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

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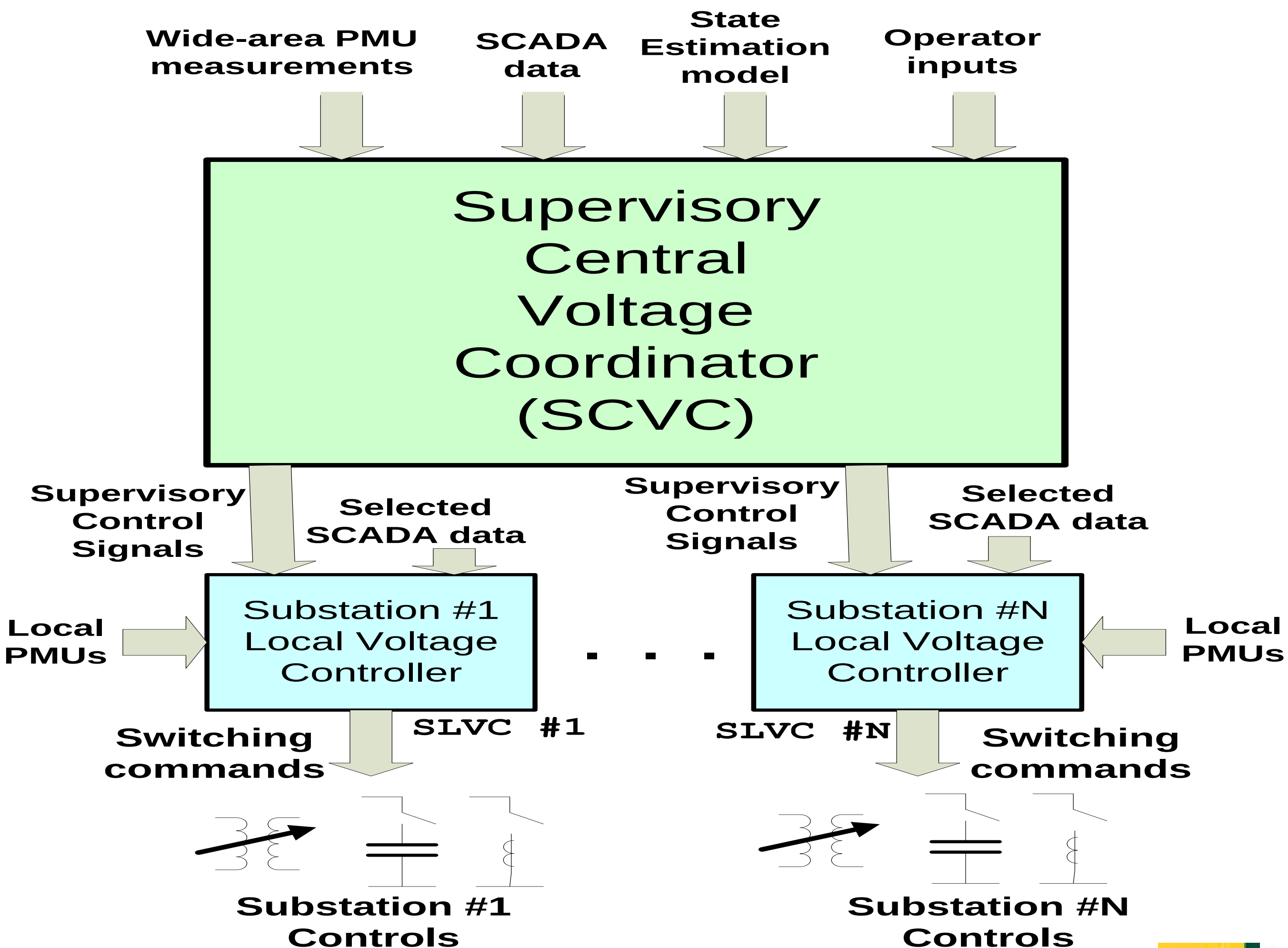
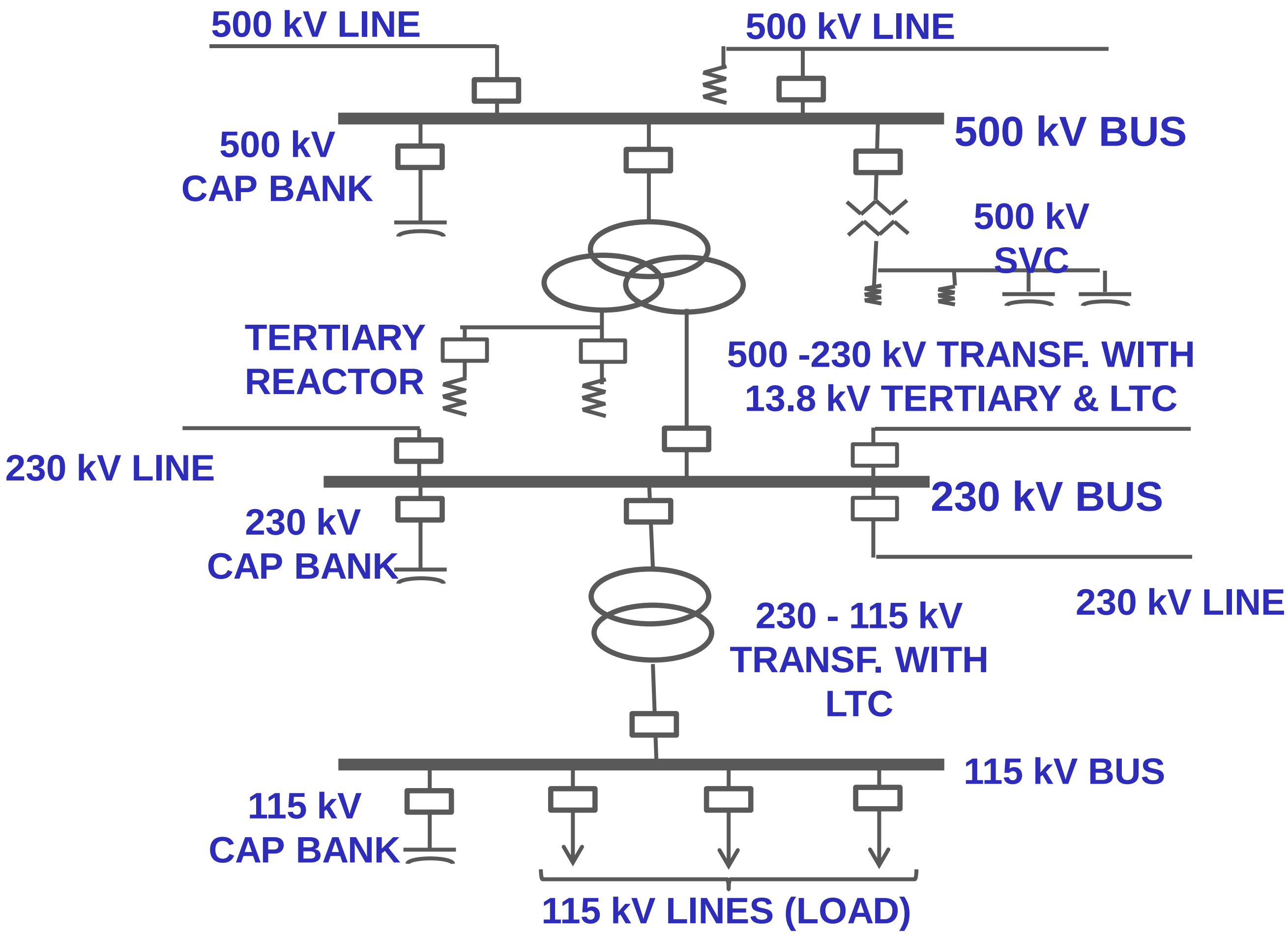
Controller Structure



Typical SCE Bulk Substation



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SLVC Controller Objectives

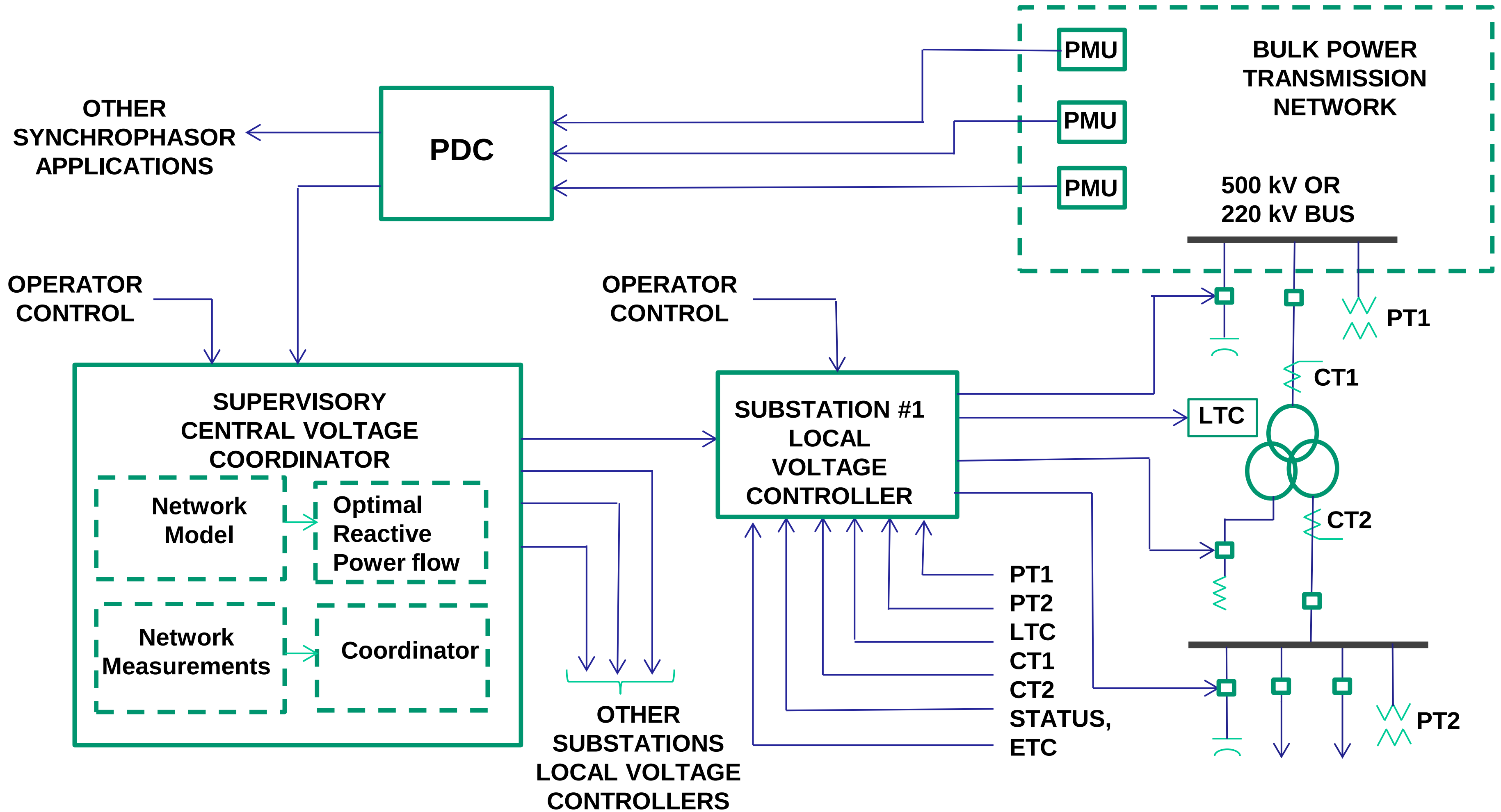
- **Substation Local Voltage Controller (SLVC)**
  - Maintain substation bus voltages by switching local VAR devices – transformer banks, capacitor banks and reactor banks
  - Maintain VAR output and VAR flow constraints
  - Minimize switching of VAR devices
  - Alerts and Alarms when nearing voltage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

(continued)

SLVC Controller Objectives

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

SCVC Central Coordinator



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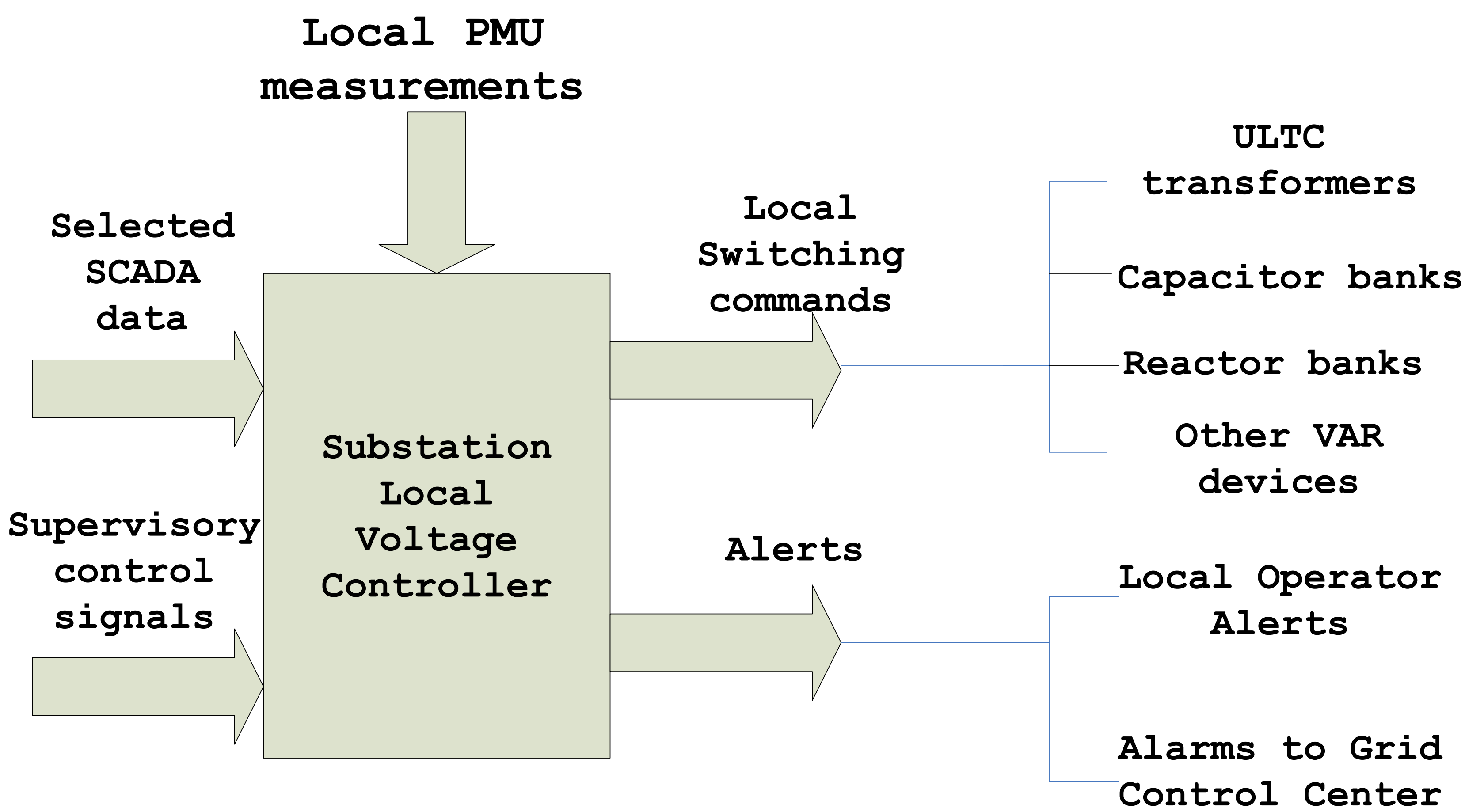
SCVC Controller Objectives

- **Supervisory Central Voltage Coordinator (SCVC)**
  - Coordinate switching of substation SLVC controllers
    - Enable specific substation SLVCs as needed
    - Disable other substations to prevent hunting
  - Optimize voltage profile towards minimizing VAR losses – convey schedules to substation SLVCs
  - Optimal management of VAR resources
  - Alerts and Alarms when nearing voltage insecurity

SLVC Controller



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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 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.**

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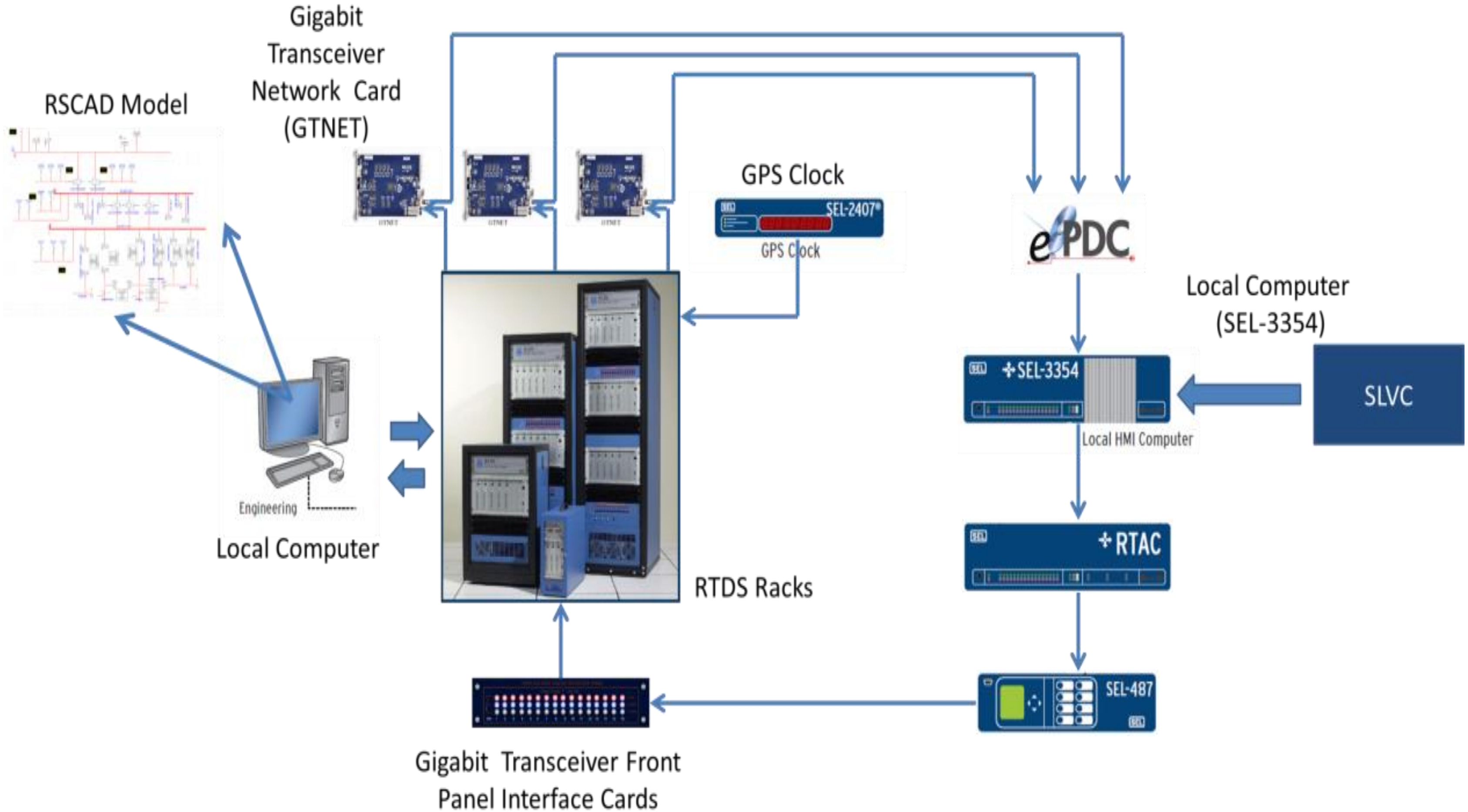
SCVC Supervisory Coordination

- 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

SCVC Optimal Management

- Optimization of substation voltage schedules
- Reduce VAR losses
- Optimal power-flow like
- Mostly based on PMU measurements
- Possibly several times a day

SLVC RTDS Test Set-up at SCE



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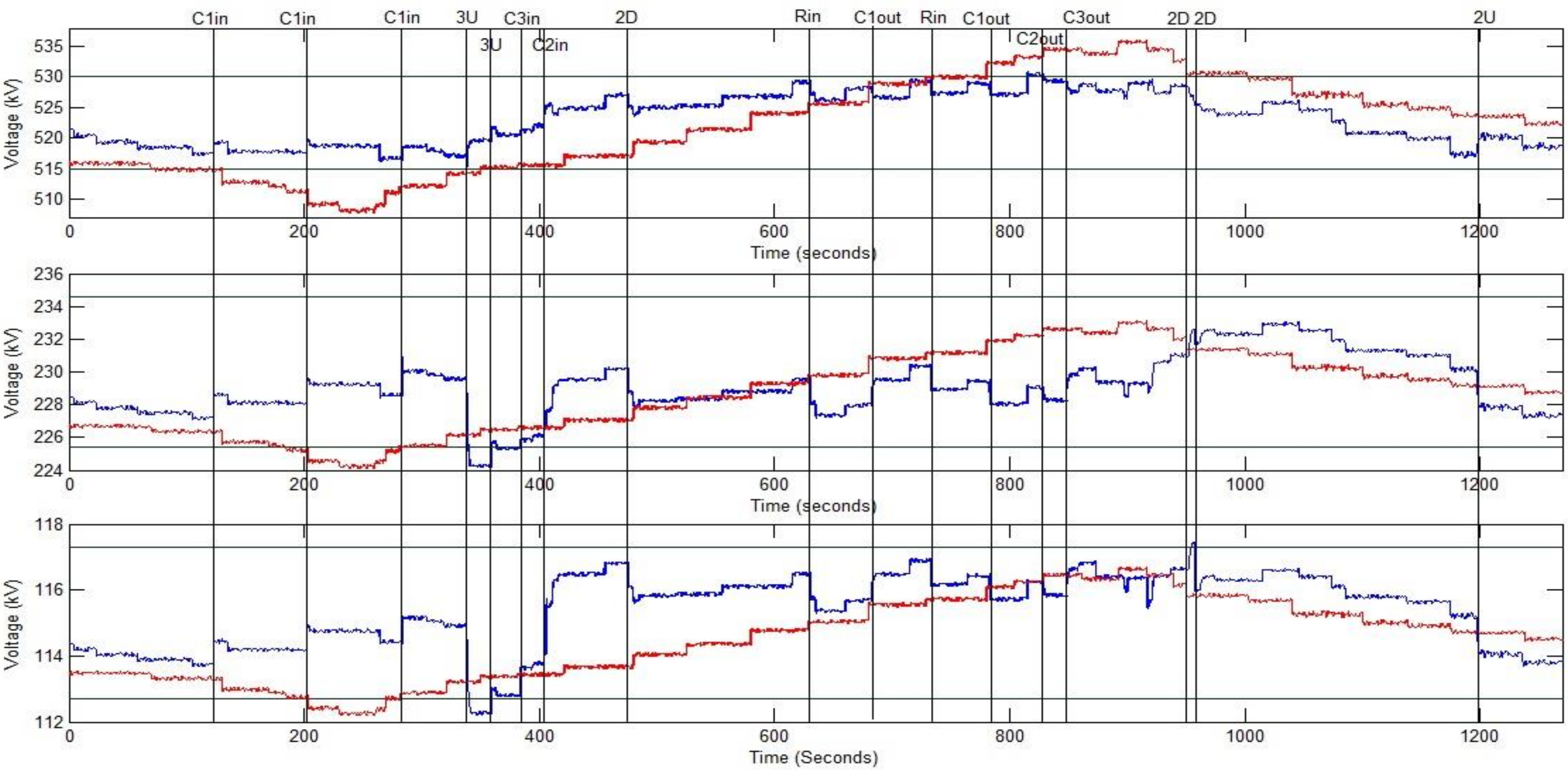
RTDC Test Results Example



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**
- **Design mostly based on 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.**
- **Adapts to system conditions. Robust methodology.**
- **Gives Alerts and Alarms to operators if unusual**
- **Phased implementation planned.**

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