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A Co-Simulation Approach for modeling Transmission – Distribution – Microgrid - DER

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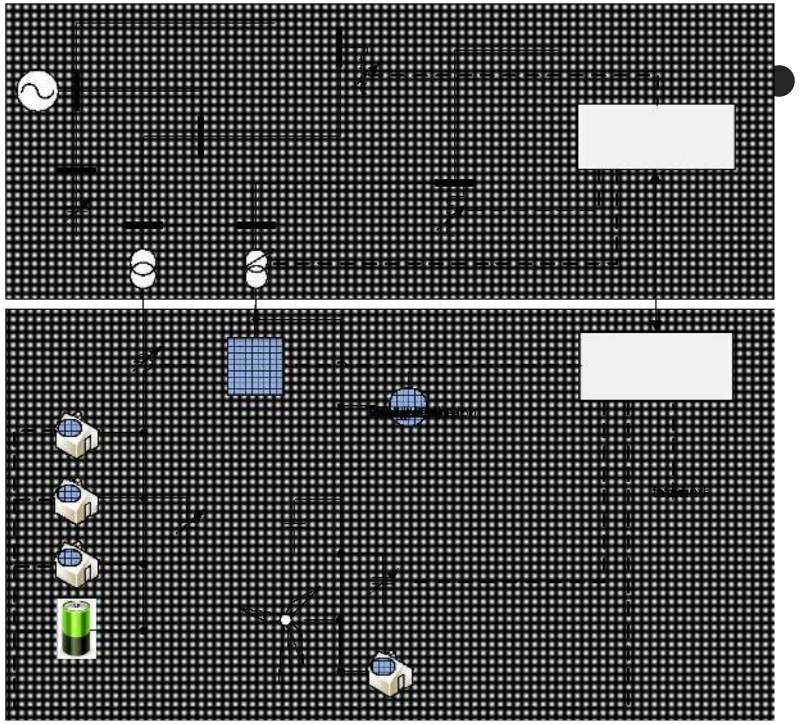
GridWrx Lab

Technology Overview

Challenges

- Voltage regulation at subtransmission impedes solar penetration.
- Regulation devices are uncoordinated, unable to cope independently with system net load changes.



Solutions

- Develop a Coordinated Real-time Sub-Transmission Volt-Var Control Tool (CReST-VCT):
  - autonomous and supervisory control via flexible algorithm
  - co-optimization of distribution and subtransmission scales
- Develop an Optimal Future Sub-Transmission Volt-Var Planning Tool (OFuST-VPT):
  - Determine the size and location of new reactive compensation equipment needed to integrate high penetration of photovoltaic (PV) generation.
  - Consider the coordination achieved by CReST-VCT.

Outcomes

- High penetration of PV (100% of substation peak load, without violating voltage requirements)
  - Allow utilities to meet ANSI, IEEE, and NERC standards.
- Planning and operational support to utilities
  - Reduce interconnection approval time and cost.

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Technical Approach 1: Faster-than Real-time

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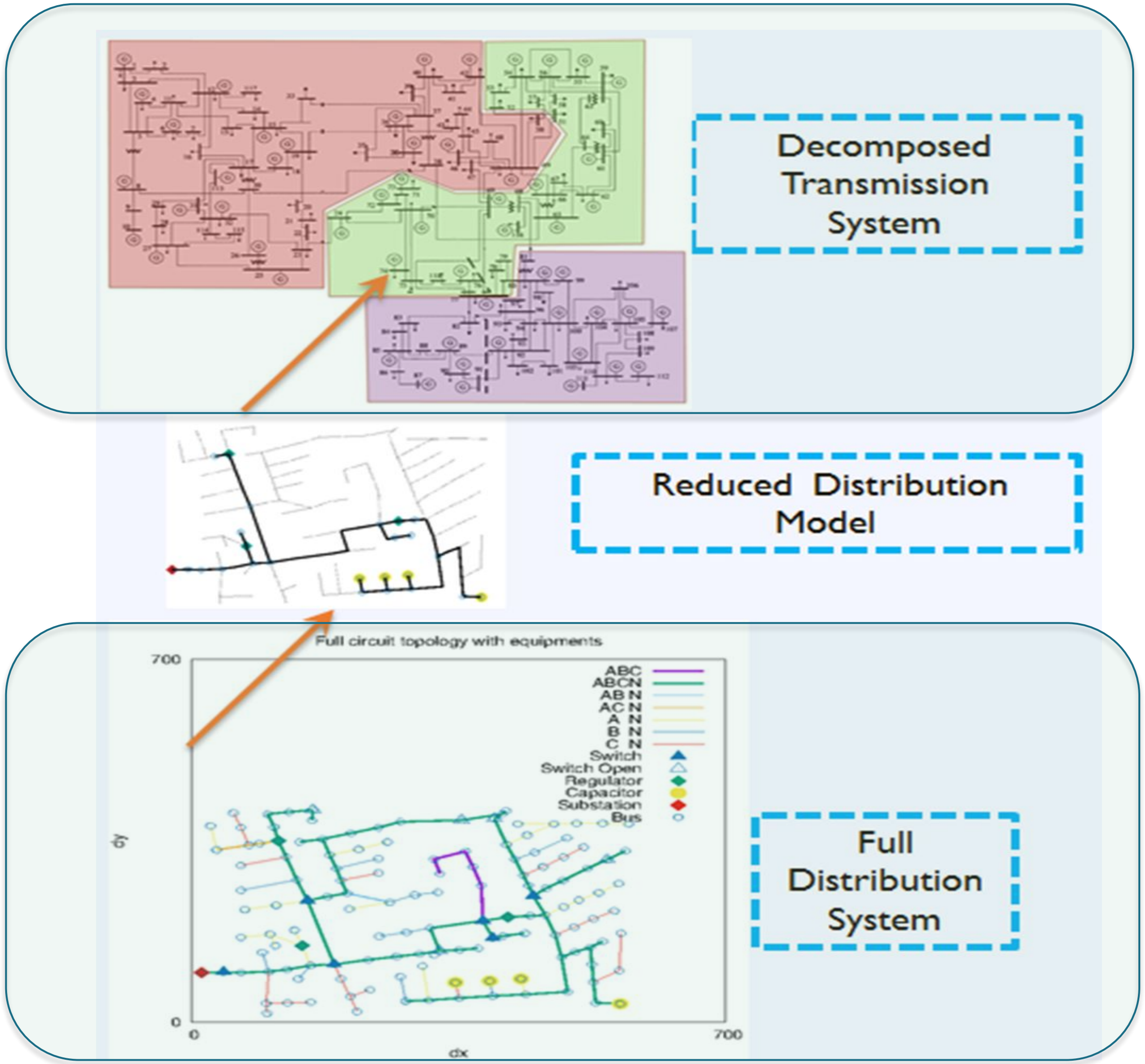
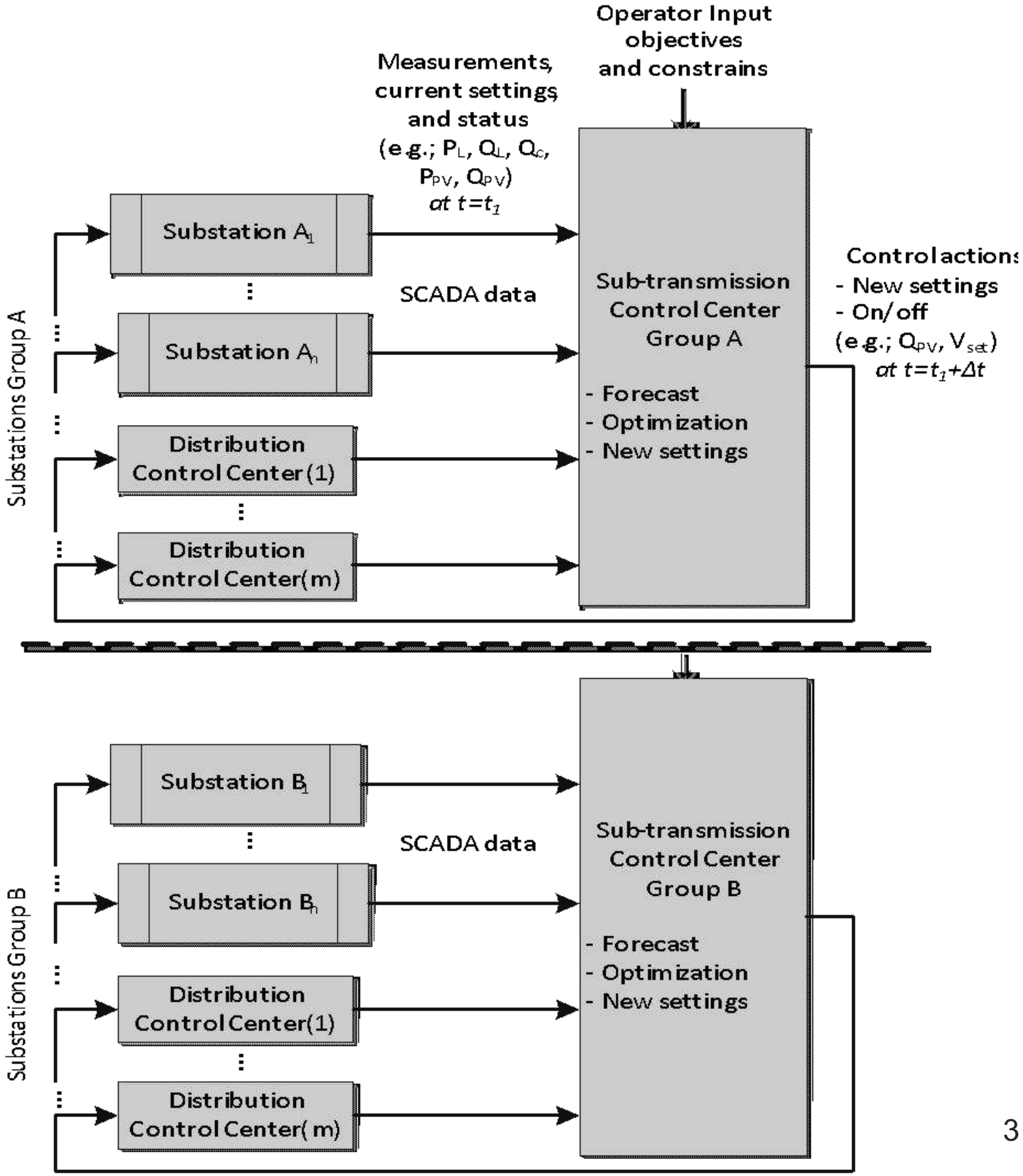
Co-Optimization of Transmission and Distribution Voltage





Transmission Side Optimization Objectives

Transmission AC Optimal Power Flow for Reactive Power Optimization

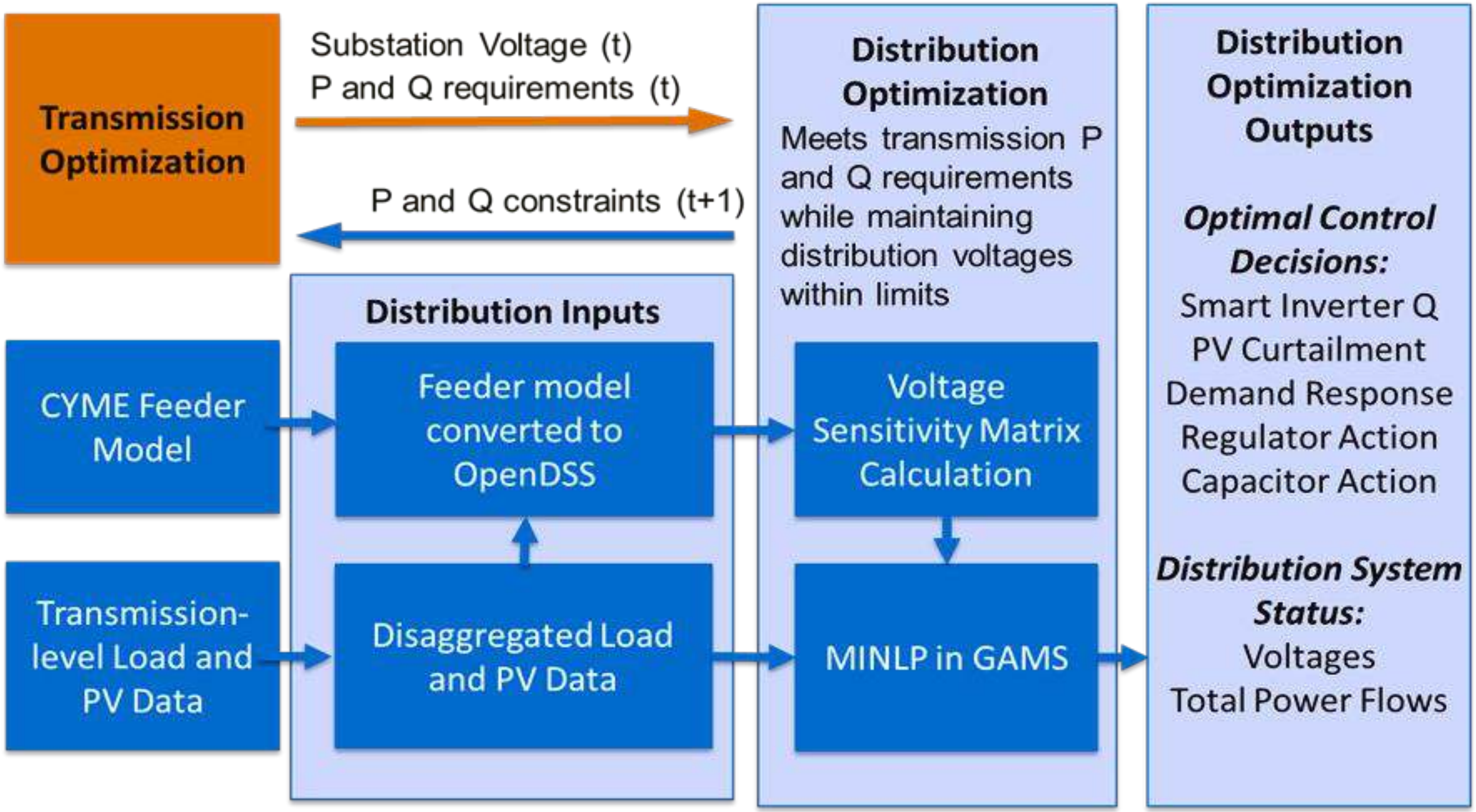
- **Objective function:** minimize weighted sum of
  - load bus voltage deviation from target value
  - transmission losses
  - capacitor bank switching
  - curtailment of controllable distributed solar output
  - use of demand response

- **Constraints:**

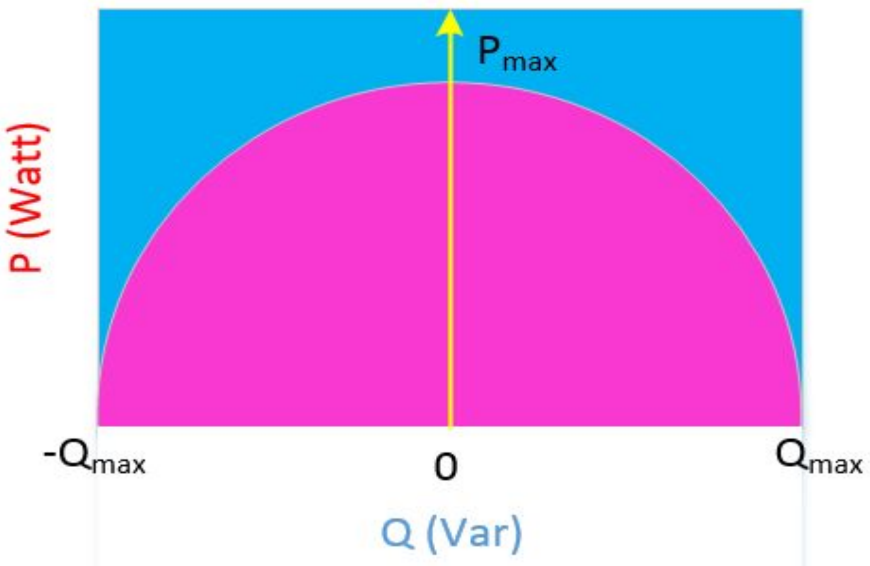
Subject to
  - AC power flow balance on each bus
  - power plant scheduled real power, except on distributed slack
  - power plant scheduled voltage and reactive power limits
  - load real and reactive power
  - distributed solar real power output
  - bounds on reactive power from distributed solar

- **Output variables:**
  - reactive power requirements from distributed PV at each substation
  - reactive power form capacitor banks at different substation
  - real/reactive power required from demand response
  - real power curtailment from PV

Distribution Side Optimization Objectives



Smart PV Inverter Modeling



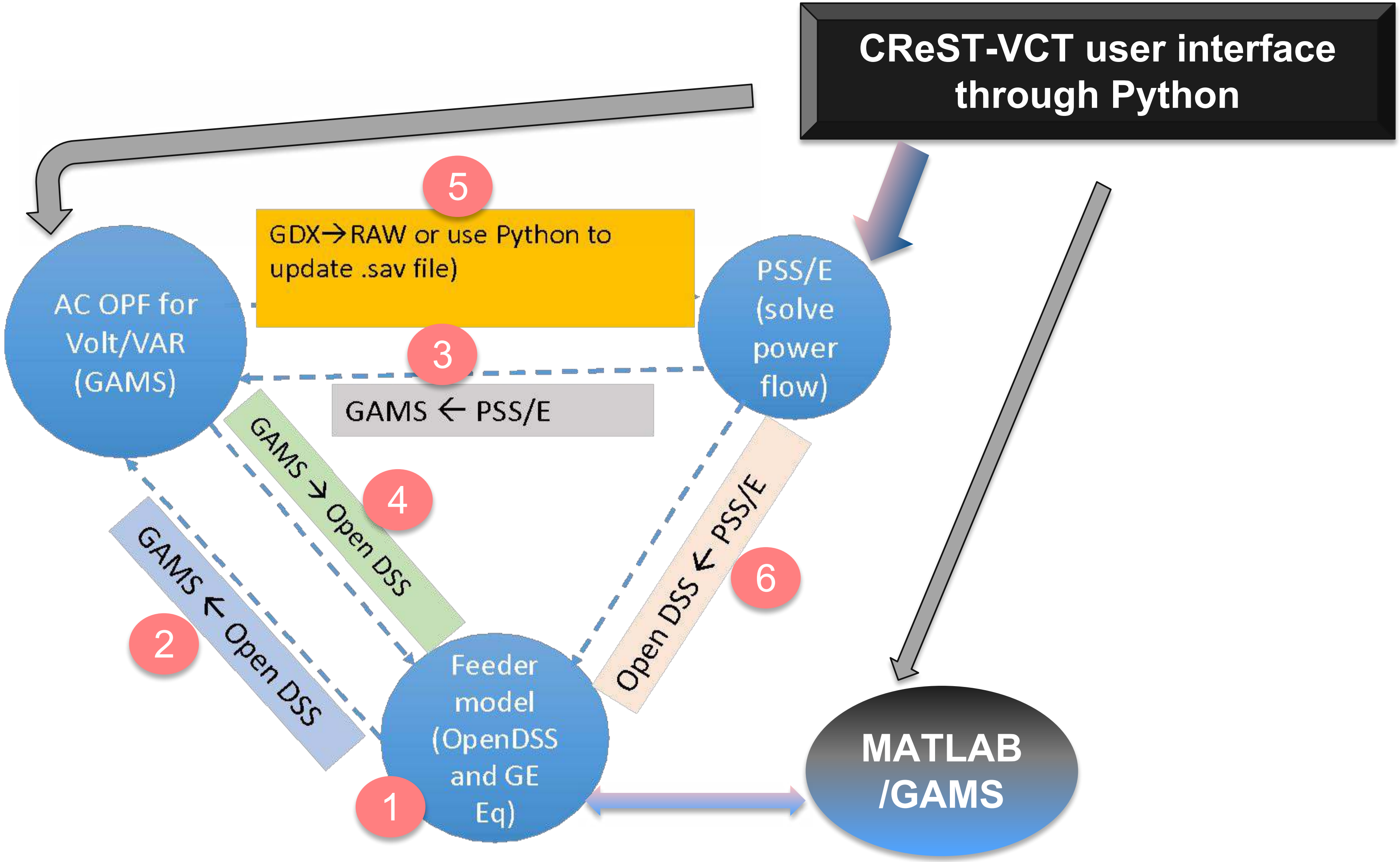
$$\frac{P^2}{P_{\max}^2} + \frac{Q^2}{Q_{\max}^2} \leq 1$$

$$Q_{\max} = kP_{\max}$$

k is the **improved factor** for reactive power constraint, **1.1** for a normal **IGBT-based** PV inverter

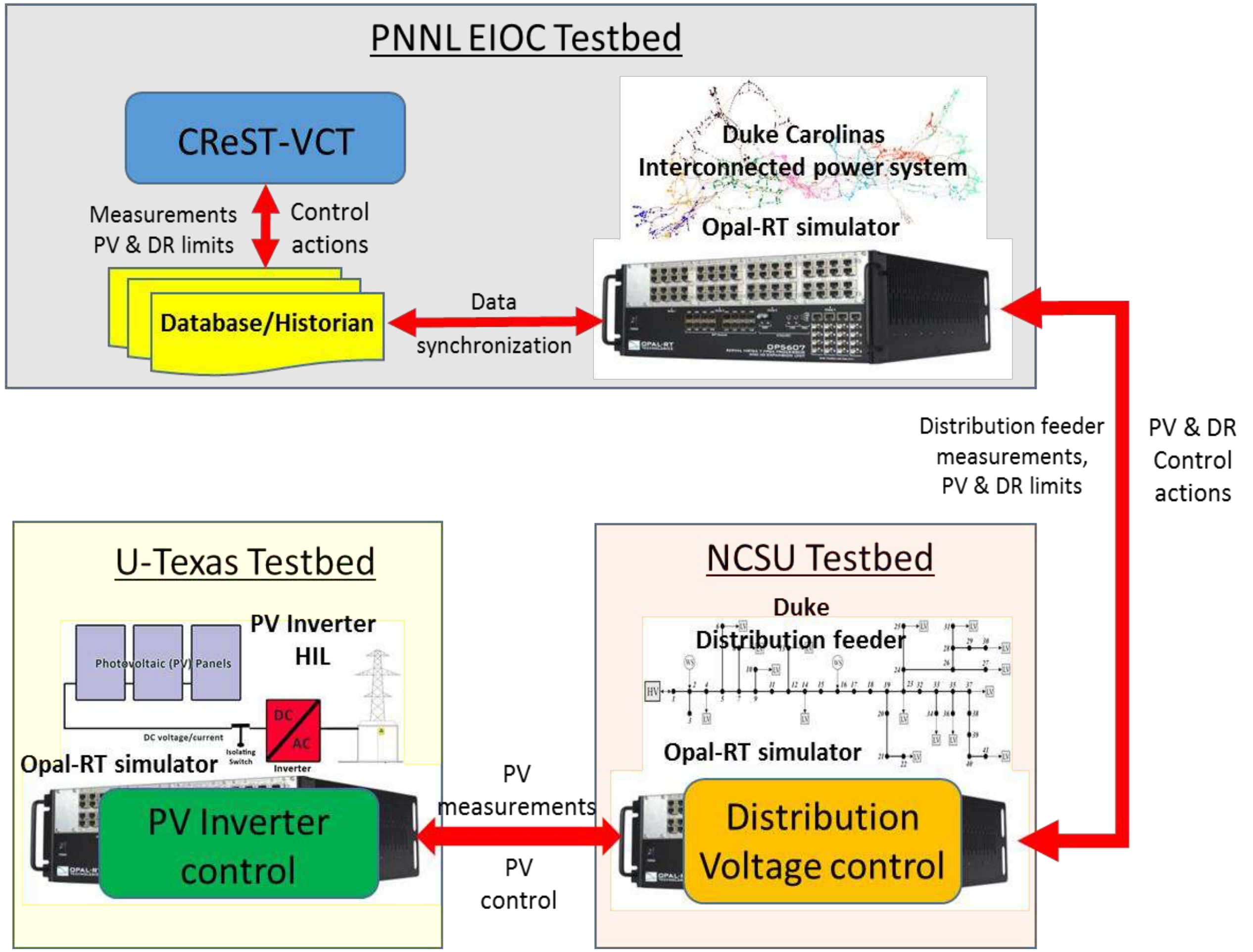
- *k* should be adjusted based on power electronics devices and modulation method.
- The *P*/*Q* constraint is also dependent on the filter and DC capacitor design.
- During nighttime when *P* = 0, reactive power injection results in additional power losses that might become an economic constraint.
- Three different reactive power regulation modes can be provided by the inverter (constant *Q*, constant Power Factor, and volt-var). We are using constant *Q* that is obtained from the optimization engine.

CReST-VCT Control Flow



Technical Approach 2: Real-time, HIL

- Three hardware-in-the-loop (HIL) test systems have been developed to test the performance of
  - CReST-VCT developed at PNNL
  - Distribution voltage control based on PV control and demand response at NCSU
  - PV control with smart inverters at UT-Austin
- An integrated HIL test system have been developed using an Opal-RT facility at each site via a selected communication protocol.



Real-time Hardware-in-the-loop Simulation

- What is **real-time**, **hardware-in-the-loop** simulation?
  - **Real-time:** Simulation time elapsed is the actual time elapsed
    - Matlab simulation runs either faster or slower than the actual time
  - **Hardware-in-the-loop: A piece of hardware is connected to the simulation platform**
    - As the simulation time of a real-time HIL test system is the same as the actual time elapsed, one can connect hardware (e.g., controllers, relays, batteries, PV inverters) to it and test their performance
  - Model **communication** protocols
  - Consider **both the steady-state and the dynamic** simulations
- Value of using real-time HIL simulation
  - A cheaper, safer, scalable, and controlled way of developing new control systems, and testing equipment.

HIL Simulation Lab Setup

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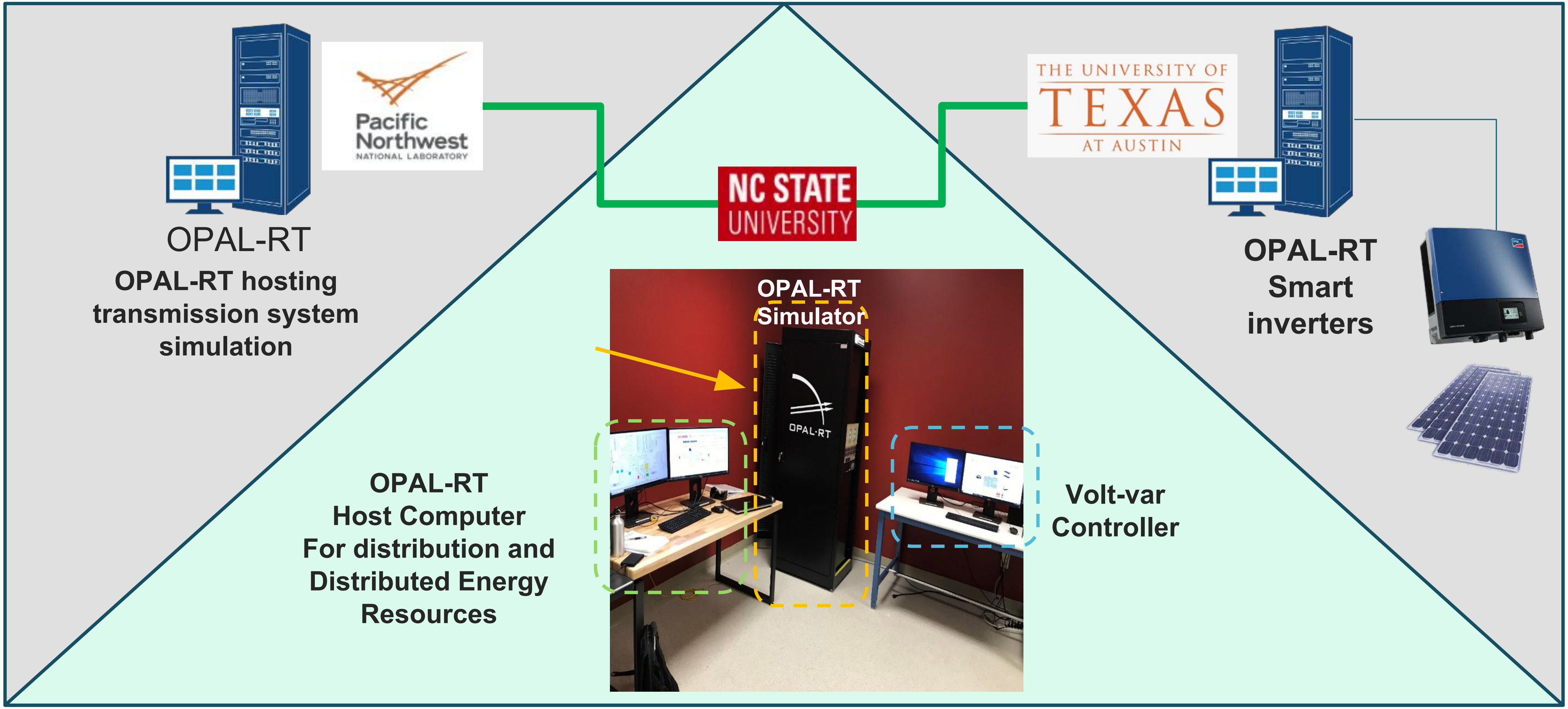

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Controller Interface Design

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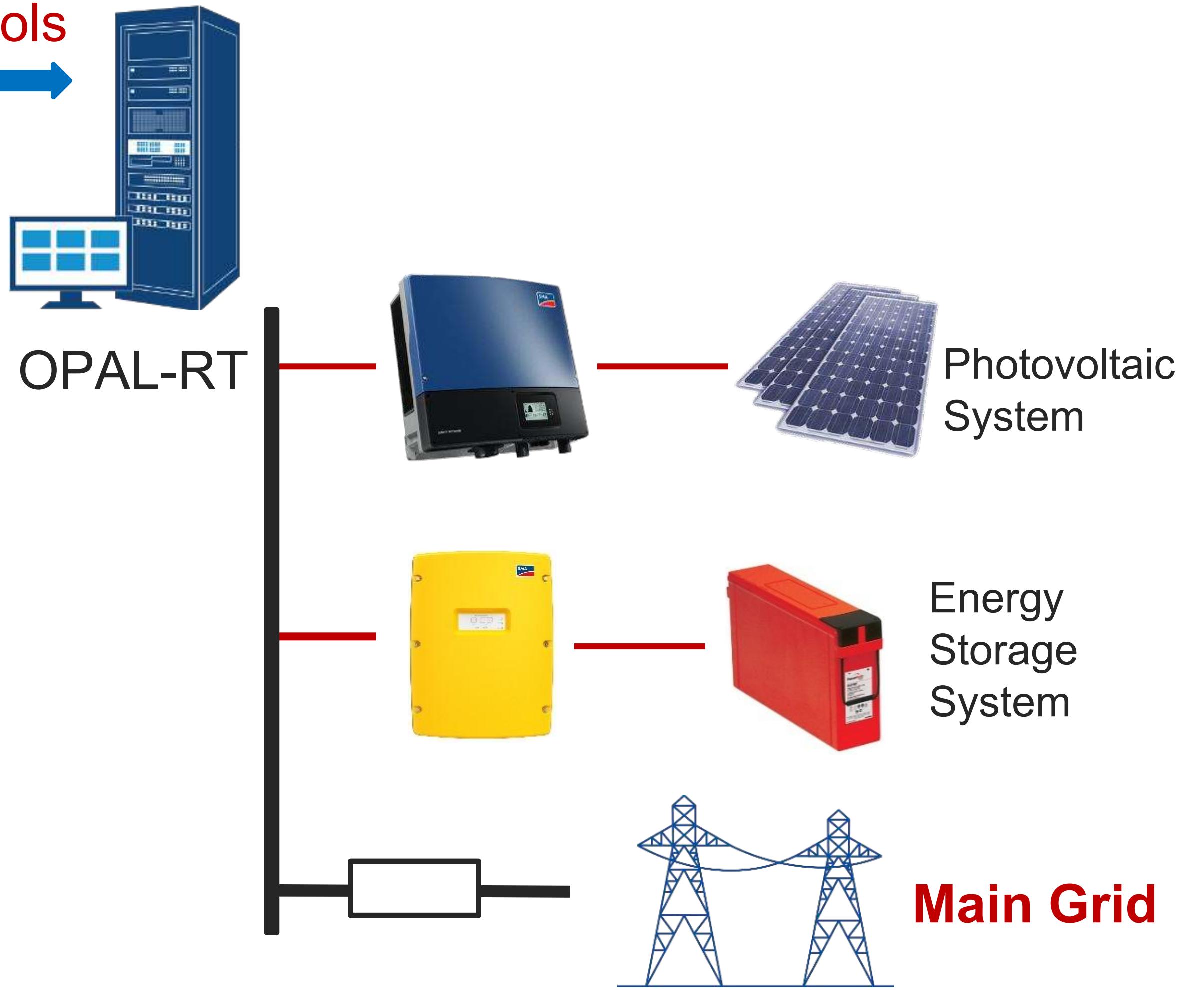
Communication Protocols

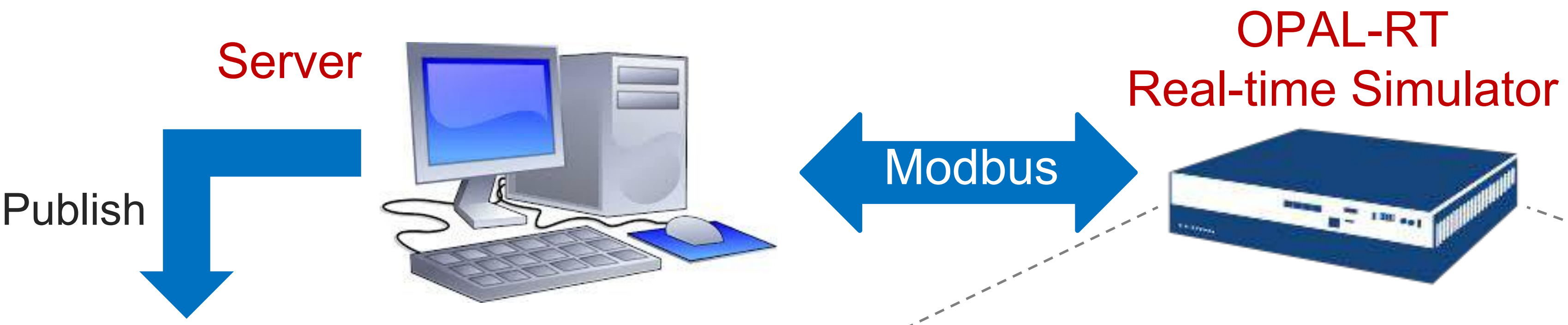
- Digital/analog I/O
- IEC 61850
- DNP3
- **Modbus**

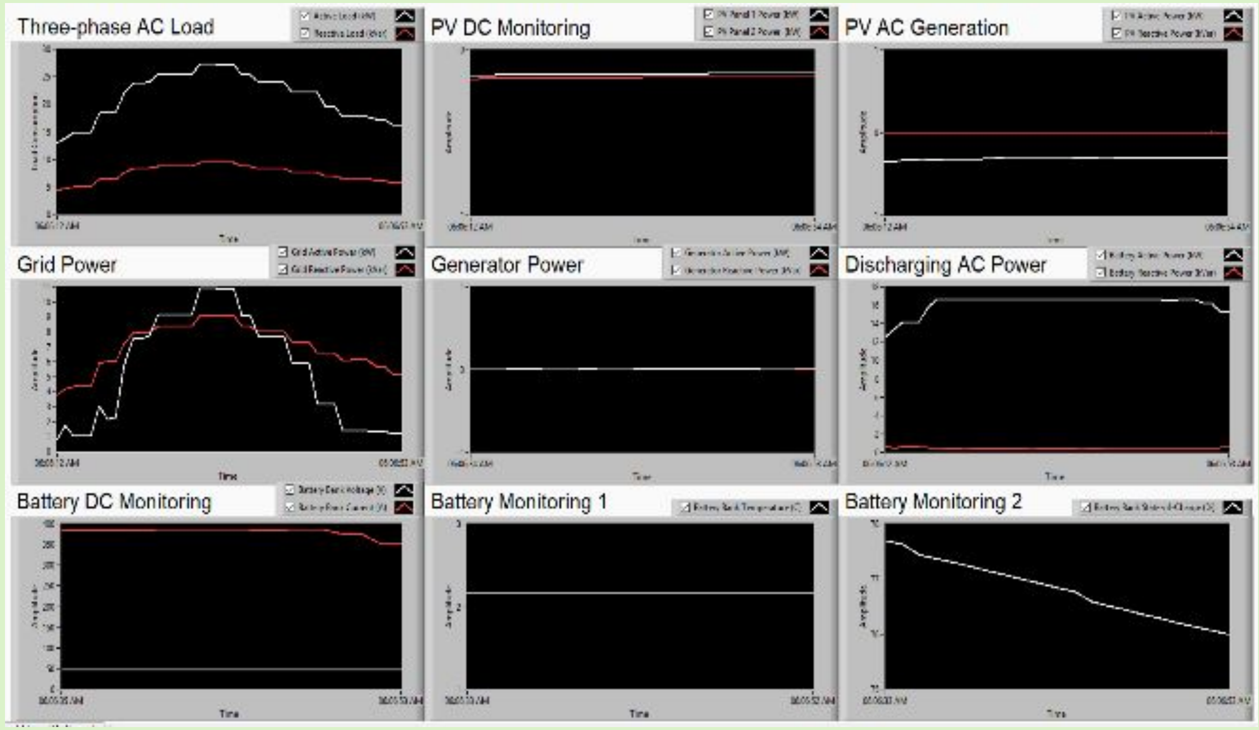


Remote Controller (Center)

- Control
  - Manual Control
  - Automated Control
  - Schedule and Dispatch
- Human–Machine Interface
  - SCADA System
  - Operation Dashboards

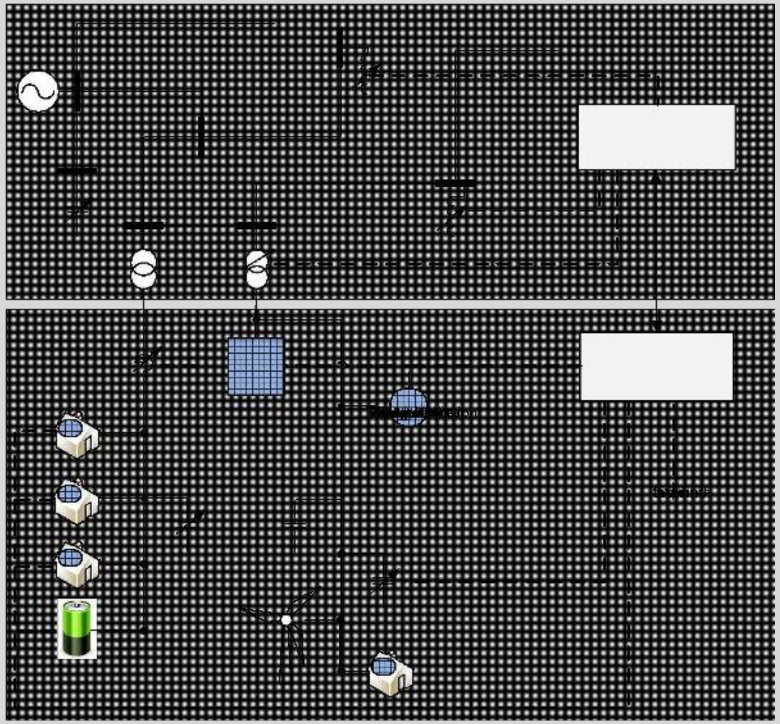
HIL Modbus-Based Web Interface





Web-based External Energy Management Interface

Hardware-in-the-loop Test Systems



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HIL Model and System Developed

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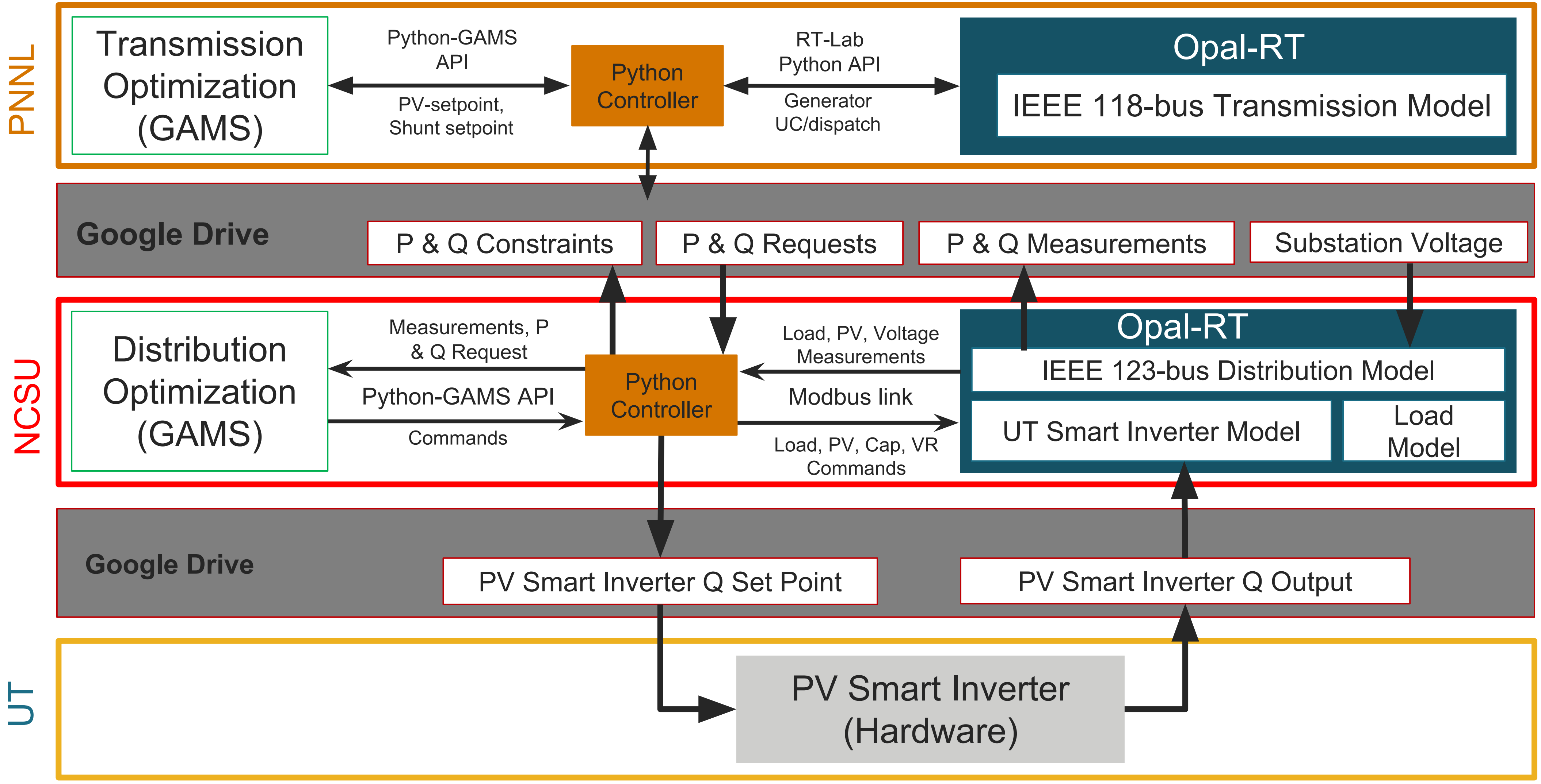
	Status	Use Case	Simulink Models	Notes
1. PV and PV inverter	X	X	X	100μs
2. Battery and Battery Inverter	X	X	X	100μs
3. Distributed Generator Model	X	X	X	100μs
4. Load Model	X	X	X	100μs
5. System Integration Functions	X		X	
Use case 1: Grid connected to off-grid	X	X		
Use case 2: Microgrid operation	X	X		
Use case 3: Reconnect to the main grid	X	X		
6. Communication layer simulation	X			ModBus
7. Web-based interface	X			LabView
8. Transmission system (118-bus)	X			10 ms
9. Distribution system model (123-bus)	X			10 ms

HIL Setup and Communication



Control Coordination Timeline

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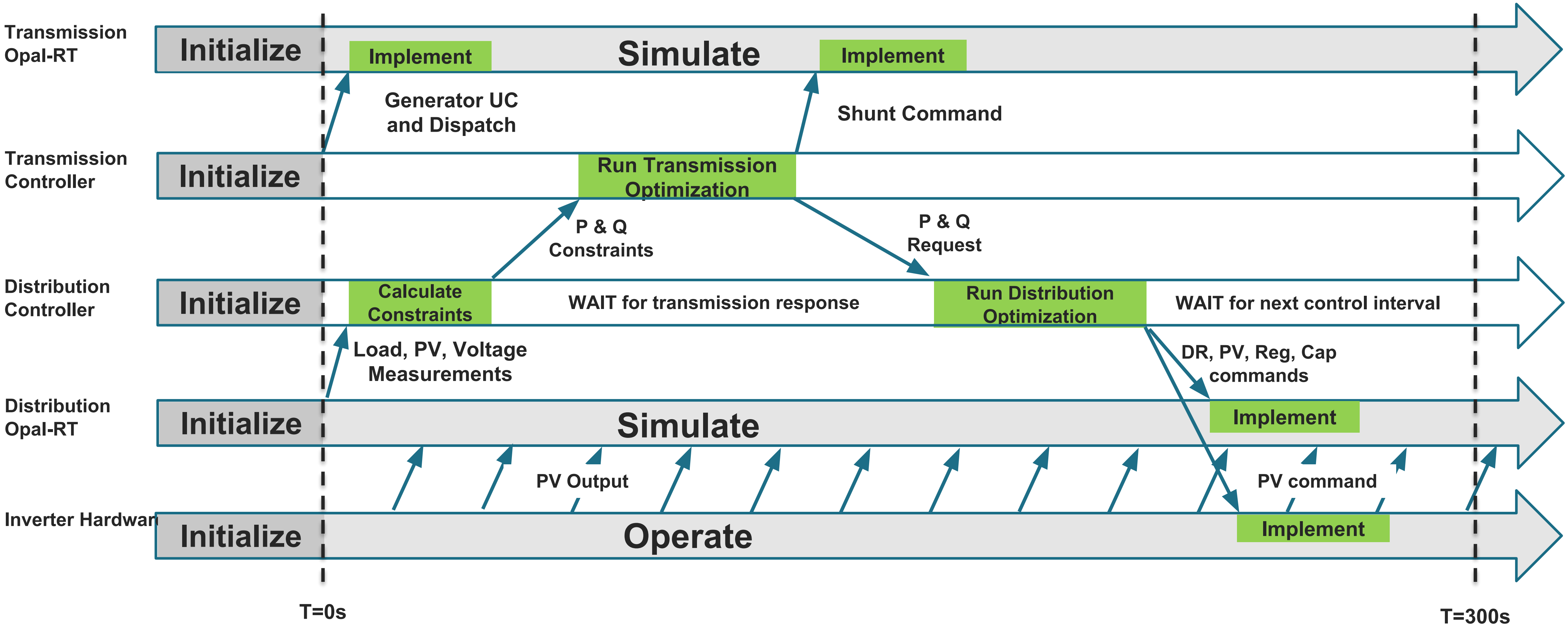

Co-Simulation Coordination Timeline

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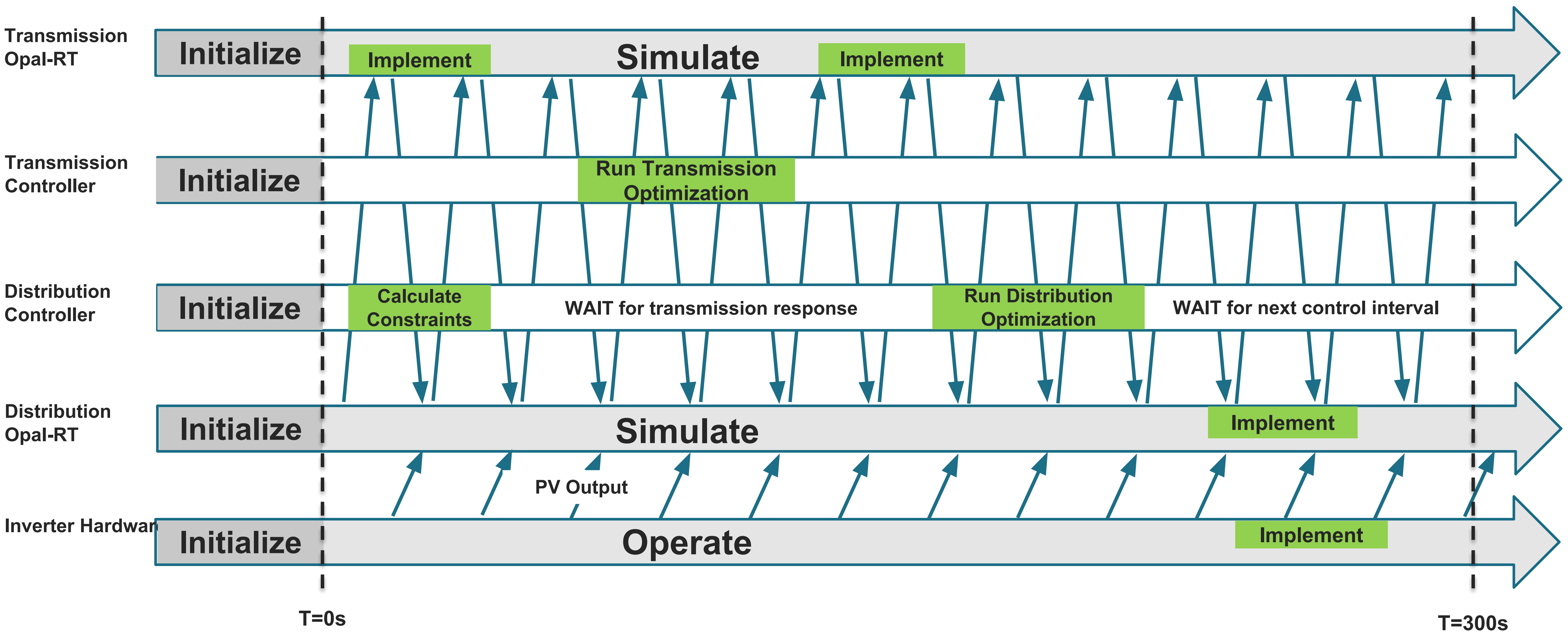

Co-Simulation Voltage Results

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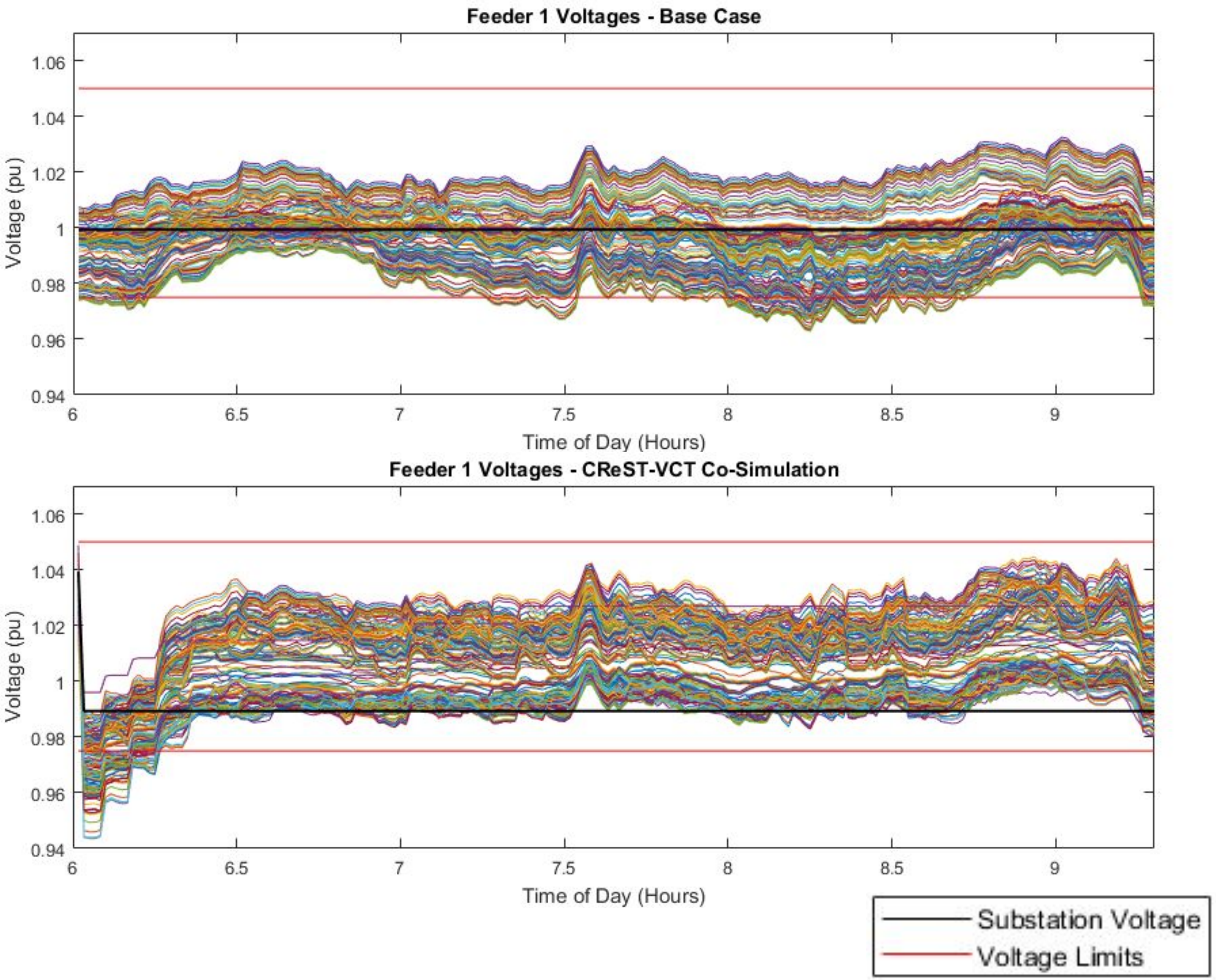

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Future Work

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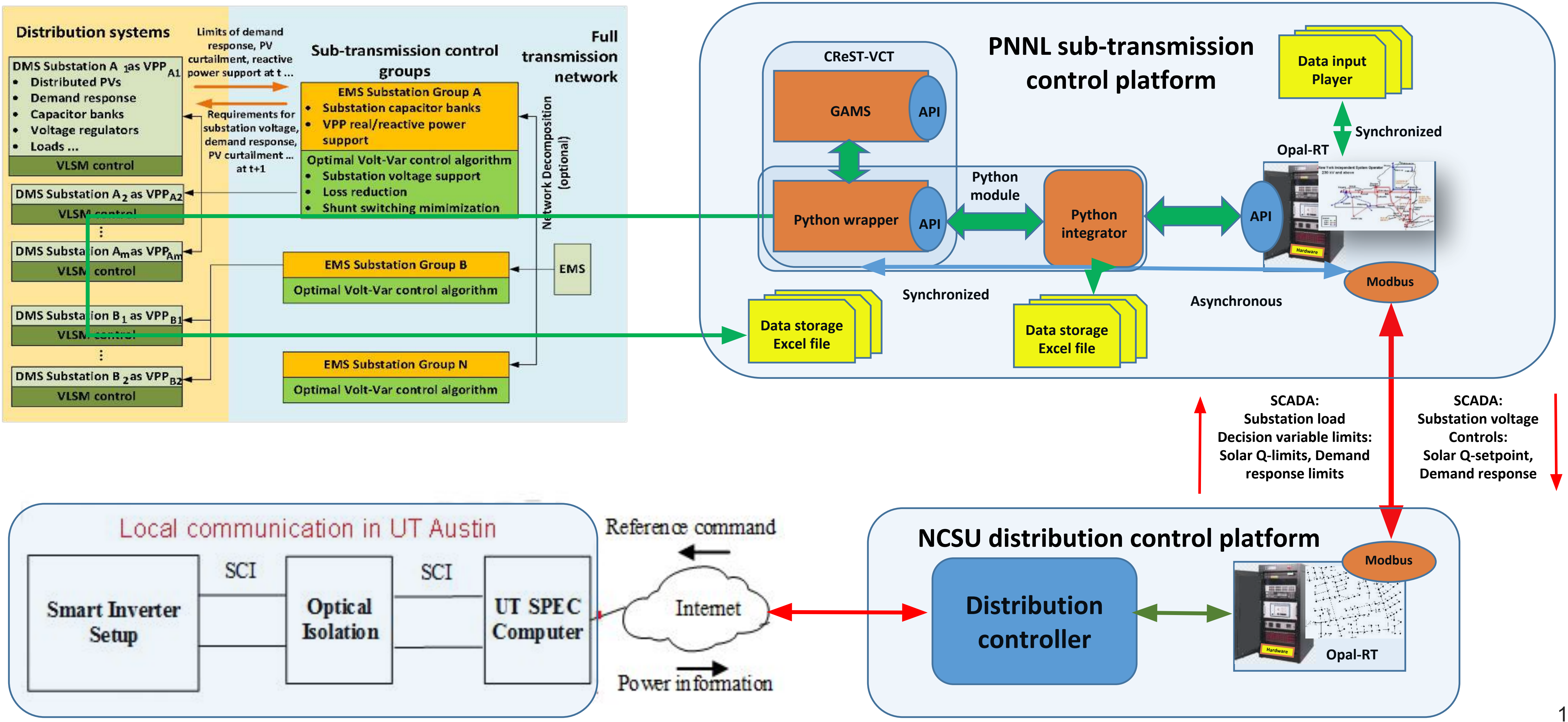
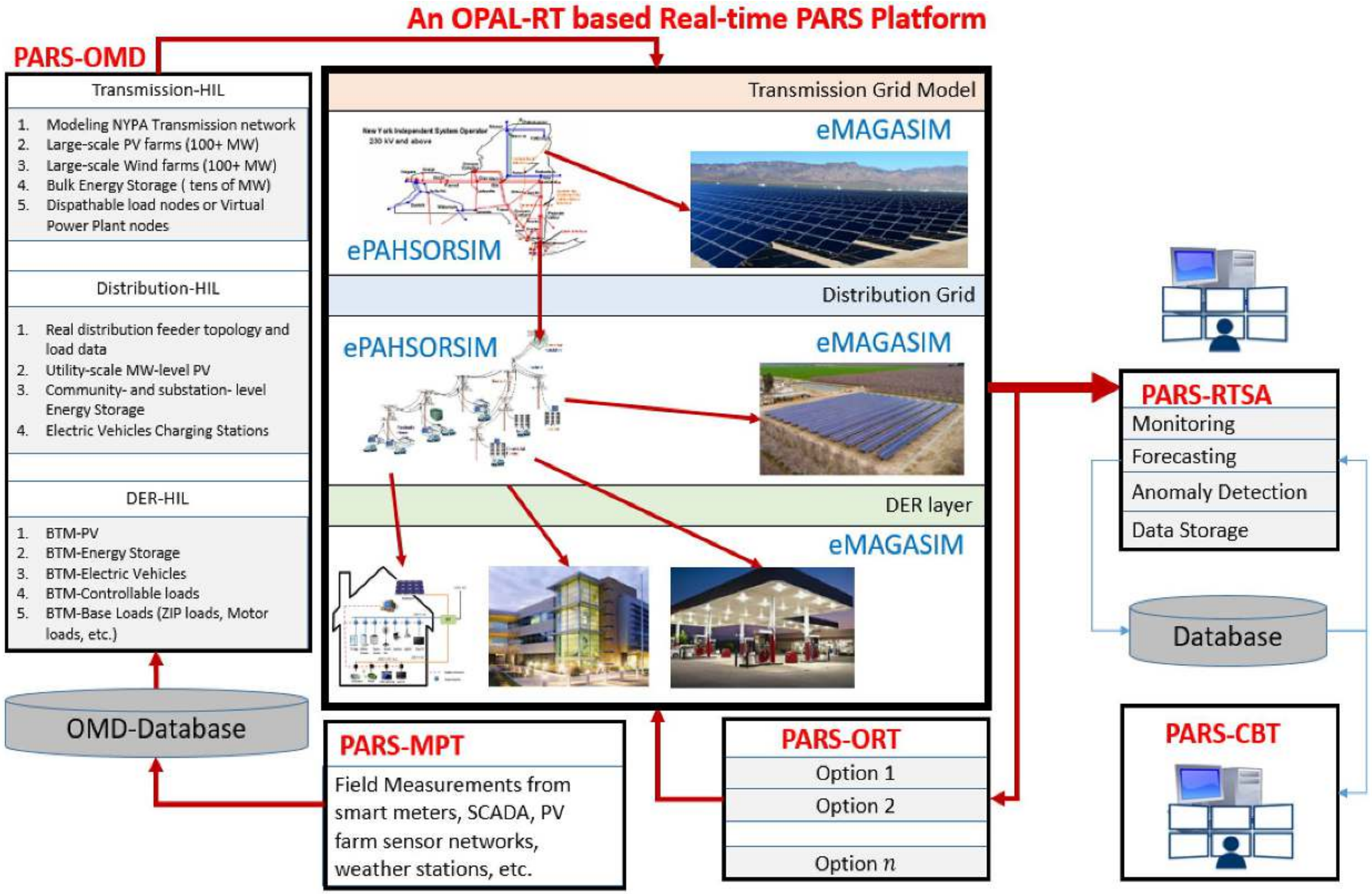
A universal co-simulation platform for multi-rate, multi-scale, multi-control mechanisms.



DOE SETO ASSIST Award

Photovoltaic Analysis and Response Support (PARS) Platform for Solar Situational Awareness and Resiliency Services



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Key Participants:

- NCSU Clean Tech
- Pacific Northwest National Lab
- OPAL-RT Corporation
- New York Power Authority
- Strata Soalr
- Roanoke Electric Cooperative

Federal funds: $3,180,000

Cost-share: $798,000

Total: $3,978,000

Acknowledgement

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Enabling High Penetration of Distributed PV via Optimization of Subtransmission Voltage Regulation

Clean Energy States Alliance (CESA) Webinar

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