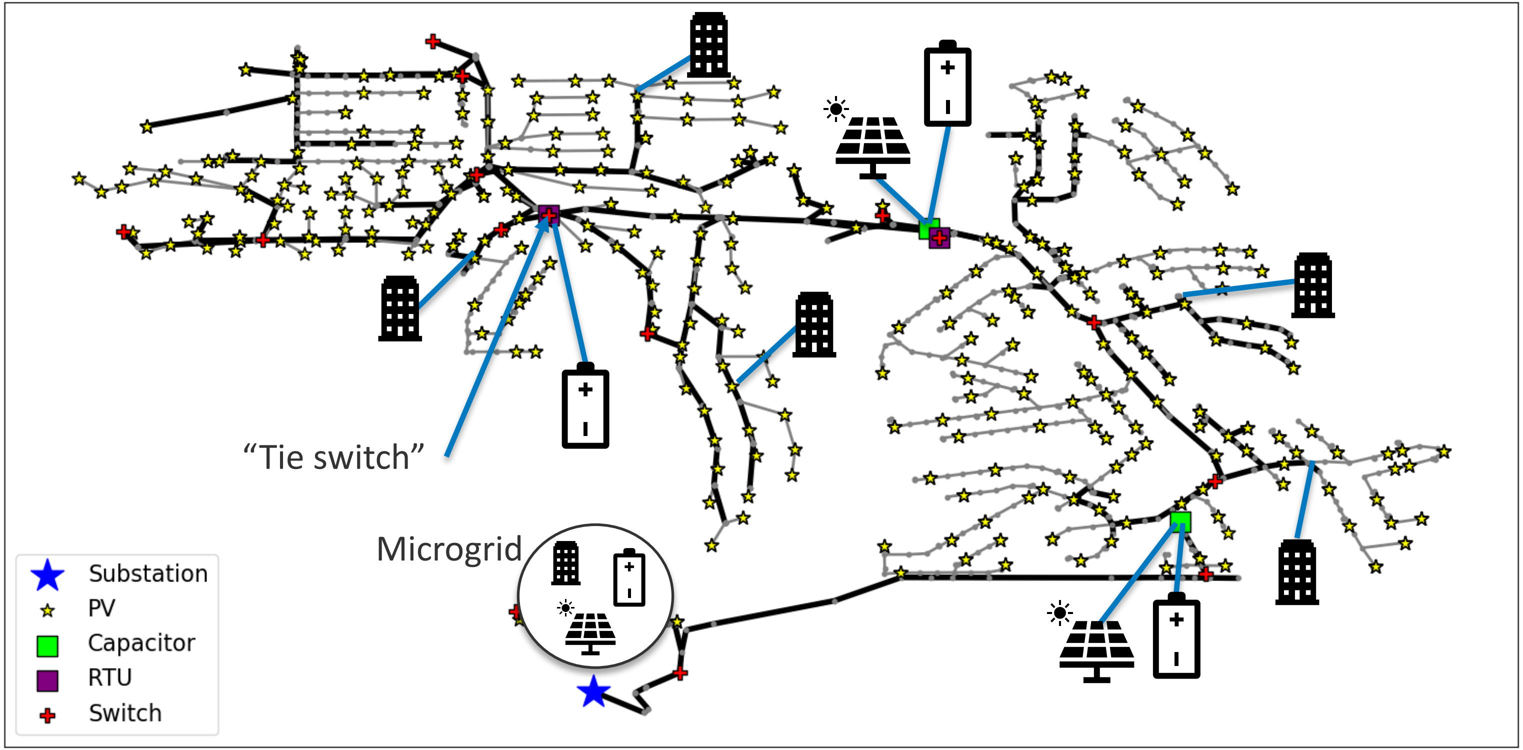
Laboratory Demonstration





Modified SDG&E feeder

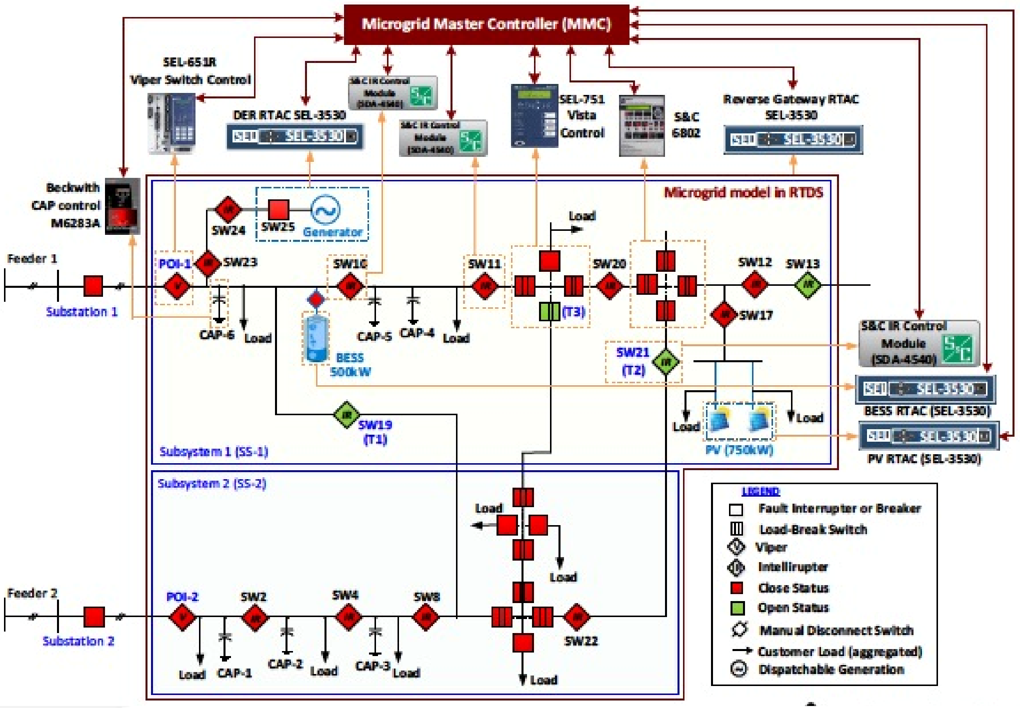
- Replace some load with 100 homes modeled with OCHRE; respond to
  - Transactive market (40), battery aggregator (60)



Microgrid Modeling and Control

BCM Model and MMC Testbed

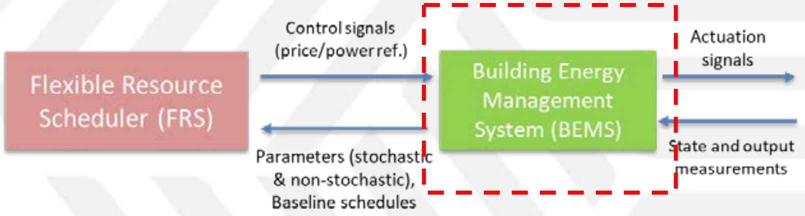
- Two feeders
- Two POI switches—POI-1, POI-2
- Three Tie Switches– T1, T2, and T3
- All DERs located in Subsystem-1
- Dynamics of microgrid modeled in RTDS
- Selected intelligent electronic devices (IEDs) communicate with RTDS and MMC
- Reverse gateway (RGW) RTAC receives data from RTDS and parses such that MMC sees it coming from individual RTUs.



R. Sharma *et al.*, "Design, Integration, Testing and Lessons Learned of a Utility Operated Microgrid Master Controller," *2022 IEEE Power & Energy Society General Meeting (PESGM)*, Denver, CO, USA, 2022, pp. 1-5, doi: 10.1109/PESGM48719.2022.9917101.

Commercial Building Modeling and Control

- Represent a building with a single equivalent battery model (EBM)
  - Enables modeling consistency
  - Reduces number of operational parameters shared with FRS
  - Capture uncertainties associated with the building's flexible resources
  - 3 building types: small office building, medium office building and warehouse
  - 2 climates: Chicago, IL, and Los Angeles, CA



OR

Power input (relative to some base profile)

Energy state

$$X_{t+1} = \alpha X_t + \Delta P_t$$

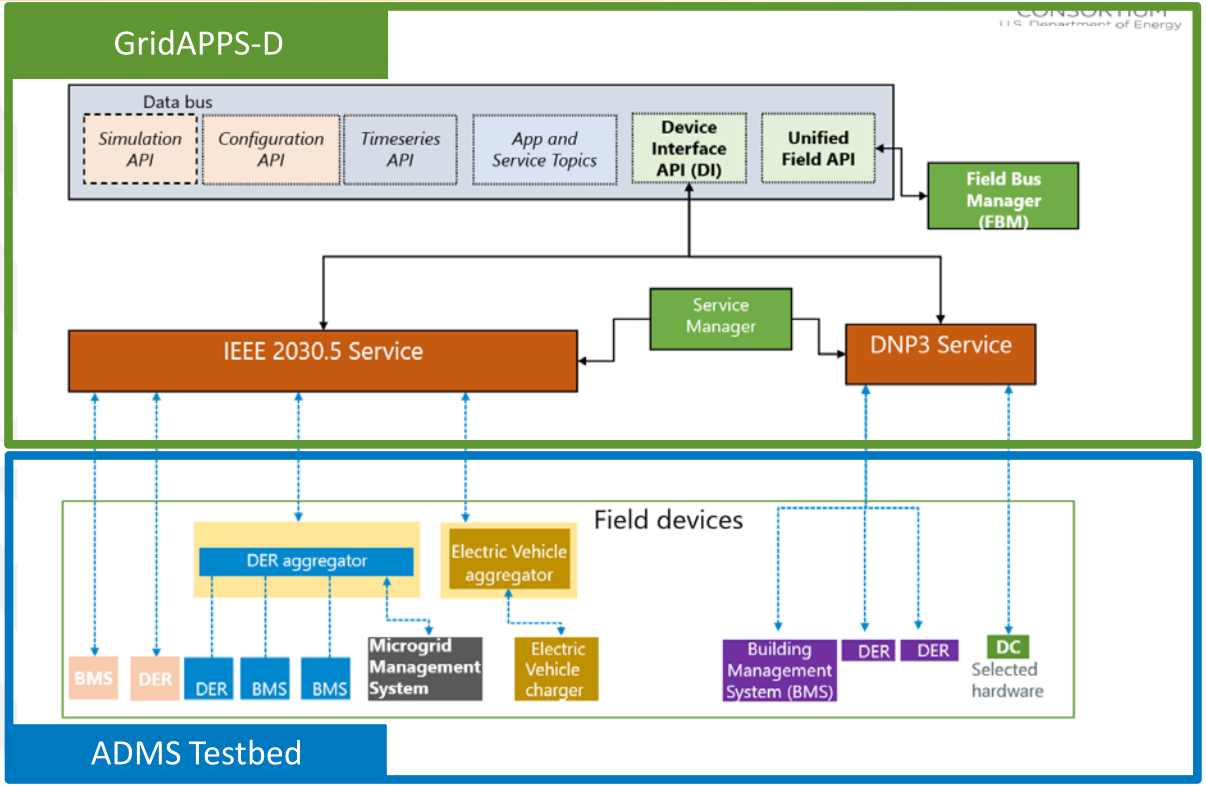
Self-discharge rate

Abbas, A., Ariwoola, R., Chowdhury, B., Kamalasadan, S. and Lin, Y., 2022, October. Evaluation of Equivalent Battery Model Representations for Thermostatically Controlled Loads in Commercial Buildings. In *2022 IEEE Industry Applications Society Annual Meeting (IAS)* (pp. 1-6).

Enhancing GridAPPS-D Communications

New capabilities added to GridAPPS-D for FAST-DERMS.

- ►Introduced a field device manager that supports service plug-ins to translate CIM API to different field protocols.
- ►Applications are now independent of field protocol.
- ►Enhanced DNP3 service to support master and outstation roles.
- ►Developed 2030.5 Server using field device manager plug-in architecture



A. Singh, V. R. Motakatla, C. H. Allwardt, H. Padullaparti, I. Mendoza and P. Sharma, "A Framework to Demonstrate a DNP3 Interface With a CIM-based Data Integration Platform," 2024 IEEE Power & Energy Society General Meeting (PESGM), Seattle, WA, USA, 2024.

FAST-DERMS Interoperability with IEEE 2030.5

- Utility partner, SDG&E, requested IEEE 2030.5 be used as one of the protocols for coordination between the utility and DER devices
  - IEEE 2030.5 is one of three allowable communication protocols for CA Rule 21
  - IEEE 2030.5 is a modern, client-server, IOT protocol,
  - Broad function set: discovery, polling and pub/sub, security, smart grid functions, e.g., demand response
- Developed both a 2030.5 client and server
  - Server runs on GridAPPS-D (utility side); clients run on ADMS Test Bed (device side)
  - Both client and server will be made publicly available
    - https://github.com/GRIDAPPSD/gridappsd-2030_5
  - Client and server developed independently, compliance tested with commercial test set, then integrated
  - Learned that developing interoperable software interface even with a released standard is challenging.

Next Steps

- Document and release open-source reference controls
- Complete Laboratory Setup
- Execute Evaluation Plan
- Disseminate results through papers and presentations

- Publish hybrid-DSO architecture addendum
- Demonstrate hybrid architecture with commercial VPP

- Continue to pursue opportunities to demonstrate architecture and controls

Thank you.

NREL/PR-5D00-92398

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Developed under this project

- Federated Architecture for Secure and Transactive Distributed Energy Resource Management Solutions (FAST-DERMS), April 2022
  - https://www.nrel.gov/docs/fy22osti/81566.pdf
- Grid Architecture Guidance Specification for FAST-DERMS, January 2022
  - https://gridarchitecture.pnnl.gov/media/Grid_Arch_Guidance_for_FAST%20DERMS.pdf

- J. S. MacDonald, M. Baudette, V. R. Motakatla and Y. Lin, “An Introduction to the Federated Architecture for Secure and Transactive Distributed Energy Management Solutions (FAST-DERMS),” 2024 Annual Conference of the IEEE Industrial Electronics Society (IECON), Chicago, IL, Oct 2024
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