NREL Transforming ENERGY | 45Th anniversary

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

Yashen Lin, NREL

AES workshop, July 2022

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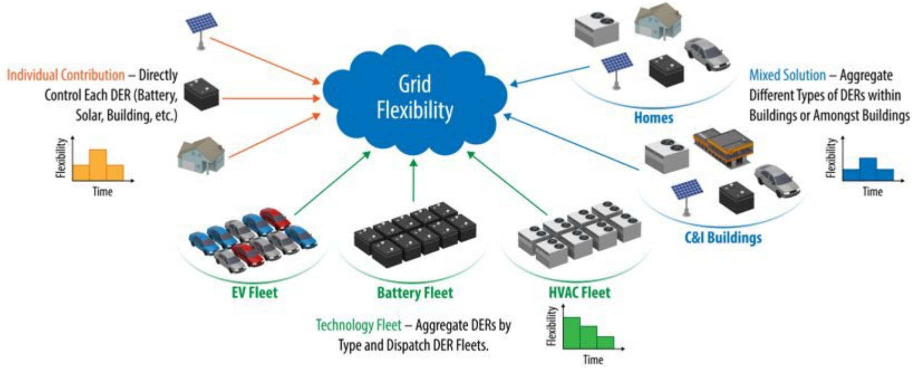
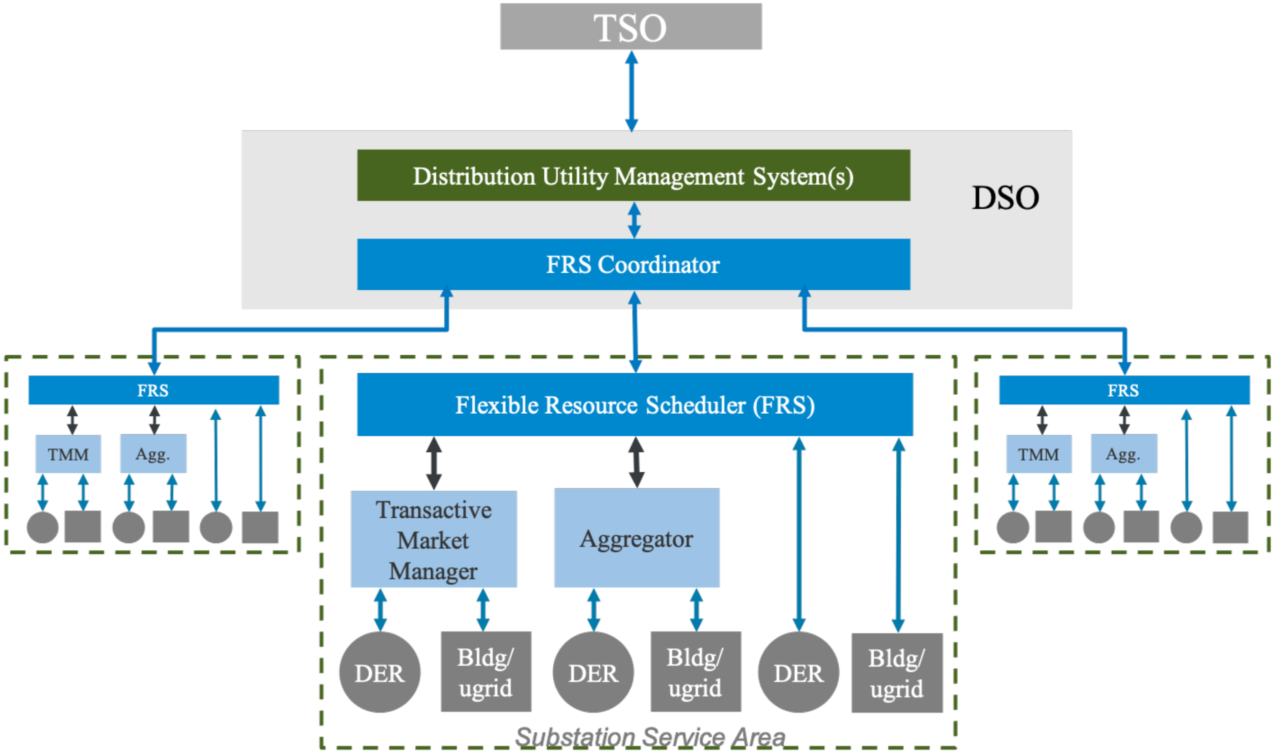
Overview

- Supported by the Department of Energy under the Grid Modernization Laboratory Consortium
- **Objective:** design and develop a federated architecture that can aggregate and manage a broad range of DERs across the grid for bulk system services
  - Provides reliable, resilient, and secure distribution and transmission grid services
  - Enables scalable, near-real-time management of utility-scale and small-scale DERs
  - Supports transactive control, aggregation, and direct control of DERs
  - Incorporates existing utility management systems



Overview



Concept diagram for FAST-DERMS

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
- Oak Ridge National Laboratory
- Pacific Northwest National Laboratory

Utilities:

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

Universities:

- Iowa State University
- University of North Carolina - Charlotte

Industry Partners:

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

Project Tasks

1. Develop federated architecture for DER management solutions
2. Develop stochastic control and optimization algorithms for DER scheduling
3. Quantify DER and aggregation flexibility
4. Develop cyber-attack detection and adaptive local DER control for bulk system stability
5. Develop a transactive control architecture for market-based coordination of DERs
6. Develop a communications architecture to support implementation of FAST-DERMS
7. Implement FAST-DERMS on the GridAPPS-D and ESIF ADMS testbed platforms
8. Demonstrate and characterize FAST-DERMS using GridAPPS-D and the ADMS test bed

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- Define system-level principles and objectives, concepts, specifications for FAST-DERMS
- Architecture document available online: https://doi.org/10.2172/1839591

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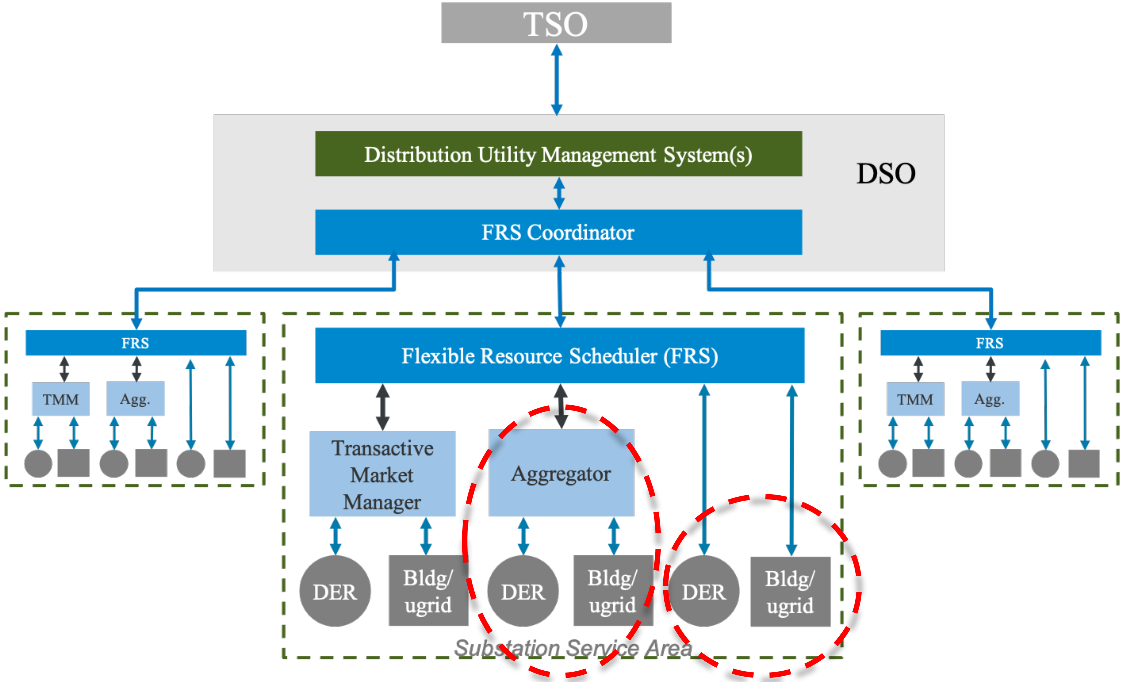
- Develop the Flexible Resource Scheduler (FRS)

Project Tasks

3. Quantify DER and aggregation flexibility

- Develop model for DERs and aggregators
  - PV, battery, flexible load, EV, MG/VPP
- Quantify their flexibility
- Quantify their uncertainty



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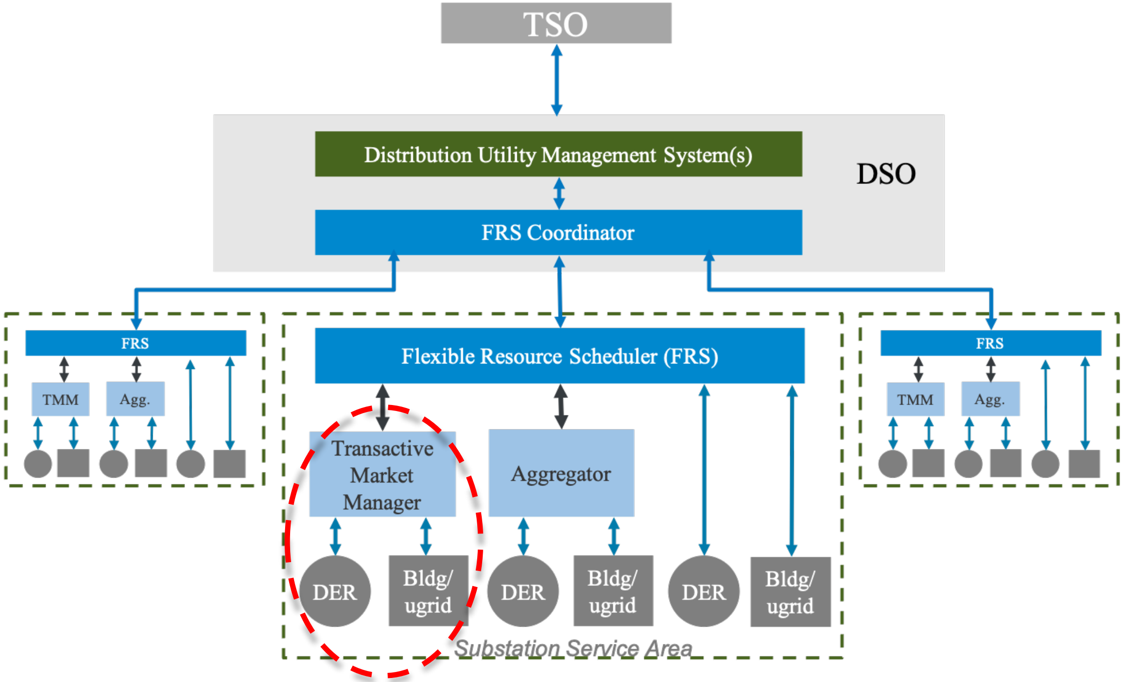
- Hybrid anomaly detection by integrating DSSE centralized detection with distributed anomaly detection at grid edge
  - Y Yao, et al. "A Hybrid Data-Driven and Model-Based Anomaly Detection Scheme for DER Operation". IEEE ISGT 2022.
- Adaptive inverter control that allows uncompromised DERs to adjust their settings to mitigate cyber attack in system

Project Tasks

5. Develop a transactive control architecture for market-based coordination of DERs

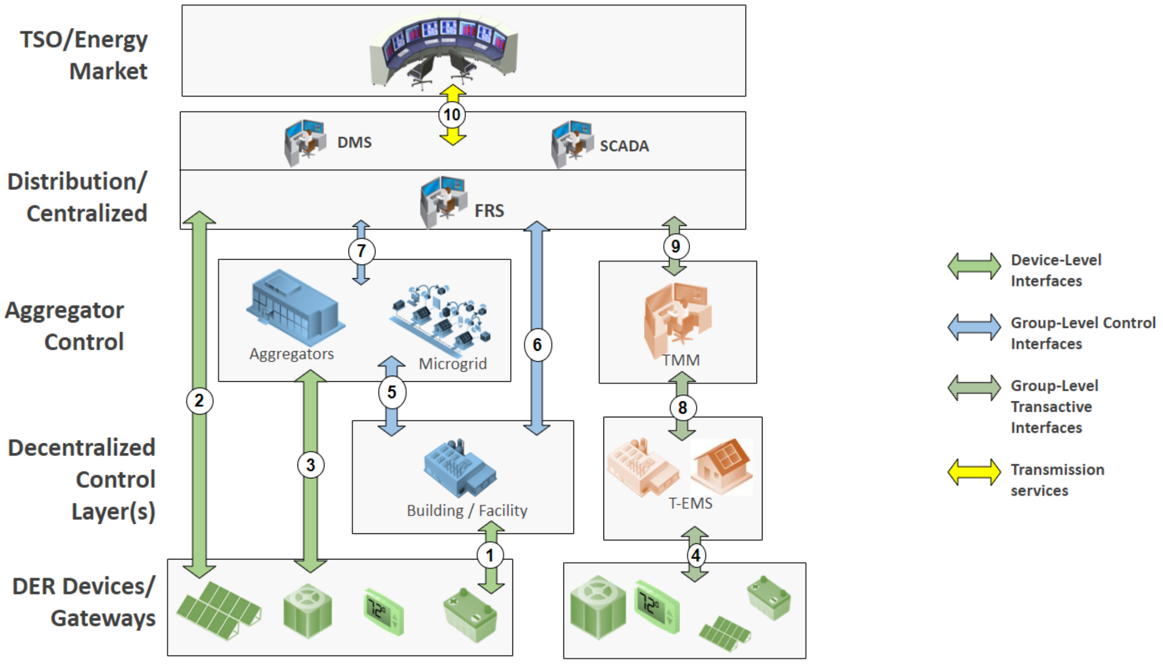
- Provide aggregated transactive information to the FRS
- Dispatch resources after receiving commands from the FRS



Project Tasks

6. Develop a communications architecture to support implementation of FAST-DERMS

- Complex communication landscape across multiple layers
- Standard based
- Interoperability
- A communications system design document is under development

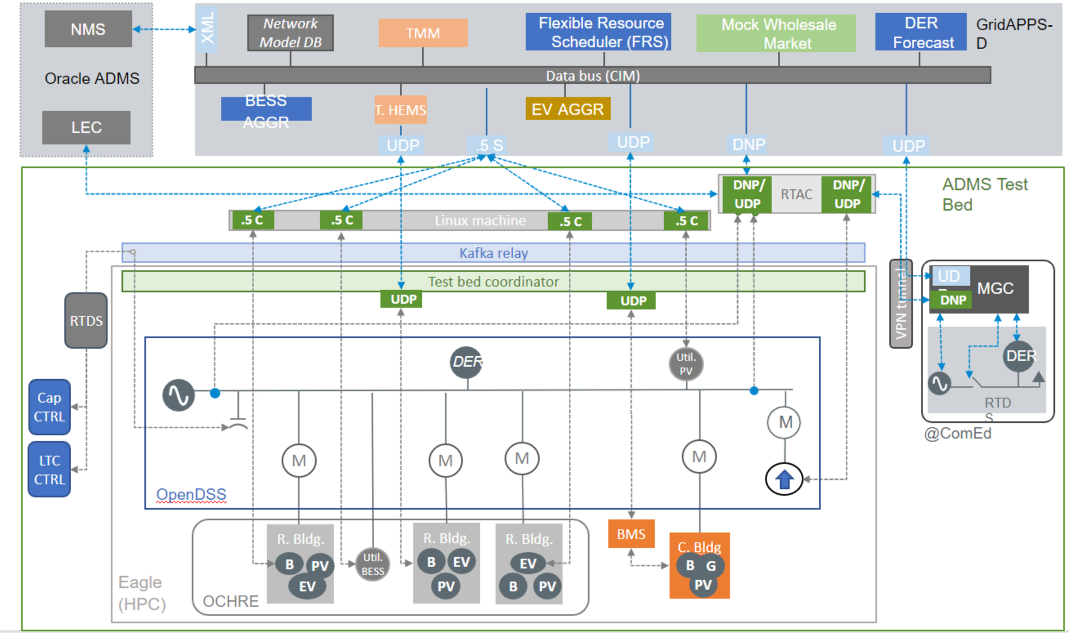


Project Tasks

7. Implement FAST-DERMS on the GridAPPS-D and ESIF ADMS testbed platforms

8. Demonstrate and characterize FAST-DERMS using GridAPPS-D and the ADMS test bed

- NREL ADMS test bed – network and devices
- GridAPPS-D – control functionalities
- Oracle ADMS – existing ADMS
- Final demo on SDG&E feeder

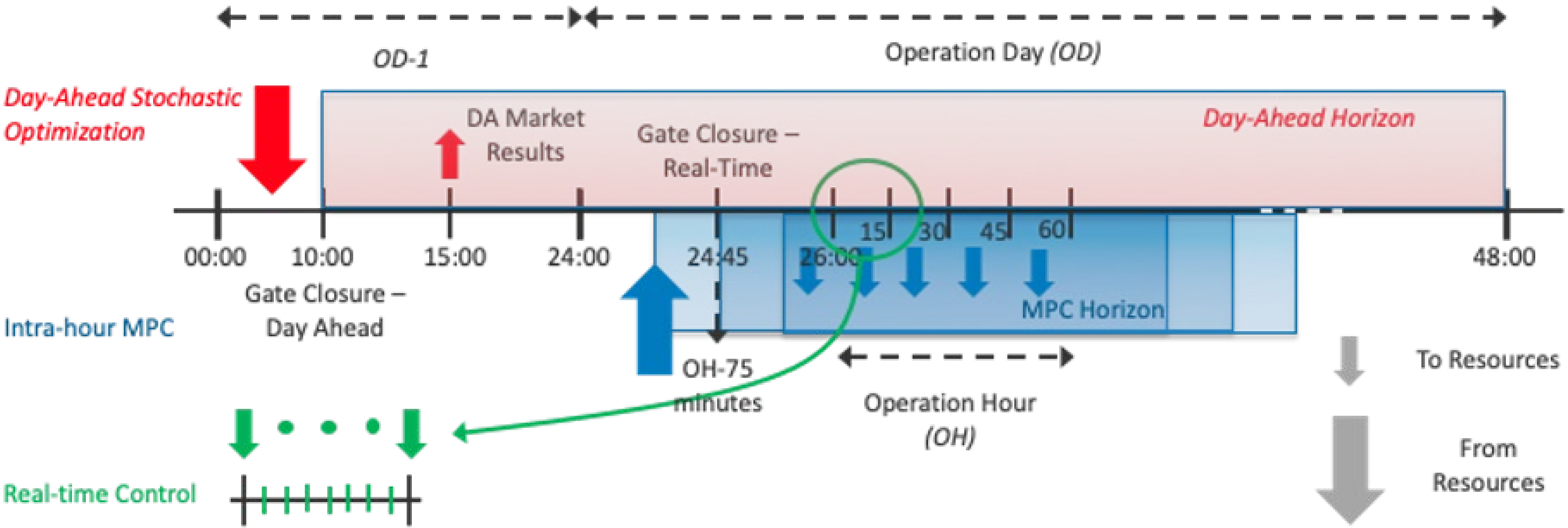


Flexible Resource Scheduler

Three-Level Hierarchy

- Three-level temporal hierarchy of control to align with wholesale market timelines
  - Day-Ahead Stochastic Optimization
    - Generate hourly network-level energy and reserve offers to wholesale market for the next day via scenario-based stochastic optimization
  - Intra-hour Model Predictive Controller (MPC)
    - Meet day-ahead market award obligations and/or adjust position in real-time markets
    - Allocate resource response for real-time controller
    - 4-hour rolling horizon optimization, run every 15 minutes
  - Real-time Control
    - Manage the difference between TSO dispatch and measured power flow at the substation
    - Dispatch signal from TSO disaggregated based on allocation outcomes in MPC
    - One-way communication to DER, primary feedback from substation meter

FRS Timeline



Day-Ahead Stochastic Optimization

- Approach: scenarios-based stochastic optimization
- General form:

$$
\begin{aligned}
&\min_{u(t)} E\left[\text{Total Cost}\right] \\
&\text{subject to: } \forall d \in N_{scenarios} \\
&\qquad \left[\text{DER Power (P \& Q) and Energy Constraints}\right]_d \\
&\qquad \left[\text{Linearized AC Power Flow}\right]_d \\
&\qquad \left[\text{Power System Constraints (Voltage and Thermal)}\right]_d \\
&\qquad \left[\text{Constant Substation Energy and Reserve Offers}\right]_d \\
&\qquad \left[\text{Minimum distribution system cost recovery}\right]_d
\end{aligned}
$$

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

Day-Ahead Stochastic Optimization

- Random variables:

What	Symbol	Number
Electricity Prices	$\Pi_{e,t}$	T
Reserve Prices - Up	$\Pi_{r,up,t}$	T
Reserve Prices - Down	$\Pi_{r,dn,t}$	T
Nodal Load - Real Power	$P_{i,l,t}$	$T * N_{bus}$
Nodal Load - Reactive Power	$Q_{i,l,t}$	$T * N_{bus}$
DER Max Power	$P_{max,DER,t}$	$T * (N_{PV} + N_{EV} + N_{DR})$
DER Min Power	$P_{min,DER,t}$	$T * (N_{EV} + N_{DR})$
DER Max Energy	$E_{max,DER,t}$	$T * (N_{EV} + N_{DR})$
DER Min Energy	$E_{min,DER,t}$	$T * (N_{EV} + N_{DR})$
EV Energy Connectivity Change	$\Delta E_{conn,EV,t}$	$T * N_{EV}$
DR Environmental Loss Parameter	$\alpha_{DR,t}$	$T * N_{DR}$
DR Inefficiency Parameter	$\beta_{DR,t}$	$T * N_{DR}$

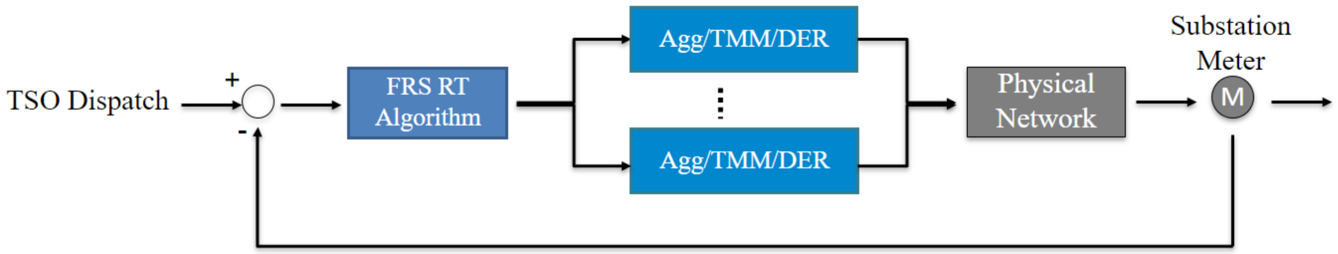
Table 1: Random variables and the number of instances

- Potentially large number of scenarios

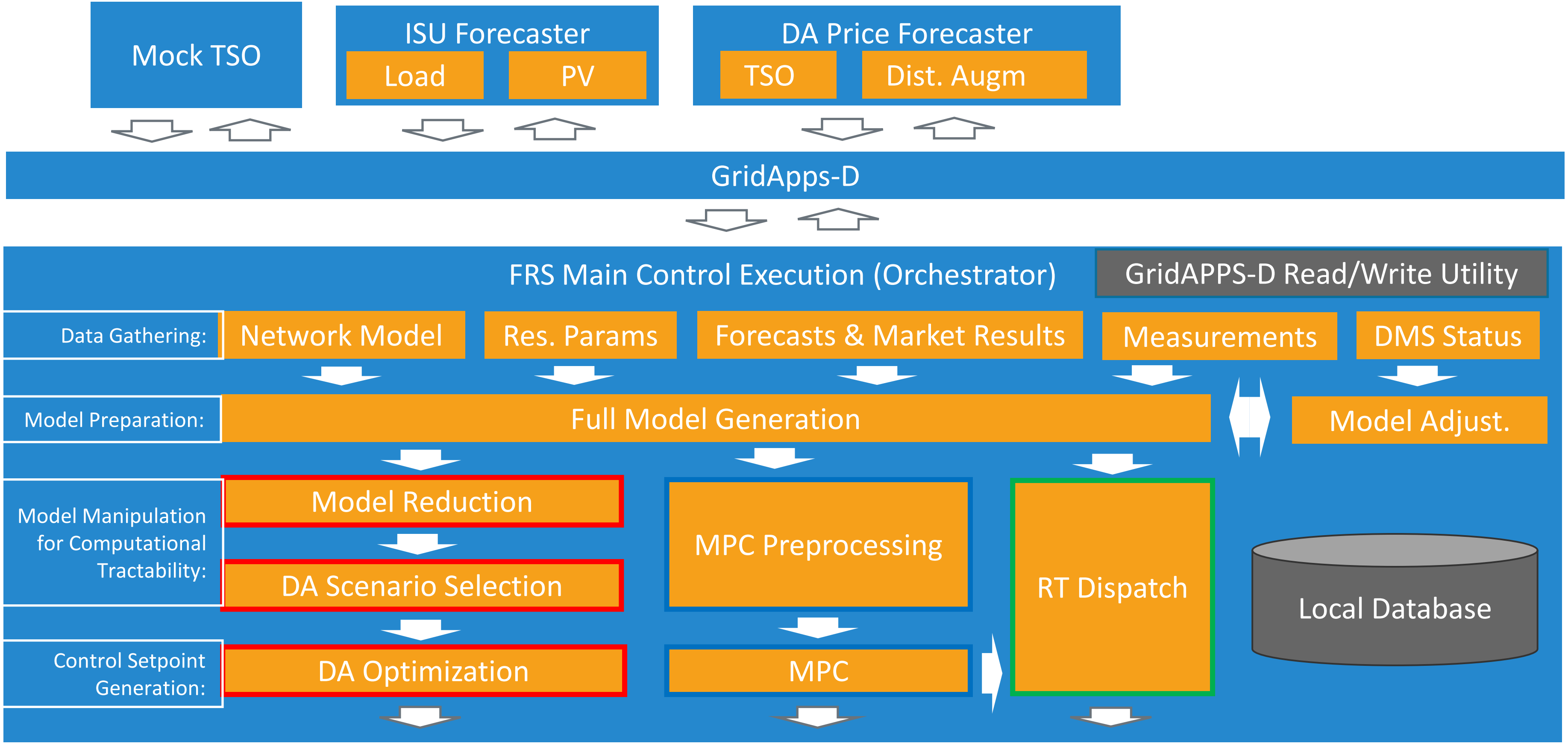
Intra-Hour MPC and Real-Time Control

- Intra-hour MPC
  – Objective: substation power setpoint deviation + regularization on battery and reserve
  – Approach: deterministic optimization with additional reserve requirement

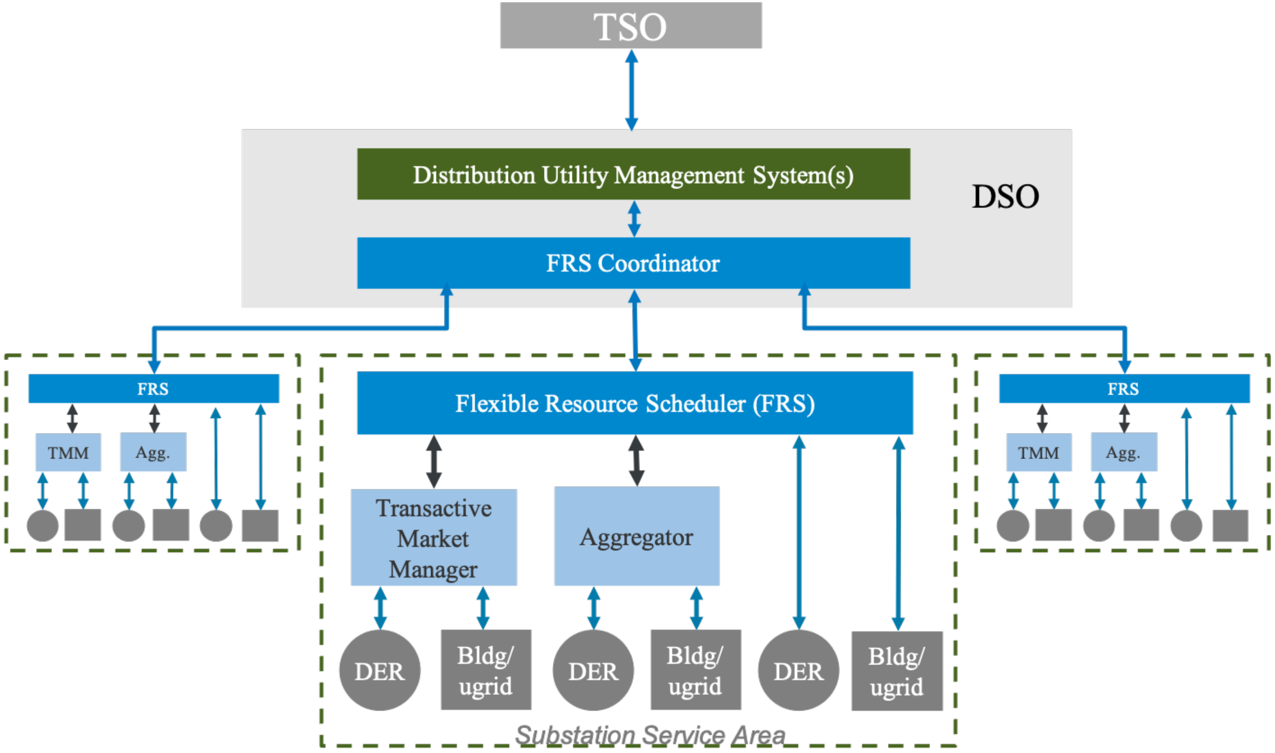
- Real-time control
  – Simplicity is key: FRS intends to primarily provide one-way communications in real time to DERs and aggregations
  – Dispatch signal from TSO disaggregated based on allocation outcomes in MPC



FRS Software Modules



Summary



1. Architecture
2. Control and optimization
3. Quantify flexibility
4. Anomaly detection and adaptive control
5. Transactive control architecture
6. Communications architecture
7. Implementation
8. Demonstration

Thank you!

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