Wide-Area Voltage and VAR Control of SCE Transmission Network

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Introduction

- In order for a Power System to operate reliably, and provide service quality to its customers, it needs to employ two types of controls: Load-Frequency Control, and Voltage Control.

- In California, Load-Frequency Control in done by CAISO, and Voltage Control is responsibility of the respective utility companies.

- SCE’s bulk power transmission system (500 kV & 230 kV) voltage control is done manually in accordance with the SOB 17 and system operator’s experience and preferences. With complexities that is being imposed on transmission system, the manual voltage control is not the appropriate choice (optimal) any more, and certainly will not satisfy operating requirements.
There is increased interest in greater power system automation to relieve operators from repetitive tasks and improve system quality and utilization. Voltage control is a perfect choice for transmission system automation.

Multi-level hierarchical voltage control of transmission network is utilized in several European countries, and the accumulated experience is reported to be highly satisfactory. In general, the control is achieved in three levels:

- Primary Voltage Control (Gen, SVC, …)
- Secondary Voltage Control (regions of network)
- Tertiary Voltage Control (system-wide optimization)
SCE’s Wide-Area Transmission Voltage Control System

- The SCE transmission system voltage controller is a two-level controller consisting of a Supervisory Central Voltage Coordinator (SCVC), and a Substation Local Voltage Controller (SLVC). The SCVC performs an OPF type of calculations to determine optimal bus voltage set points, enables/disables each SLVC, and each SLVC maintains the bus voltage set points by controlling local VAR resources in an optimal fashion.

- The control system is aimed at maintaining transmission voltage profile at steady state. SCVC serves as a Tertiary Voltage Control element, and SLVC serves as a Secondary Voltage Control Element. Primary Control is not directly activated, but its reactive power output is kept at a minimum so that its full capacity is available during a large disturbance.
Block Diagram of Wide-Area Voltage Control in SCE Transmission Network

Wide-area PMU measurements
SCADA data
State Estimation model
Operator inputs

Supervisory Central Voltage Coordinator (SCVC)

Supervisory Control Signals
Selected SCADA data
Supervisory Control Signals
Selected SCADA data

Local PMUs
Substation #1 Local Voltage Controller
Switching commands
Substation #1 Controls

Substation #N Local Voltage Controller
Switching commands
Substation #N Controls

Substation #1

. . .

Substation #N

. . .
Substation Local Voltage Controller (SLVC)

- Maintain substation bus voltages by switching local VAR devices – transformer banks LTC, capacitor banks and reactor banks.
- Maintain VAR output and VAR flow constraints.
- Minimize switching of VAR devices.
- Alerts and Alarms when nearing voltage insecurity.
- Switching decisions mostly based on local PMU measurements – bus voltages, VAR flows, device status
- Supervisory guidance from central coordinator – voltage schedules, SLVC enable/disable

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SLVC Design Details

- **Slave Mode (Substation SVC in service)**
  - Maintain 115 kV and 230 kV bus voltages by switching local VAR devices – transformer banks LTC, 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 LTC, capacitor and reactor banks
  - Maintain VAR flow constraints

- **Automatic switching between Master and Slave Modes using SVC status. Manual override optional.**
SLVC Controller Design Concept
Optimal Predictive Controller

Three prediction methods:

- Local voltage estimator (LVE) based on on-line reactive power flow analysis using local PMU data:

\[
\Delta Q = B \Delta V
\]

- Off-line switching estimates (OVE) from off-line power-flow studies

- Recent switching analyzer (RSA) from PMU data analysis of recent switching actions
SLVC Controller Design Concept
Execution

- Exhaustive search among candidate control actions
- Find feasible subset
- Simple rules for control priority specifications
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
SCVC Design Details

➢ Supervisory Coordination
  o Monitor grid voltage profile and select *optimal* substation controllers to address voltage problems. Issue Enable/Disable commands as needed
  o Mostly based on PMU measurements (assuming sufficient PMU measurements of analog and digital states)

➢ Optimal Management
  o Optimize grid voltage profile to minimize VAR losses by coordinating substation voltage schedules
  o Power-flow formulation – runs periodically
SCVC Design Details

- Supervisory Coordination

  - System-wide voltage estimator based on on-line reactive power flow analysis using wide-area PMU data:

  \[
  \Delta Q = B \Delta V
  \]

  - Exhaustive search among candidate control actions. Find feasible subsets. Simple rules for control priority specifications
SCVC Design Details

Optimal Management

\[
\begin{align*}
\text{Min} & \sum \sum |Q_{ij} + Q_{ji}| \\
V_i^{\text{min}} & < V_i < V_i^{\text{max}} \\
Q_i^{\text{min}} & < Q_i < Q_i^{\text{max}} \\
P_i & = \sum_{j} Y_{ij} V_i V_j \cos(\delta_i - \delta_j - \theta_{ij}) \\
Q_i & = \sum_{j} Y_{ij} V_i V_j \sin(\delta_i - \delta_j - \theta_{ij})
\end{align*}
\]
Functional Diagram
Wide-Area Voltage Control in SCE Transmission Network

PDC

SUPERVISORY CENTRAL VOLTAGE COORDINATOR
Network Model
Optimal Reactive Power flow
Network Measurements
Coordinator

SUBSTATION #1 LOCAL VOLTAGE CONTROLLER
OTHER SUBSTATIONS LOCAL VOLTAGE CONTROLLERS
PT1
PT2
LTC
CT1
CT2
STATUS, ETC

OPERATOR CONTROL
OTHER SYNCHROPHASOR APPLICATIONS

OPERATOR CONTROL

BULK POWER TRANSMISSION NETWORK

500 kV OR 220 kV BUS

PT1
CT1
CT2
PT2
Control Block Diagram
Wide-Area Voltage Control in SCE Transmission Network
Preliminary RTDS Test
Preliminary RTDS Test
THANK YOU