Can a Grid be Smart without Communications?
A Look at an Integrated Volt Var Control (IVVC) Implementation

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Overall Project Scope


– Invested $50 million on 931 Feeders
– 380 MW reduction when voltage is lowered at peak
– Estimated 1.0% load reduction per 1.0% voltage reduction
– Voltage reduction originally used for reduction of system load during high cost generation periods
– Voltage reduction now used for offset of declining 200 MW PV generation during peak demand periods
– Green Solar CVR
Green Solar CVR

• Initiating CVR during the summer peak maximizes the benefit of CVR.
• Combining CVR with solar generation, allows both systems to work together to reduce generation requirements.
• 274 MW of CVR reduction will offset 200 MW of solar reduction.
• The reduction feeders will be called on using a randomized system so that no customers are favored for reduction.
• The remaining 106 MW of CVR could be held in reserve for emergencies.
IVVC Operational Objectives

• Flatten the line voltage profile
  – Minimize voltage reduction impact to customers along the line
  – Allow Conservation Voltage Reduction (CVR) Levels to 2.5 – 3.5%

• Balance capacitors with system reactive vars
  – Provide near unity power factor at the transmission source
  – Regulation range will be +/- 97PF
  – Reduce feeder reactive loads during normal operations
  – Postpone capital expenditures for upgrades and additions

• Provide MW reduction
  – Green Solar randomized automatic dispatch
  – System emergencies via Scada control
Design Goals

• Create an integrated system that will work *without* centralized control
• Operate the regulation and capacitors as a system where the components have a coordinated behavior
• Provide a self-learning system compatible with permanent, temporary or automated (restoration) switching
• Provide a system that can be applied and maintained with minimal engineering attention
• Limit negative exposure to customers and hardware by design
Basic Application Method

• **System operating voltage:** Consistently apply regulator & capacitor Voltage band center (Vbc) along the line.

• **Capacitors as Fine Regulation:** When the capacitors sense lower voltage as load increases, a cap bank will close to correct the voltage. The capacitors are used as primary voltage regulation for the feeder.

• **Regulators as Coarse Voltage Regulation:** Regulators will react to system gross voltage changes and correct the line voltage

• **Regulators as Var Balancing:** Source regulation is optimized to balance the Vars with the transmission source. The regulators are setup to assure the feeder is properly matched using typical digital controls.
Advanced Application Method

These are features that improve behavior and assure proper operation into the future:

• **Limit LDC compensation response:** Limit the voltage correction applied for regulator control compensation

• **Assure maximum voltage reduction when enabled:** Using a method of LDC inversion or nulling, assure that the regulator control will bias to lower the voltage

• **Automatically generate capacitor voltage limits:** Using the change in voltage (delta V) at the capacitor site, the control panel will automatically create adequate limits about the chosen band center.

• **Automatically generate capacitor timing limits:** Using delta V again, adjust open/close timing to provide proper operating order and adequate response spacing
Line Voltage Profile - Regulators only

Voltage = 7470
Power Factor = 85%

Upper Operating Limit
Lower Operating Limit
Applying Distribution Capacitors

*Capacitor banks can be used to regulate feeder voltage...*

- Allow the voltage to be regulated near customer loads, allowing for finer voltage control
- Capacitors can be sized to approximate and cancel var demand with corresponding voltage drop
- Cancel lagging Var loads, reducing system losses, leaving feeders available for greater KW transport
- Allow the distribution system to be var neutral with the Transmission provider
- Possible lower maintenance costs over service lifetime when compared to line regulators
- Reduce tapping operations on LTCs and regulators when properly applied
Applying Distribution Capacitors

Capacitor banks should be applied as follows…

• Install enough fixed capacitor banks to equal the minimum constant VAr load, 1200 KVAR each
• Install enough switched banks to equal ([max. VAr load – min. VAr load] x 1.10) Bank sizes 1200 Kvar – 25kv, 600 Kvar – 12kv
• Modeling studies identify preferred capacitor locations
• Or – place capacitors evenly spaced across the line as pole space allows. Having the capacitors at VAr centers is desirable but not required.
• Switched banks are controlled using voltage only with time delays; capacitors at the end of the line come on first and off last
Line Voltage Profile - With Capacitors

Voltage = 7410
Power Factor = .99%

[Diagram of electrical system with voltage profile graph showing upper and lower operating limits]
Application Issues to Consider

• Lack of capacitors will provide lagging power factor at the source
• Excess capacitors will provide leading power factor at the source
• Oversized capacitor banks can cause over-operation of capacitor and regulation controls
• Circuit reconfiguration – fixed, automatic or manual
• Repairs and Maintenance – will organization culture and workforce effectively apply and maintain the system?
• Engineering planning – How critical is planning to deployment and long term operation of the system?
Deployment of the System

**Regulating Circuit Var Loads**

*Add the necessary capacitor banks on each circuit...*

- Select voltage band center for system operation
- Install fixed banks to cancel Vars during load valleys, these locations can be switched banks if funds allow
- Install switched banks for a total of 110% of the remaining Peak Var Demand (110% x Peak Var – Fixed Caps)
- Setup fixed or auto-adaptive voltage control limits to prevent excessive operation
- Setup fixed or auto-adaptive control timers to switch capacitors in the desired order
Circuit with Fixed Settings

Substation Regulation

- **Raise = 90s**
- **Lower = 90s**
- **BC = 123.5**
- **BW = 2.5**
- **R = 0**
- **X = -6**

- **Fixed 1200 Kvar**
  - **T close = 60s**
  - **T open = 20s**
  - **Delta V < 1.5**
  - **V hi = 124.2**
  - **V lo = 121.7**

- **Switched 600 Kvar**
  - **T close = 50s**
  - **T open = 30s**
  - **Delta V < 1.5**
  - **V hi = 124.2**
  - **V lo = 121.7**

- **Fixed 1200 Kvar**
  - **T close = 40s**
  - **T open = 40s**
  - **Delta V < 1.5**
  - **V hi = 124.2**
  - **V lo = 121.7**

- **Switched 600 Kvar**
  - **T close = 30s**
  - **T open = 50s**
  - **Delta V = 2.0**
  - **V hi = 124.5**
  - **V lo = 121.5**

- **Switched 600 Kvar**
  - **T close = 20s**
  - **T open = 60s**
  - **Delta V = 2.5**
  - **V hi = 124.7**
  - **V lo = 121.2**
Beckwith M6280A Auto-Adaptive Method

Delta Voltage Adaptable Setting Technology

- Standard startup settings are applied by the supplier so off the shelf relays can be installed without field programming
- The capacitor voltage rise Delta V can fix the position of the capacitor bank on the line and be used to set the operating characteristics
- Band-center is factory programmed in each control
- Delta voltage is sensed by the control; upper/lower limits are adjusted automatically
- Installers and planners do not have to pre-program voltage rise limits based on source impedance or empirical measurement
- Close/open sequence timing characteristic is determined by delta voltage
- Automatically adjusts the open/close timing similar to manual setting method to assure proper staging of the capacitors
- Source impedance changes will automatically be learned assuring proper operation, ideal for automatic restoration schemes
Circuit with Adaptive Settings

Substation Regulation

- Raise = 180s
- Lower = 180s
- BC = 123.5
- BW = 2.5
- R = 0
- X = -6
- Or
- VarBias = 1

Fixed 1200 Kvar
- T close = 160s
- T open = 30s
- Delta V = 0.7
- V hi = 124.3
- V lo = 122.3

Switched 600 Kvar

Fixed 1200 Kvar
- T close = 140s
- T open = 50s
- Delta V = 1.1
- V hi = 124.3
- V lo = 121.9

Switched 600 Kvar
- T close = 120s
- T open = 70s
- Delta V = 1.5
- V hi = 124.4
- V lo = 121.6

Switched 600 Kvar
- T close = 115s
- T open = 75s
- Delta V = 1.6
- V hi = 124.4
- V lo = 121.5

Switched 600 Kvar
- T close = 90s
- T open = 100s
- Delta V = 2.1
- V hi = 124.5
- V lo = 121.1
Beckwith M6280A Auto-Adaptive Method

Delta Voltage adaptive voltage limit scheme

![Graph showing the relationship between Delta Voltage and Switching Limits and Bandcenter. The graph includes three lines: Open Limit (green), Bandcenter (black), and Close Limit (red). The x-axis represents Delta Voltage, ranging from 0 to 5, and the y-axis represents Switching Limits and Bandcenter, ranging from 118 to 126. The lines indicate how the limits change with respect to Delta Voltage.](image-url)
Beckwith M6280A Auto-Adaptive Method

Delta Voltage adaptive timing scheme

![Graph showing Delta Voltage adaptive timing scheme](image)
Beckwith M6280A Auto-Adaptive Method

Delta Voltage adaptive settings

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Preferred Band Center</td>
<td>123.5</td>
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<tr>
<td>Voltage Deadband</td>
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<td>Delta V Divisor (M)</td>
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<td>Delta V Operation to Average</td>
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<td>Maximum Time Delay</td>
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<td>Minimum Time Delay</td>
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<td>Maximum Delta Voltage</td>
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<td>Minimum Delta Voltage</td>
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<td>KVAR Base</td>
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<td>No Operation Days</td>
<td>60</td>
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</table>

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Minimum</th>
<th>Maximum</th>
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<tbody>
<tr>
<td>Preferred Band Center</td>
<td>100.0</td>
<td>135.0</td>
</tr>
<tr>
<td>Voltage Deadband</td>
<td>0.0</td>
<td>5.0</td>
</tr>
<tr>
<td>Delta V Divisor (M)</td>
<td>0.2</td>
<td>10.0</td>
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<tr>
<td>Delta V Operation to Average</td>
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<td>30</td>
</tr>
<tr>
<td>Maximum Time Delay</td>
<td>10</td>
<td>1200</td>
</tr>
<tr>
<td>Minimum Time Delay</td>
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<td>600</td>
</tr>
<tr>
<td>Maximum Delta Voltage</td>
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<tr>
<td>Minimum Delta Voltage</td>
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<td>5.0</td>
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<tr>
<td>KVAR Base</td>
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<td>4800</td>
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<tr>
<td>No Operation Days</td>
<td>1</td>
<td>365</td>
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Deployment of the System

Regulating Circuit Var Loads

.Setup regulation controls...

• Select a voltage band center and bandwidth for system operation, start with the same voltage & bandwidth as the capacitors, changing the band center will affect the balance point for the vars

• Extend the raise/lower operation timer to allow capacitor operation first, this time should be longer than the any capacitor operation under normal conditions

• Using negative reactance (-X) compensation, the control will lower when lagging and raise when leading to react properly with the capacitor behavior, limit compensation bias when the LDC Limit feature is available

• Inverse timing will help improve regulation response when large changes occur, like transmission switching
LDC Limit Method

- Solutions
  - Limit LDC bias in LTC/Regulator controls
    - Slope of R and X can be set
    - Larger \(-X\) values can be used without risk, possibly \(-18\)
    - As an example an X of \(-6\) can be set with a Limit at 3 volts
Deployment of the System

**Voltage Reduction (VR)**

*Setup regulation controls...*

- Select the Voltage Reduction levels required (2.5 – 3.5% typical)
- A small 1% reduction may be allowable without any change to the circuit configuration
- Establish communications method for applying voltage reduction with the source regulation
- Determine application criteria for activating voltage reduction – via scada path using automated script
- To maximize reduction when called, zero or invert the –X LDC behavior to force the regulation to the lower band limit
Line Voltage Profile - Reduction Applied

Voltage = 7230
Power Factor = -97%

[Diagram showing voltage profile with upper and lower operating limits and voltage reductions indicated.]
Deployment of the System

Changing sources by auto or manual restoration:

Setup regulation controls...

• Substation - Utilize delta voltage sensing on the voltage regulator to lockout automatic tapping when back fed
• Polemount - Utilize delta voltage sensing on the voltage regulator to lockout, reverse operation or run to neutral

Setup capacitor controls...

• Use Delta V sensing to vary voltage limits; will adjust automatically within 8 operations
• Use Delta V sensing to vary timing limits; will adjust automatically within 8 operations
• Limits may be too great when sources are changed, for those cases, the panel will re-initialize after a set time
## Regulator control settings and feature availability

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<tbody>
<tr>
<td>Bandcenter</td>
<td>123.5</td>
<td>x</td>
<td>x</td>
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<td>Time Delay</td>
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<tr>
<td>Inverse Time Delay</td>
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<td>x</td>
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<td>x</td>
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<tr>
<td>LDC Reactive</td>
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<td>x</td>
<td>x</td>
<td>x</td>
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<tr>
<td>LDC + limit</td>
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<td>x</td>
<td>future</td>
<td>future</td>
<td>add logic</td>
</tr>
<tr>
<td>LDC – limit</td>
<td>-1.3</td>
<td>x</td>
<td>future</td>
<td>future</td>
<td>add logic</td>
</tr>
<tr>
<td>LDC invert on VR</td>
<td>Yes</td>
<td>x</td>
<td>future</td>
<td>future</td>
<td>Use 2 Groups</td>
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<tr>
<td>LDC zero on VR</td>
<td>Yes (if no invert)</td>
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<td>n/a</td>
<td>n/a</td>
<td>x</td>
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<td>V Reduction 1</td>
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<td>x</td>
<td>x</td>
<td>x</td>
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<tr>
<td>V Reduction 2</td>
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<td>x</td>
<td>x</td>
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<td>x</td>
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<td>x</td>
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<td>x</td>
<td>future</td>
<td>future</td>
<td>n/a</td>
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</tbody>
</table>
Any questions?

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