Hierarchical Two-Level Voltage Controller using Synchrophasors for Southern California Edison

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Voltage Controller Objectives

- Aim to automate routine voltage dispatch duties of system operators. Closed loop controls.
- SCE a transmission operator in a deregulated market. SCE cannot change generator voltage schedules. SVCs at critical buses.
- Voltage schedules met by mostly switching discrete VAR devices: shunt capacitor and reactor banks, and transformer banks.
- Phased implementation over the next several years.

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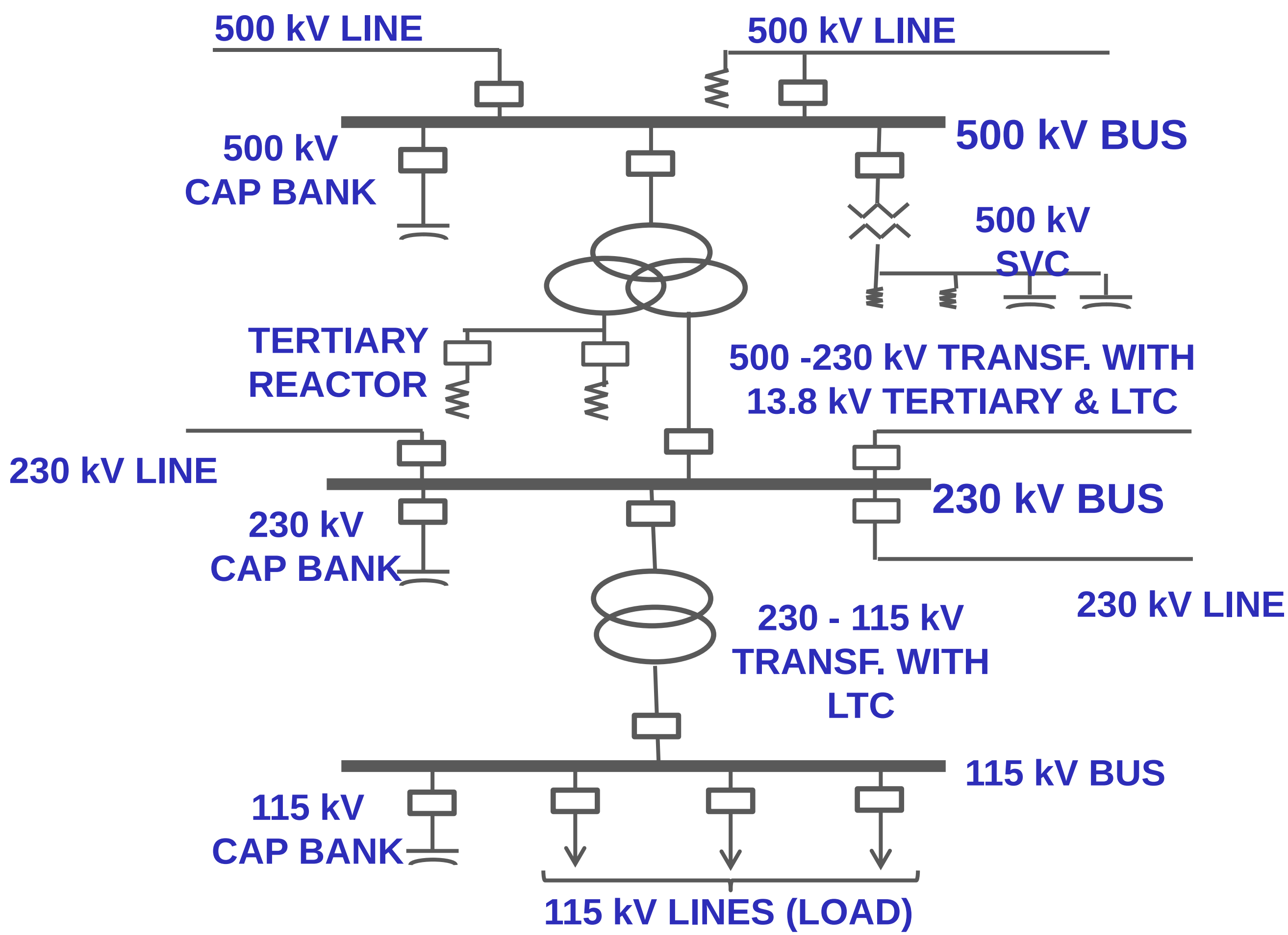
Typical SCE Bulk Substation



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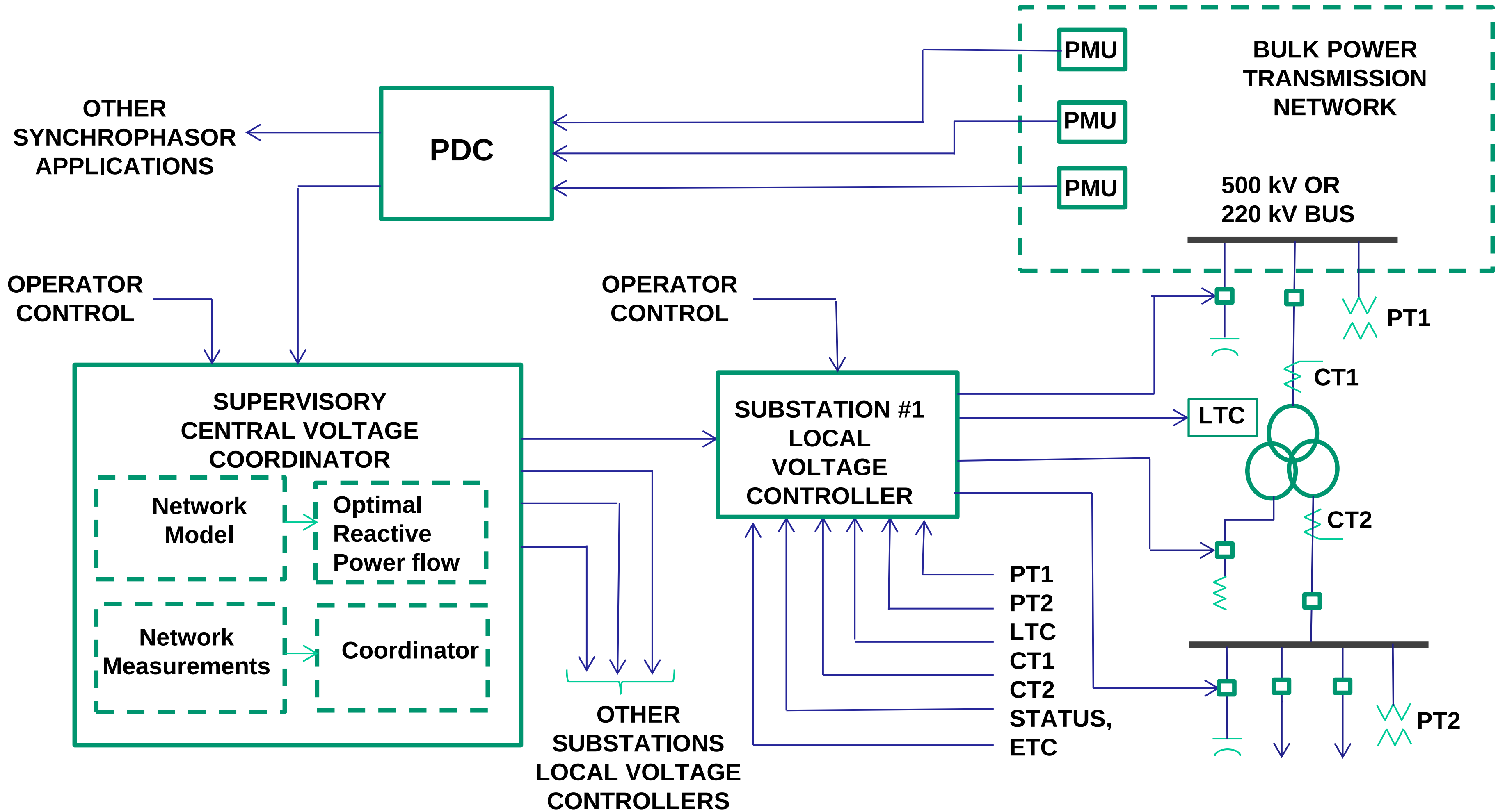
Controller Architecture



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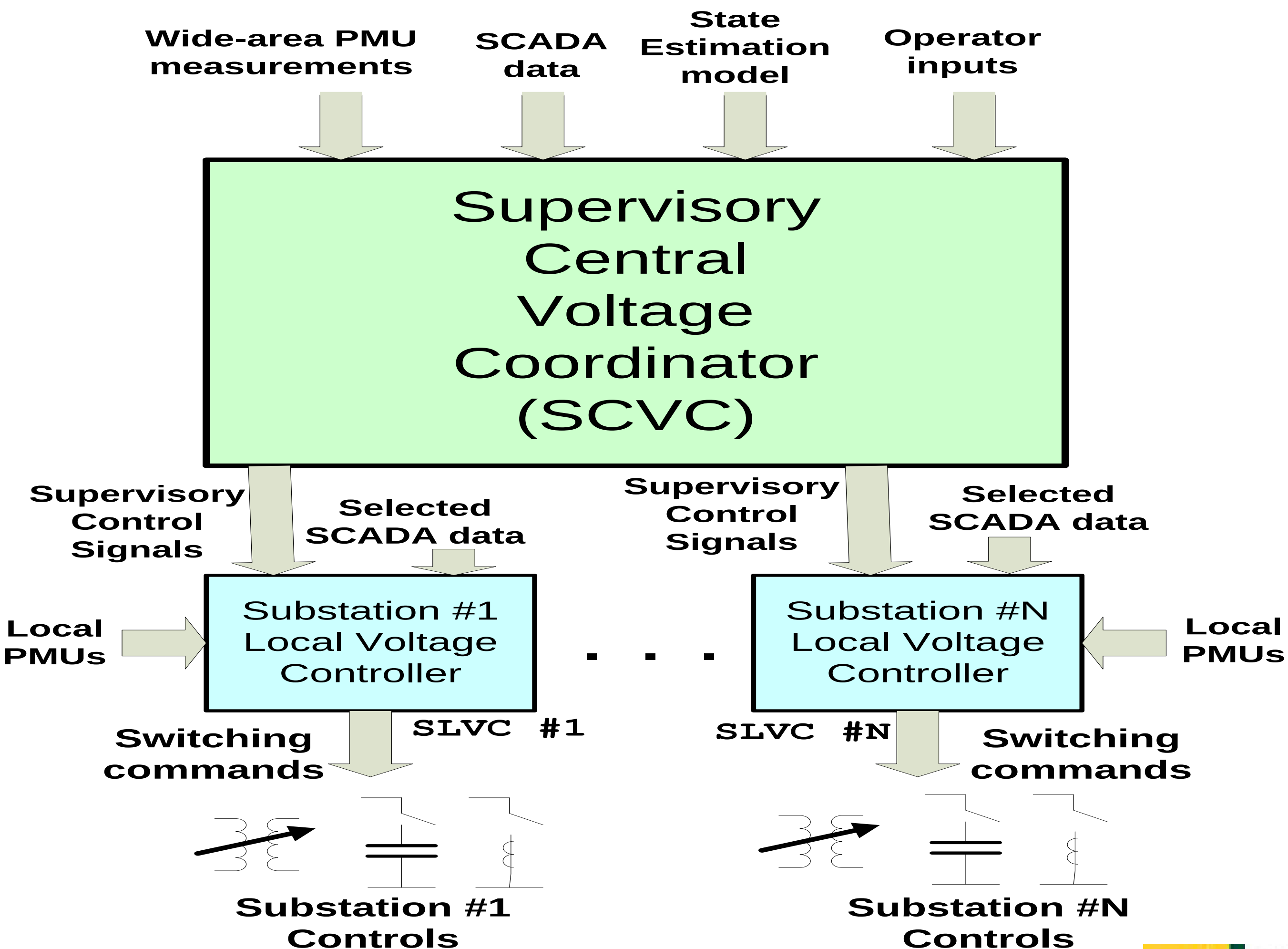
Controller Structure



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SLVC Controller Objectives

- **Substation Local Voltage Controller (SLVC)**
  - Maintain substation bus voltages by switching local VAR devices – transformer banks, capacitor banks and reactor banks
  - Maintain VAR output and VAR flow constraints
  - Minimize switching of VAR devices
  - Alerts and Alarms when nearing voltage insecurity
  - Lessens burden on substation operators

(continued)

SLVC Controller Objectives

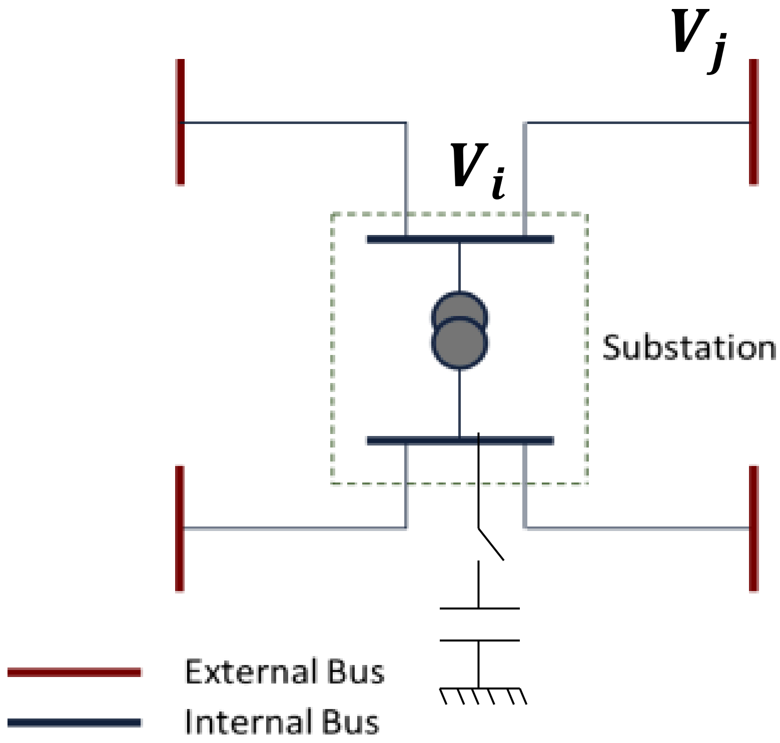
- **Substation Local Voltage Controller (SLVC)**
  - Switching decisions based on local substation PMU measurements – bus voltage phasors, current phasors, VAR flows, device status
  - Supervisory guidance from central coordinator – voltage schedules, SLVC enable/disable
  - Closed-loop monitoring of system conditions – corrective actions whenever needed

Substation Controller Modes

- **Slave Mode (Substation SVC in service)**
  - Maintain 115 kV and 230 kV bus voltages by switching local VAR devices – transformer banks, capacitor banks and reactor banks
  - Maintain 500 kV SVC VAR output within limits and other VAR flow constraints
- **Master Mode (SVC out of service)**
  - Maintain 115 kV, 230 kV and 500 kV bus voltages by switching local VAR devices – transformer banks, capacitor and reactor banks
  - Maintain VAR flow constraints
- **Automatic switching between Master and Slave Modes using SVC status. Manual override optional.**

Substation Local Power-flow

Bus voltages after switching?
Only local PMU measurements available.



Assume $\Delta V_j = \alpha_{ij}^{k} \Delta V_i$

$$\Delta Q_i = \sum_{j \in J_i} \left(\frac{\partial f_{ij}}{\partial V_i} \Delta V_i + \frac{\partial f_{ij}}{\partial V_j} \Delta V_j \right)$$

$$\Delta V = [B]^{-1} \Delta Q = [S] \Delta Q$$

Local Voltage Estimator (LVE) very effective.

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SCVC Controller Objectives

- **Supervisory Central Voltage Coordinator (SCVC)**
  - PMUs provide the system model (state estimation)
  - Optimize voltage profile towards minimizing VAR losses – convey schedules to substation SLVCs
  - Coordinate switching of substation SLVC controllers
    - Enable specific substation SLVCs as needed
    - Disable other substations to prevent hunting
  - Switch to centralized switching when system stressed

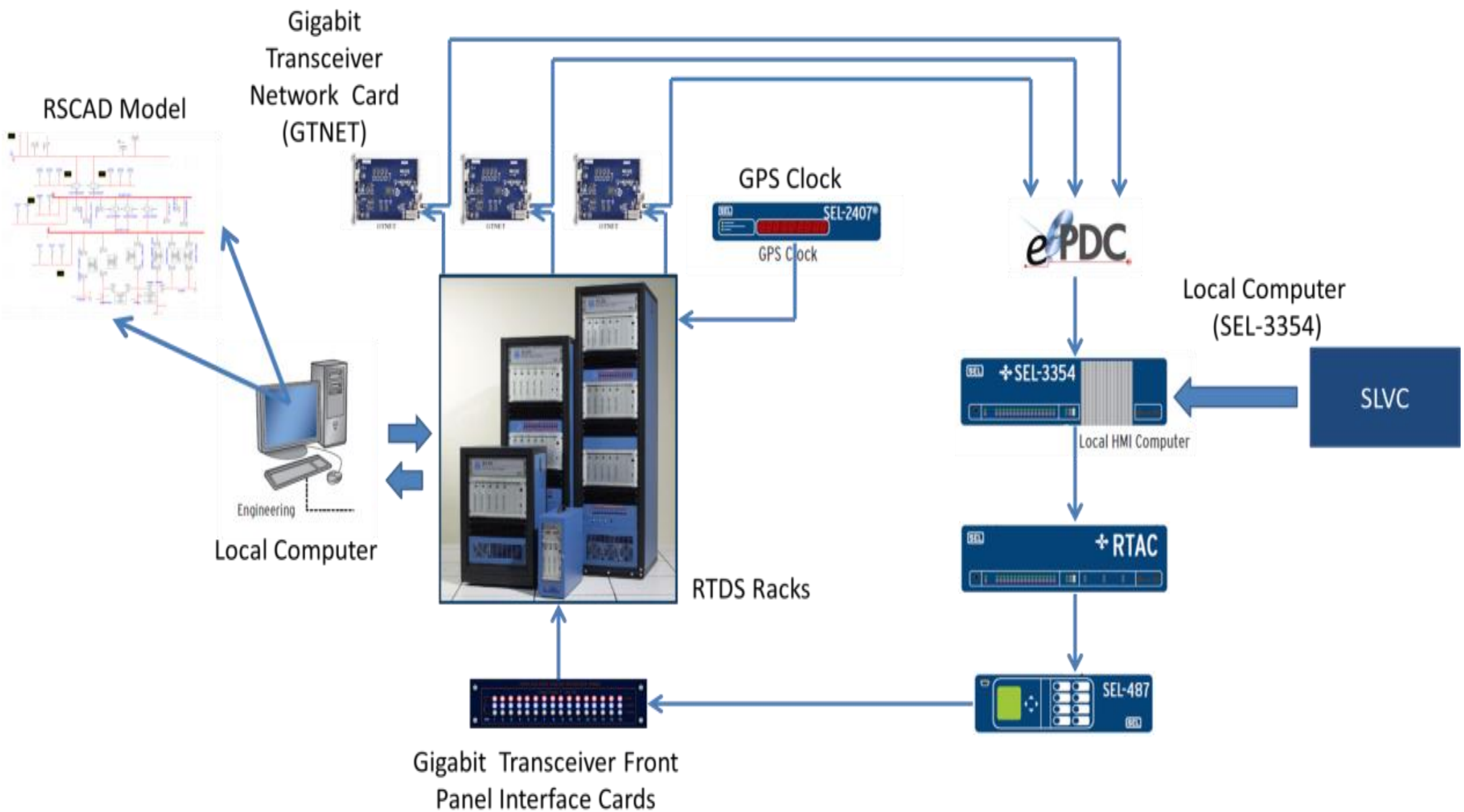
SCVC Optimal Management

- Optimization of substation voltage schedules
- Reduce VAR losses
- Optimal power-flow like
- SE model from PMU measurements
- Possibly several times a day
- Use commercial software

SCVC Supervisory Coordination

- Fast real-time coordination of substation SLVC controllers
- Discrete optimization based on voltage schedules and PMU measurements
- Decide which substations to enable and which ones to disable
- Closed-loop monitoring and corrections

SLVC RTDS Test Set-up at SCE



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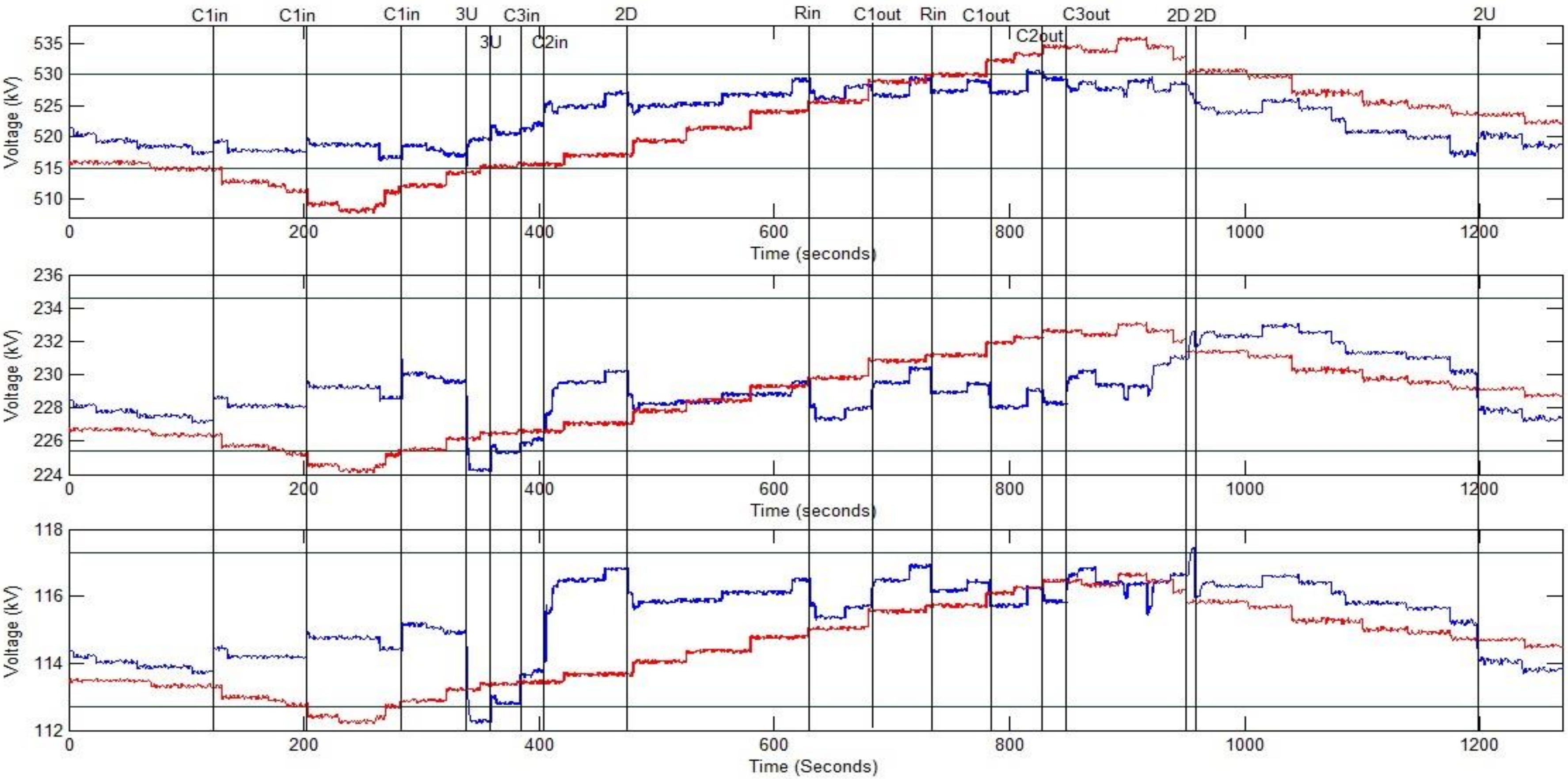
RTDS Test Results Example



C1: One of 4 79.2 MVAr cap banks @ 230 kV C2:46.8 MVAr Cap. Bank @ 115 kV C3: 28 MVAr Cap. Bank @ 115 kV

R:One of 6 45 MVAr reactor banks @ 13.8 kV m:U/D: m Taps Up/Down @ all 2 AA LTCs

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Two-Level Controller Summary

- Automatic management of VAR resources at substations
- Substation controller with local PMU measurements
- Discrete controller design – Slave and Master modes
- Predict switching effects and find optimal actions after including control constraints
- Closed-loop monitoring after switching. Take corrective actions as needed.
- Gives Alerts and Alarms to operators if unusual
- Details in IEEE Trans. Power Systems paper
- Phased implementation underway.

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