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

David Aldrich
Beckwith Electric Company
Goals

• Flatten voltage profile across entire circuit
• Reduce system losses
• Provide better voltage to consumers
• Reduce labor required for installation and maintenance of system
• Enable load reduction system wide
• Efficiently regulate distribution circuits without communications
• Handle circuit reconfiguration automatically
How?

• Consistently apply capacitor Voltage band center (Vbc) along line

• Coordinate this with source voltage regulation to balance VArs

• System measures VAr flow and alters regulation at source

• Capacitor banks react to correct voltage and consequently VArs at regulation site

• Using only line Voltage and Vars as the communications method
What about using DMS or IVVC for VVO/CVR?

- Costly
  - Can comms reach everywhere on their system?? Reliably??
- How long can you wait for DMS/IVVC implementation?
- Requires accurate distribution system model
  - Expense to create (needs GIS and system parameters)
  - Expense and time intensive to maintain
- Requires near real time dynamic model updates and communications to system elements
- Data quality impacts load flow model results
- Tap position data requirements for model
- Multiple substation and feeder configurations need to be reflected in model, handled in real time
- Need a smart control regardless when communications from DMS-SCADA fails
Traditional Distribution Controls Use

- LTC Transformer and Regulator Controls are deployed to maintain voltage using R and X line drop compensation

- Capacitor Controls are deployed to minimize losses by dispatching VARs
Coordination is Key

- If circuit is lagging and voltage is low
  - Regulator Tapping
    - Corrects voltage
    - Spread still same
    - Added operation to more expensive equipment
    - PF not changed

---

Loads only
Coordination is Key

- If circuit is lagging and voltage is low
  - Cap Bank Closing
    - Corrects voltage
    - Brings PF closer to Unity
    - Reduces spread as voltage is adjusted further down circuit
    - Reduces operations on LTC or regulator

With cap #1 on only

Loads only
Distribution Capacitor Advantages

- Capacitor banks as primary device to regulate feeder voltage – Why use them?
  - Capacitors allow voltage to be regulated near customer loads
  - A switched capacitor bank costs $13,000 installed cost compared to regulator’s $80,000 installed cost
  - Capacitors cancel lagging VAr loads, reducing system losses
  - Capacitor banks aid in having distribution system being VAr neutral to transmission grid
  - Capacitor banks have low maintenance cost over their lifetime
  - Using capacitor banks to regulate voltage reduces number of LTC and regulator operations
Application Problems to Consider

• Lack of capacitors
  ▪ For system to work properly, each circuit requires sufficient VAr to offset peak load VAr plus 10%

• Hunting between capacitor banks and source regulation can cause excessive operations
  ▪ Effect of each capacitor on voltage must be less than 3% at capacitor site and 0.6% at source
  ▪ Typically, this requires using 600 KVAR banks on 12 kV circuits and 1,200 KVAR banks on 25 kV circuits

• Excess capacitors providing leading power factor at substation bus (-97% or below)
  ▪ Regulators/LTCs must be coordinated to raise voltage when power factor is above 0.98 leading; forcing capacitors to open
Application Problems to Consider

• Circuit changes - automatic or manual
  ▪ Any device specific settings that rely on electrical order on line might be affected by changes to distribution circuit
  ▪ Planning must assure permanent feeder and source changes include capacitor planning

• Repairs and Maintenance
  ▪ When a control fails, it is important to have original settings and control scheme installed in replacement to maintain proper operation

• Engineering planning
  ▪ Placement of cap controls using fixed timing requires settings planning per device
  ▪ Scheme inherently conceals VAr load used to trigger capacitor additions
Voltage Profile – With Capacitors Added

Capacitors affect voltage level, losses, capacity, etc.
Voltage Profile – With Capacitors Added

Regulator can now shift the voltage up or down
Capacitors affect voltage level, losses, capacity, etc. Volt Var Optimization + Conservation Voltage Reduction
DNA of Ultra VVO/CVR

- Allow Capacitor Banks to be primary voltage regulating devices
  - Cap banks not only affect voltage but also power factor
  - Use voltage sensing for cap banks
    - Less expensive controls
    - No line post sensors required
    - Can be placed anywhere on circuit
    - Not impacted as much as Var controls when reverse power conditions occur due to DG or sectionalizing

- Voltage Regulators (or LTCs) tap only to address emergency or dramatic voltage changes
  - Loss of load due to recloser tripping
  - Large increase in voltage due to transmission voltage increasing
  - When power factor needs to be adjusted
Why *Ultra VVO/CVR*?

- Reduced energy consumption at all times
  - CVR and non-CVR (normal) operating conditions
- Near Unity Power Factor at all times
- Decreases tapchanger operations in LTCs and Regulators
  - Preserves capital equipment life; reduces maintenance costs
- **No communications required to capacitor controls**
- Limited communication to LTC/Regulator controls
  - CVR signal required controls used in CVR application
  - No communications required for non-CVR application
  - Allows a Utility to use capital for cap banks
    - Instead of communications and DMS
- **No** DMS or IVVC required
- **No** modeling (not even LDC)
General Rules for Improved CVR factor

- Series Regulators
  - Regulator closest to source taps first (shortest time delay)

- Cap Banks have narrower bandwidth that LTC/REG controls
  - Helps use cap banks for small voltage adjustment instead of LTC/REG controls

- Multiple Cap Banks (Voltage Controlled)
  - Cap banks furthest from source close first, open last

- Caps switch before regulators
  - Decreases LYC/Regulator operations
  - Save the assets, saves maintenance $$$$$
How to Implement

Stage One – Regulating Circuit VAr Loads

• Add necessary capacitor banks on each circuit
  ▪ Fixed banks to meet minimum VAr load
  ▪ Switched banks added to total 110% of Peak VAr Demand (110% x Peak VAr – Fixed Caps)
  ▪ Select average voltage band center for operation
  ▪ Setup voltage limits to prevent excessive operation
  ▪ Setup control timers to switch capacitors in desired order
How to Implement

Stage One cont’d – Regulating Circuit VAr Loads

• Setup regulation controls
  ▪ Select average band center for operation (start same as caps)
  ▪ Extend operation timer to allow capacitor action first
  ▪ Set up control to lower voltage as VArs become lagging
  ▪ Set up control to raise voltage as VArs become leading
  ▪ Adding voltage to band center relative to capacitor controls will change VAr balance point for feeder
How to Implement

Stage Two – Voltage Reduction (VR)

• Select Voltage Reduction levels required (2.5 – 3.5% typical)
• Small 1% reduction may be allowable without any change to circuit configuration
• Setup regulation controls for required voltage reduction levels
• Establish communications method for applying voltage reduction
• Determine application criteria for activating voltage reduction – when/how/areas/by whom
How to Implement

• Stage Three – Proving and Monitoring
  ▪ Add communications to typical sample circuits for all devices and monitor data
  ▪ Leverage other circuit data such as AMI for voltage and capacitor neutral current monitoring
  ▪ Have data available for load profiling if a full centralized IVVC is desired

• Stage Four – Centralized Load Management
  ▪ Have a centralized IVVC system tested on typical sample circuits to see if added benefit (if any) justifies cost of implementation
First Deployment

1998 – 2001

  - 1998: technology installed at 53 feeders
  - 1999-2000: technology installed at 314 feeders
  - 2001: technology installed at 48 feeders
- 180 MW reduction when voltage is lowered
- 1.0% load reduction per 1.0% voltage reduction
  \[ CVRf = 1 \]
- Used to reduce system load full time and for on-demand reduction
Second Deployment

2010 - 2013

• Invested $27 million with Smart Grid Grant
  ▪ 47 feeders studied and updated from original project
  ▪ 516 new feeders studied and upgraded
  ▪ Includes 1,400 new capacitor controls and 2,700 new regulator controls
  ▪ Add 1,731 AMI neutral monitors to fixed and switch capacitor banks

• Estimated 200 MW reduction with VR applied
• 1.0% load reduction per 1.0% voltage reduction
• Used to reduce system load and for on-demand reduction of system kW
Minimum Capacitor Requirements

• Install enough fixed capacitor banks to equal minimum constant VAr load; 1,200 kVAr each

• Install enough switched banks to equal ([max. VAr load – min. VAr load] x 1.10) Bank sizes 1,200 kVAr – 25kV, 600 kVAr – 12kV

• Modeling studies identify preferred capacitor locations

• Or – place capacitors evenly spaced across line as pole space allows; having capacitors at VAr centers is desirable but not required.

• Switched banks controlled by using voltage only with time-delays; capacitors at end of line come on first and off last
Minimum Regulation Controls

This is system used for first deployment

• Typical Regulator settings used before application
  ▪ +5R + 3X
  ▪ Typically, 30-second time-delay
  ▪ High as 127 V at station low as 115 V at end of line

• Regulation control must support the following
  ▪ R=0 x=-6
  ▪ Band Center 123.5 V, bandwidth 2.5 V, 90-second delay
  ▪ As the regulator control senses additional VAr load, the voltage lowers, turning on more capacitors and operating near a negative 99% power factor
  ▪ If voltage reduction is desired, a controllable and settable scheme for desired level (~ 2.5%)
Minimum Capacitor Controls

- Typical Capacitors settings used before application
  - Scheme: Temperature with Voltage Override
  - Override Low = 119 V and High = 127 V
  - Override time-delays are Low = 30-sec and High = 30-sec
  - Voltage change + Margin = 2 VAC
- Capacitor control must support following:
  - Bandcenter based on limits = 123.0 V
  - 121.7 V Low with 0.1 volt settings resolution
  - 124.2 V High with 0.1 volt settings resolution
  - Open time-delay, range 5 – 120 sec, 5 sec resolution, adjusted based on position in the line (30, 40, 50, 60)
  - Close time-delay, range 5 – 120 sec, 5 sec resolution, adjusted based on position in the line (60, 50, 40, 30)
Second Deployment Improvements

LDC –X usage can have side effects

• If a circuit did not have enough capacitors and had a lagging power factor, –X would force voltage lower to cause additional capacitors to come on as designed
  ▪ Capacitor banks on circuit were out of service
  ▪ Circuit did not have enough capacitor banks to supply needed VAr support
  ▪ We call this issue “–X voltage rundown”

Solutions for –X voltage rundown

• Add neutral current sensing to fixed and switched capacitor banks using 120 VAC AMI meter
  ▪ Identify inoperable capacitors, blown fuses, bad switches to assure capacitor availability and limit chance of capacitor shortages
  ▪ Also used for site voltage tracking
  ▪ Last gasp voltage outage information for outage management
Second Deployment Improvements

Solutions for –X voltage rundown

Replace –X in LTC/Regulator controls with one of two approaches:

• VAr Bias Method
  ▪ Intended to limit reaction to VArS and reduce tapping
  ▪ For leading power factor at regulator/LTC, 1 volt is added to upper band edge, with intention of allowing capacitors to open first (no change to lower edge or center)
  ▪ For lagging power factor at regulator/LTC, 1 volt is subtracted from lower band edge, with intention of allowing capacitors to close first (no change to upper edge or center)
  ▪ A time-delay on bias application; when required capacitance is not met, band returns to normal after time delay (set at 300 seconds)
  ▪ Alarm can be generated to SCADA indicating lack of capacitance on circuit (failed bank or more banks required)
  ▪ One consideration is dead space between +/- limits where subtle changes in reactance are ignored
LTC/REG VAR Bias

- Lagging VARs
- Leading VARs
- Unity PF

Bandcenter

Lower Band Edge to allow cap bank to close
Raise Band Edge to allow cap bank to open
Second Deployment Improvements

Solutions for –X voltage rundown

Replace –X in LTC/Regulator controls with one of two approaches, cont’d:

• LDC Limit Method
  ▪ Allows for sharper response at lower load changes to properly bias control to raise or lower; forcing capacitors out-of-band much quicker
  ▪ Limits maximum effect to avoid lowering voltage too much if lacking capacitance (lagging)
  ▪ Limits maximum effect to avoid raising voltage too much if capacitors exceed demand (leading)
  ▪ Beneficial for auto-restoration schemes to limit LDC effect when circuits are carrying additional load
  ▪ May result in more tapping than VAr bias method
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, \(X\) of -6 can be set with Limit at 3 volts

[Graphs showing LDC -6X and LDC -6X with 3 volt Limit]
Second Deployment Concerns

• Circuit changes - automatic or manual
  ▪ Fixed settings may not operate as intended
    • Different source impedance may cause band overshoot
    • Different location relative to source will not have correct timing
    • Not best solution for automatic restoration methods

• Repair and Maintenance issues
  ▪ Capacitor controls fail and must be replaced
    • Fixed settings may not be properly transferred
    • Control may be installed with default settings
    • Skill and PC equipment required for proper setup

• Engineering Planning
  ▪ VAr balancing scheme conceals circuit VAr demand
    • Assumptions of Power Factor must be used
    • Estimate VAr demand using only kW measurement
    • Routine review of circuits to assure adequate capacitors
Second Deployment Improvements

Use of Delta Voltage Adaptable Setting Technology

- Standard startup settings are applied by supplier so off-the-shelf relays can be installed without field programming.
- Capacitor voltage rise Delta V can fix position of capacitor bank on line and be used to set operating characteristics.
- Bandcenter is factory programmed in each control.
- Delta voltage is sensed and upper/lower limits are adjusted automatically.
- Installers and planners do not have to preprogram voltage rise limits based on source impedance or empirical measurement.
- Automatically adjusts open/close timing to assure proper staging of capacitors.
- Source impedance changes will automatically be learned assuring proper operation.
- Ideal for automatic restoration schemes.
Second Deployment Improvements

- Delta Voltage adaptive voltage limit scheme
Second Deployment Improvements

- Delta Voltage adaptive timing scheme
Typical Circuit

- Kathwood K7332
  - V2262 Fixed 1200 Kvar
  - V2835 Switched 600 Kvar
    - V5366 Switched 600 Kvar
      - V5355 Fixed 1200 Kvar
    - V0650 Switched 600 Kvar
    - V5367 Switched 600 Kvar
  - V2834 Switched 600 Kvar
Circuit with Adaptive Settings

Substation Regulation

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

- Fixed 1200 Kvar
  - T close = 150s
  - T open = 30s
  - Delta V = 0.7
  - V hi = 124.3
  - V lo = 122.3

- Switched 600 Kvar
  - T open = 50s
  - Delta V = 1.1
  - V hi = 124.3
  - V lo = 121.9

- Fixed 1200 Kvar
  - T close = 140s
  - T open = 70s
  - Delta V = 1.5
  - V hi = 124.4
  - V lo = 121.6

- Switched 600 Kvar
  - T close = 120s
  - T open = 75s
  - Delta V = 1.6
  - V hi = 124.4
  - V lo = 121.5

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

- T close = 90s
  - T open = 100s
  - Delta V = 2.1
  - V hi = 124.5
  - V lo = 121.1
Feeder 7332 Phase 1 Spring 2012

Voltage at 121 to 126

VARs between 680 kVAR lagging to 800 kVAR Leading
Feeder 7332 Phase 1 Spring 2012

Tap Position from 2L to 11L

Current ranges from 120 amps to just over 400 amps

Regulator Taps 707 times in 210 days or 3.4 taps per day on average
THANK YOU

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

David Aldrich, P.E.
Beckwith Electric Company
daldrich@beckwithelectric.com
www.beckwithelectric.com