VOLTAGE REGULATION OF THE DISTRIBUTION GRID

BECKWITH ELECTRIC

Bob McFetridge

Voltage Regulation and Power Quality Track
Monday and Tuesday Sessions

HUBBELL

SESSION 8 –Advanced Coordination

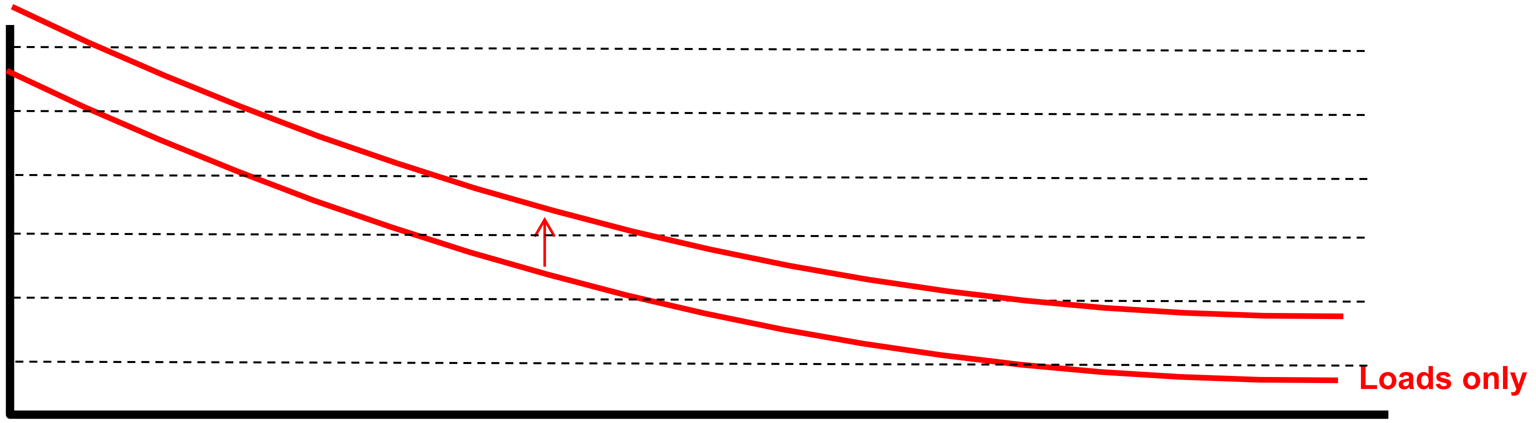
BecoGrid Coordination

- If the pF is lagging and voltage needs to Raise allow capacitor bank to close, taking operations off the LTC and improving power factor and increasing system capacity while reducing line losses.
- If the pF is leading and the voltage needs to lower, allow capacitor bank to open, taking operations off the LTC and improving power factor and increasing system capacity while reducing line losses.
- If pF is lagging and voltage needs to be lower, LTC or regulator should tap.
- If pF is leading and the voltage needs to be raised, allow the LTC or regulator to tap.

Coordination is The Key

If the circuit is lagging and the voltage is low, Regulator Tapping:

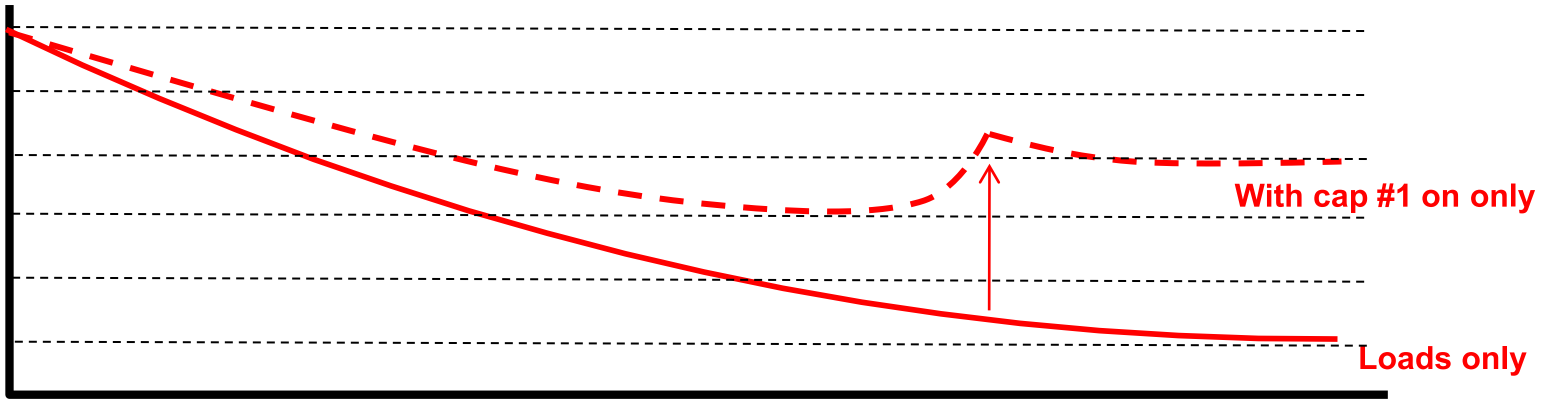
- Corrects the voltage.
- Spread still the same.
- Added operation to more expensive equipment.
- Losses and pF not changed.
- It is sliding the voltage up and down but not flattening the voltage.



Coordination is The Key

If the circuit is lagging and the voltage is low, Cap Bank Closing:

- Corrects the voltage.
- Brings pF closer to Unity while reducing losses.
- Reduces the spread as voltage is adjusted further down the circuit.
- Reduces operations on LTC or regulator.



DNA of a BecoGrid

Allow the Capacitor Banks to be primary voltage regulating devices and use voltage sensing for cap banks:

- Cheaper controls - Correct the voltage corrects the Vars.
- No line post sensors required.
- Can be placed anywhere on the circuit.
- Not impacted as much as Var controls when reverse power conditions occur due to DG or sectionalizing.
- Cap banks not only affect voltage but also power factor.

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 capacitors are offline.

Capacitors First

To allow the capacitors to be the primary regulating devices the design need to:

- Have many smaller switched capacitor banks.
- Enough (or no) fixed banks for low load conditions only.
- Capacitors must be able to operate before regulators.
- Capacitor must affect the secondary voltage (Delta Voltage) by no more than 1.5 - 2 volts to reduce possibility of hunting with upstream regulators.

Voltage Regulators (or LTCs) are Coordinated with Capacitors downstream as follows:

- All devices can have same bandcenter and bandwidth.
- Capacitors will have shorter time delays than upstream regulators.
- LTCs and Regulators must support inverse time curves to allow for slow operation for fine tuning but fast operation for system emergencies.

Inverse TD Example

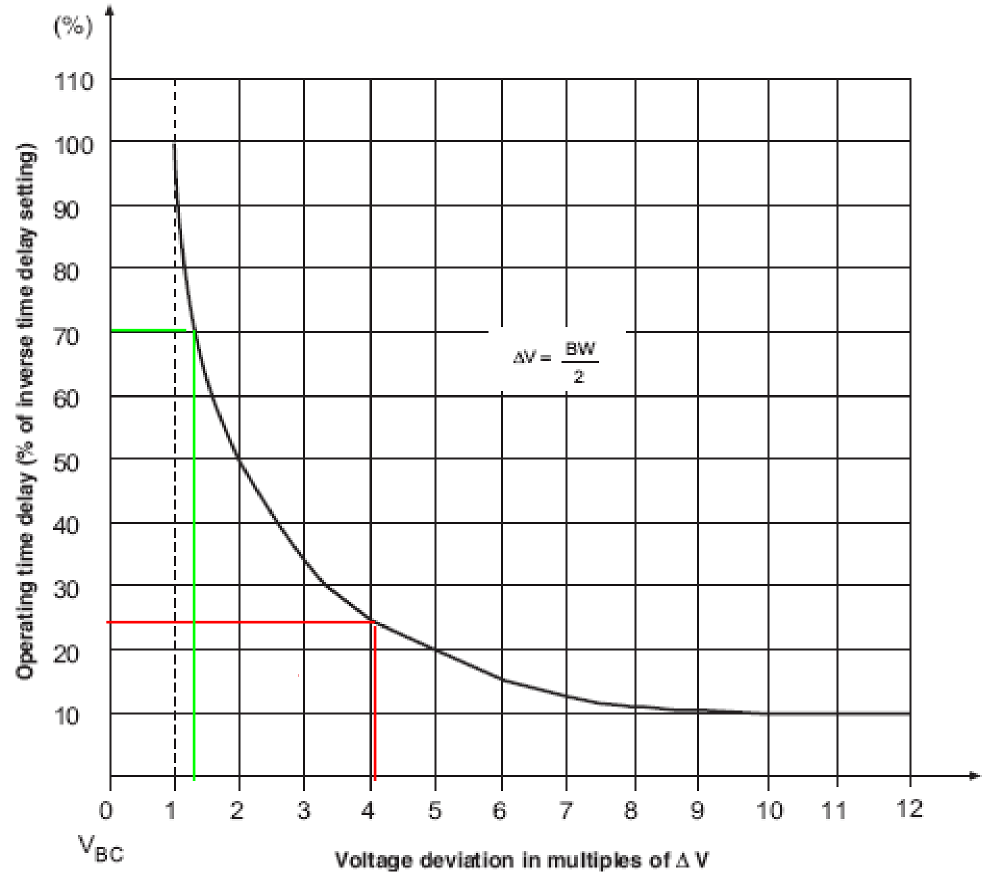


Figure 3-1 Inverse Time Delay Curve

Settings

Bandcenter – 122

Bandwidth – 3

Inverse Time Delay 120

If the sense voltage is 128, TD is

Delta V = (V_{sense} - V_{bc})/(BW/2)

(128-122)/(3/2) = 6/1.5 = 4

From graph TD = 25%

120 * .25 = 30 Seconds

If the sense voltage is 125, TD is

Delta V = (V_{sense} - V_{bc})/(BW/2)

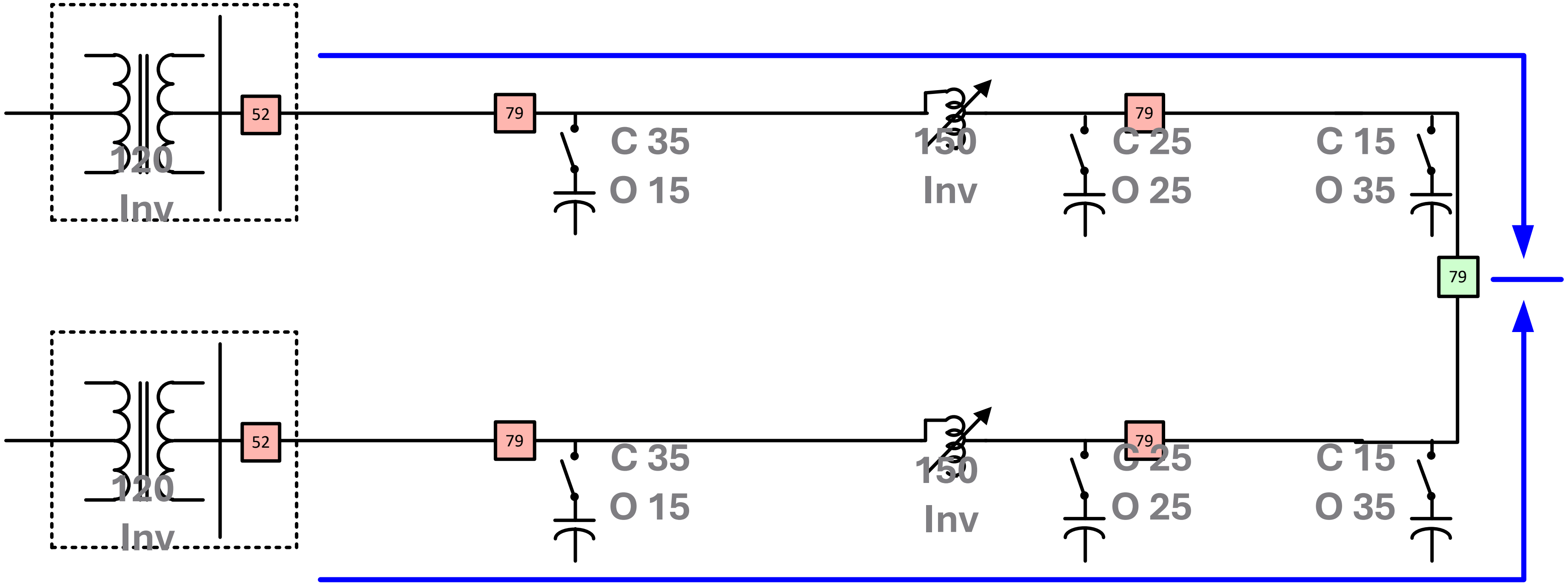
(124-122)/(3/2) = 2/1.5 = 1.33

From graph TD = 70%

120 * .7 = 84 seconds

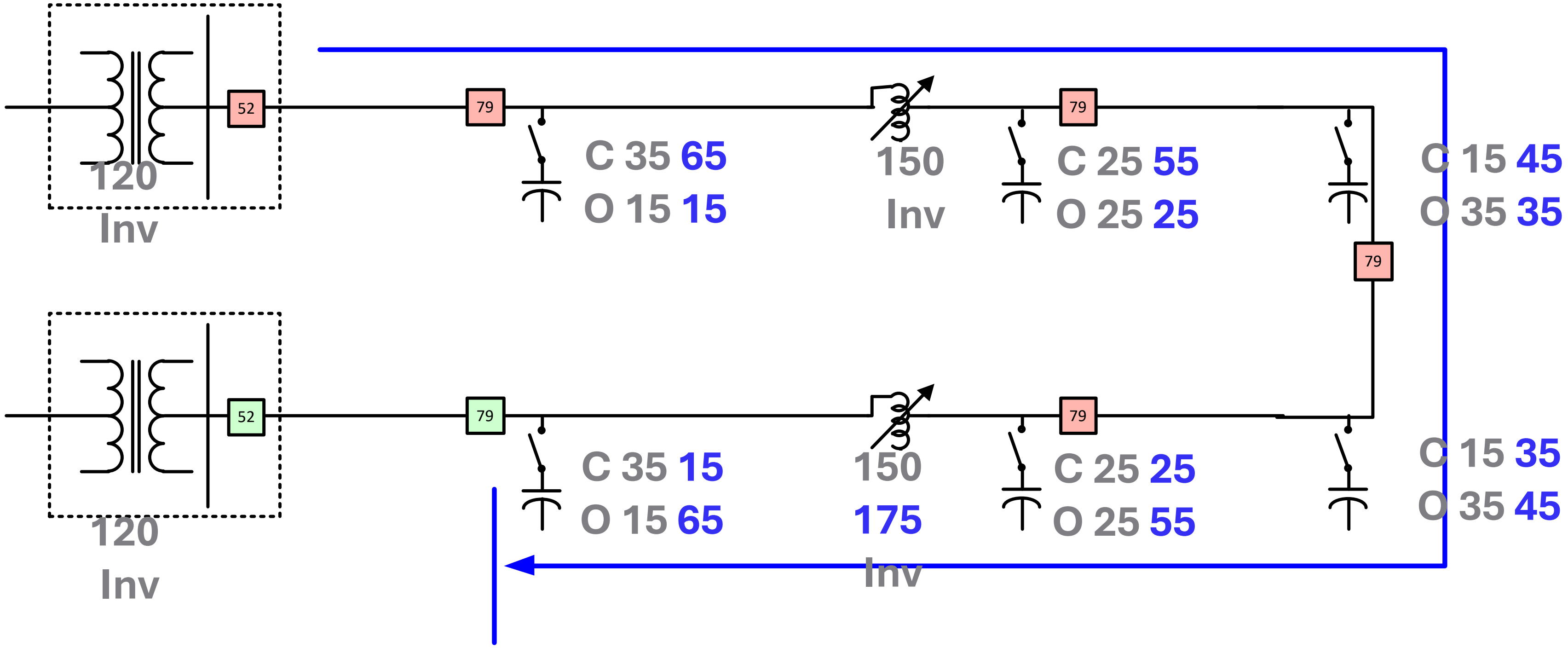
BecoGrid Coordination

- To raise the End-of-Line voltage the cap banks furthest from the source should have the fastest close and slowest open time delays.
- These could be programmed in but...



BecoGrid Coordination

- The circuit had 3 cap banks before being reconfigured and now 6 cap banks. It also picked up a regulator.
- Time Delays have lost their coordination.
- Values in Blue is what would be required for this circuit configuration.



Autodaptive Capacitor Control

Capacitor control's Autodaptive Enhanced algorithms consist of the following main functions:

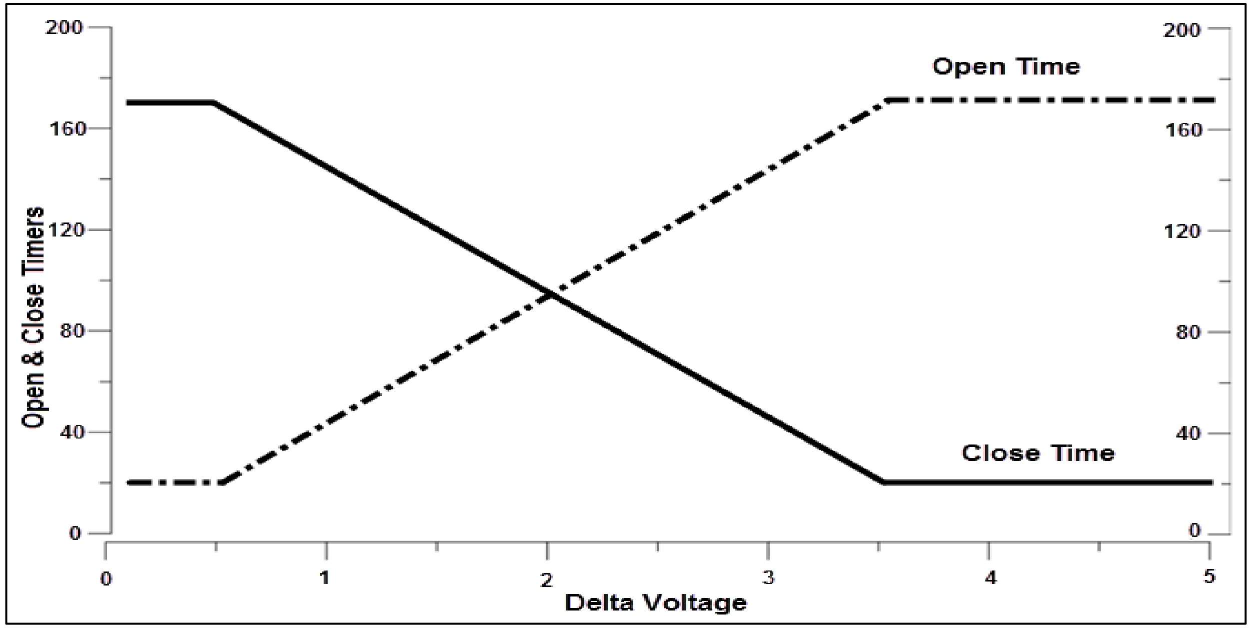
- The control measures the change in local voltage when the capacitor bank switches open or closed. This value is called measured delta voltage or Delta V.
- Relative to the size of switched capacitor banks across a feeder, the Delta V will increase as the capacitors are located further from the substation.
- Using the measured voltage and the Delta V, the control will automatically set the controlling voltage limits and timer values for open- and close-operation that is unique to that location on the distribution feeder.

Autodaptive Capacitor Control

- The Delta Voltage (DV) is the voltage rise effect the capacitor bank has on the circuit voltage when operated and is affected by two components.
- The first component is the capacitor bank size; a larger bank will generate higher the DV when switched. The second component is the distance the capacitor bank is placed from the source, related to the upline accumulated impedance to the source.
- The further the bank is away from the source the greater the DV. Therefore, for a given bank size, this component is useful to determine the bank's relative position in the circuit.
- To remove the first component (the size of the bank) all banks need to be normalized to the same relative size.
- A base size is used to normalize settings, so if the $KVAR_{base}$ is 1200, then the DV of a 600 KVAR bank would be doubled to obtain the same normalized DV, or in other words, the $DV_{normalized}$.

Autodaptive Capacitor Control – Time delay

- Have the Time Delay with all capacitors having the same base setting.
- Have the Delta Voltage change the bases Setting:
  - Close TD = Base TD/Delta Voltage.
  - Open TD = Base T*Delta Voltage.



Autodaptive Capacitor Control – Time delay

- This allows for common settings being applied to all capacitor banks, where the individual time delays are automatically calculated and updated based on Delta V, which is driven by bank location as described earlier.
- The result is a distribution of time delays across the circuit while providing for adequate time spacing between banks, with the shortest delay always being on the bank farthest from the source, and longest delay closest to the substation.
- The time delays will thus automatically adjust for changes in system impedance or circuit reconfiguration as Delta V adjusts.

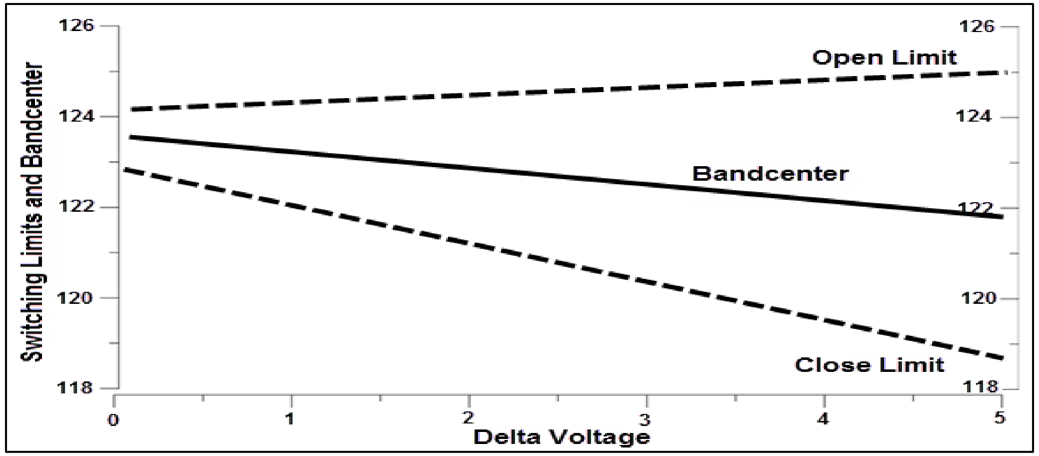
Autodaptive Capacitor Control – Band Center

- Preferred Band Center – This is the desired voltage where the bank is located in the circuit and should be set to the same value as the bandcenter on the upstream regulator or substation LTC. A difference between these levels can be adjusted to yield the desired balance point for the utility. The upper and lower switching limits are dynamically calculated based on the measured Delta V and a Bandwidth setting. This ensures the capacitors will not overshoot the limits when switching.

Autodaptive Capacitor Control – Bandwidth

Bandwidth (Adder to Delta V) – Bandwidth is the value used to calculate the open and close voltage levels of the capacitor bank. This bandwidth value is added to the Delta $V_{normalized}$ and the result is divided in half. That subsequent value is then either added (to obtain the open voltage) or subtracted (to obtain the close voltage) from the $BandCenter_{actual}$. If this value is zero, the capacitor bank closing would move the actual voltage from the lower band edge to the upper band edge, and hunting could occur.

Open Bank Voltage = $BandCenter_{actual}$ + ($DV_{normalized}$ + Bandwidth) / 2
Close Bank Voltage = $BandCenter_{actual}$ - ($DV_{normalized}$ + Bandwidth) / 2



Autodaptive Capacitor Control – Band

- As an example, if the $BandCenter_{actual}$ is 123 Vac and the $DV_{normalized}$ is 1 volt and the Bandwidth is 1.5 volts, then the capacitor bank operating limits would be as follows.
- Open Bank = 123 + (1+1.5)/2 = 124.25Volts
- Close Bank = 123 – (1+1.5)/2 = 121.75Volts
- Leaving all settings the same but changing the Bandwidth to 3Vac would then result in operating limits as follows:
- Open Bank = 123 + (1+3)/2 = 125.0Volts
- Close Bank = 123 – (1+3)/2 = 121.0Volts

Line Resistance Band Center Correction (LRBC)

- This setting adjusts the Preferred Bandcenter by a factor of the Delta V to account for the resistive voltage drop that occurs across a circuit.
- The capacitor banks will attempt to minimize the reactive current but can’t change the real current. If there is significant real current in the circuit the voltage drop due to this real current will cause the banks at the end of the circuit to operate (close) and can drive the circuit too far leading.
- The compensation in the tapchanger controls will then tap to force the voltage higher attempting to turn one or more capacitor banks back off.
- The solution is instead to lower the bandcenters on each capacitor control by the amount of voltage drop caused by the real current. In doing so, each control only responds to the voltage drop that is due to the reactive portion.

Autodaptive Capacitor Control – Summary

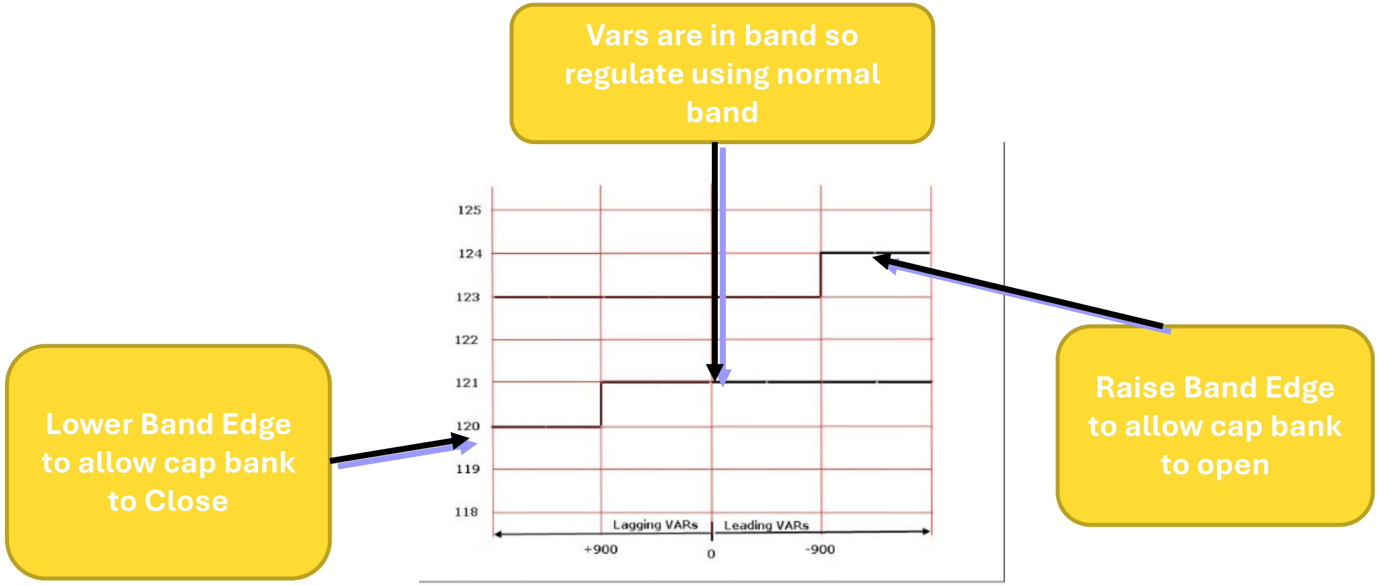
- The Cap banks have a nominal size and the Delta V is nominalized from this so that cap banks of different sizes have proportional DV.
- All Cap banks have the same base TD and the Delta V of each is used to make them unique.
- Care must be taken to verify that the Delta V is different for each (2 cap banks off of different laterals may have the same Delta V).
- Bandcenter is the Average voltage seen on the circuit.
- Bandwidth is a function of the DV plus some margin to reduce hunting.
- This will allow the cap bank with the largest DV to be first to close and last to open without settings.
- When sectionalized, cap banks will mis-coordinate for 1 operation but will automatically calculate new time delays as the DV changes.
- Works equally well under forward and reverse conditions

Caps First Now Regulators/LTC

- The Auto-Adapter functions allow the capacitors to operate in the desired sequence.
- Next, we need to coordinate the Regulators and LTCs to assist by using Var Bias.
- Use a “VAR-Bias” characteristic to change the response of the REGC or LTCC.
- The VAR-Bias characteristic can be tailored for normal operation (non-CVR) and CVR operation:
    - Normal (non-CVR) Operation: Negative VAR Bias.
    - CVR Operation: Positive VAR Bias.
    - Intent is to drive the circuits to unity power factor and reduced losses.

Step Var Bias

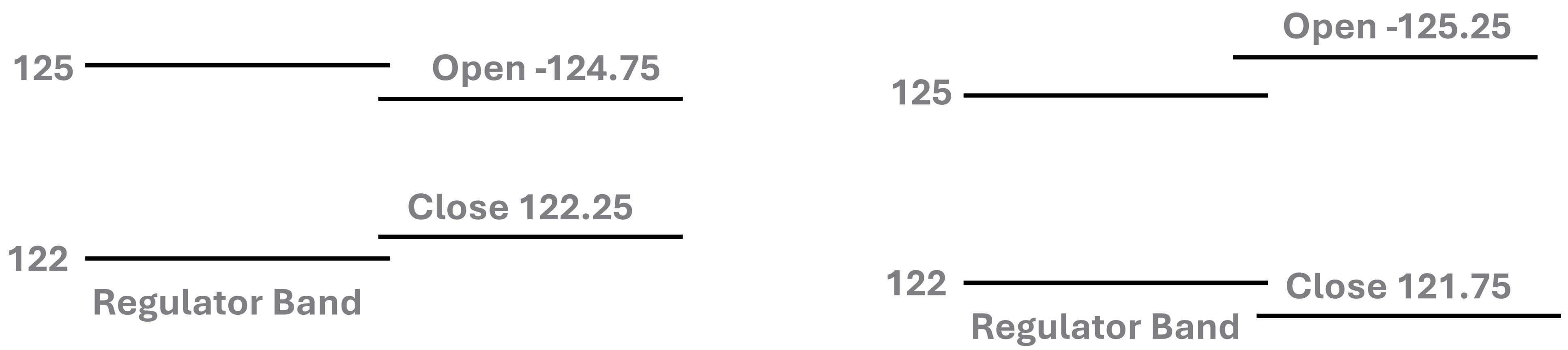
- Shifts one band edge only.
- LTC now looks at both voltage and Vars to determine the operating band.
- Lowers the Low band for lagging Vars to slow down the raise and allow cap banks to close.
- Raises the Upper Band for leading Vars to slow down a lower and allow a cap bank to open.
- Timer will release the Bias if cap banks don't operate and will generate an alarm to SCADA to indicate either failed cap banks or a circuit that needs additional cap banks.



VAR Bias Band Edges with 122 Volt Bandcenter and 2 Volt Bandwidth

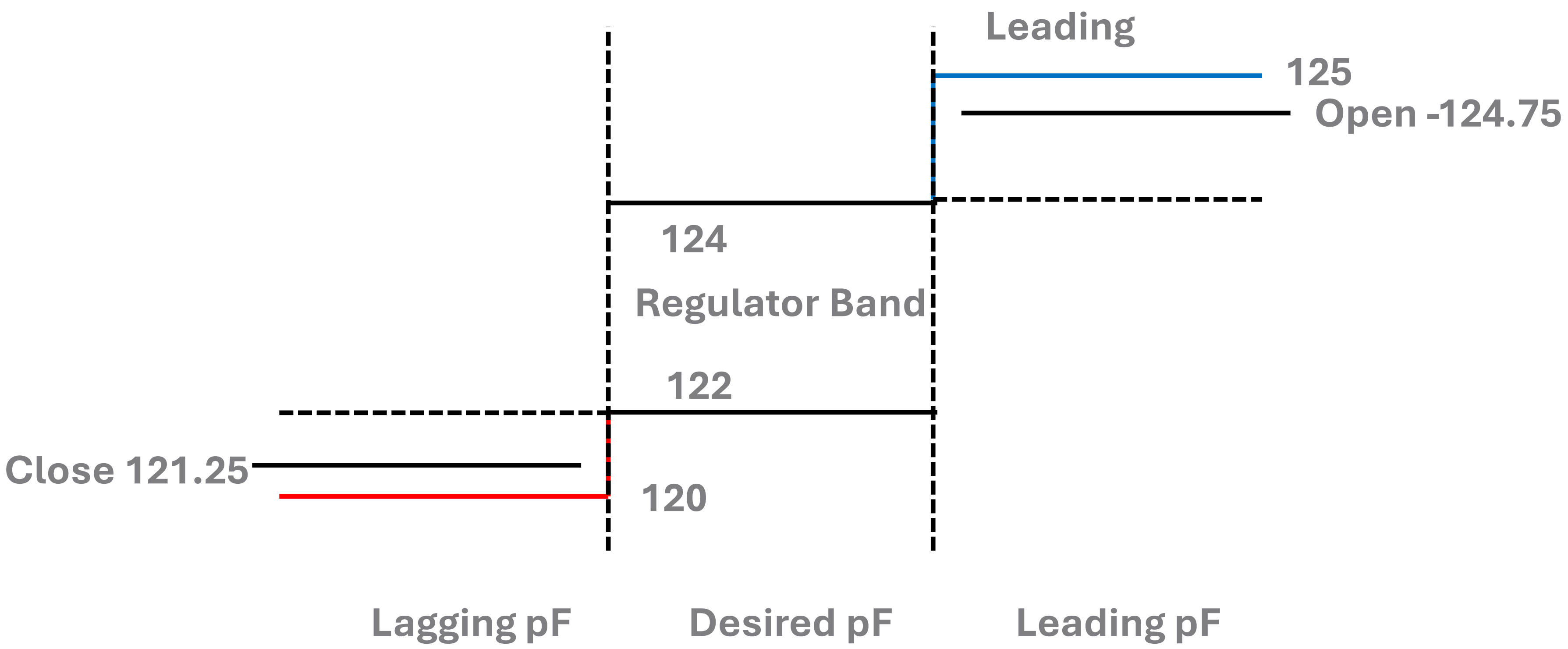
Step Var Bias

- To coordinate Caps and Regs prior to VAR Bias the Cap Bands needed to be inside the Reg Bands.
- This places a limit on the amount of Voltage Rise a Cap Bank can create.
- If the Cap Band edges are outside the LTC/Reg then the caps may not operate as the LTC/Regs may correct the voltage first.



Step Var Bias

- Var Bias allows for a larger Delta V.
- When pF is within desired limits the edge of the regulators will be inside that of the cap bank and the regulator will correct the voltage.
- When the pF is outside the desired limits, the regulator will dynamically shift edges to allow the cap bank to know be inside the edge of the regulator and the cap bank will operate to fix the voltage.



VAR Bias

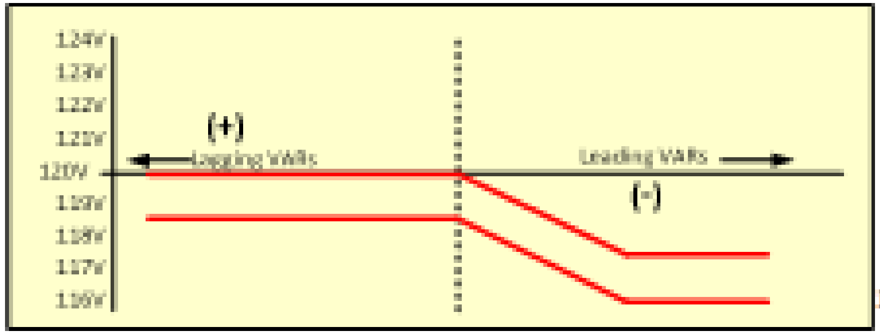
VAR Bias (LTCC and RECC)

- In the **Positive Mode (CVR)**, as:
  - VARs flow toward source (leading VAR at LTCC/REGC)
    - – Voltage bandcenter lowers, causing voltage-controlled:
      - ▪DERs to increase VAR output
      - ▪CAPCs to switch banks on, outputting VAR
  - VARs flow toward load (lagging VAR at LTCC/REGC)
    - – Voltage bandcenter rises, causing voltage-controlled:
      - ▪DERs to decrease VAR output
      - ▪CAPCs to switch banks off, stopping VAR output

➢ This action tends to allow deep voltage reduction at the feeder origin as end of line voltage is higher than at REG or LTC output

CVR Application

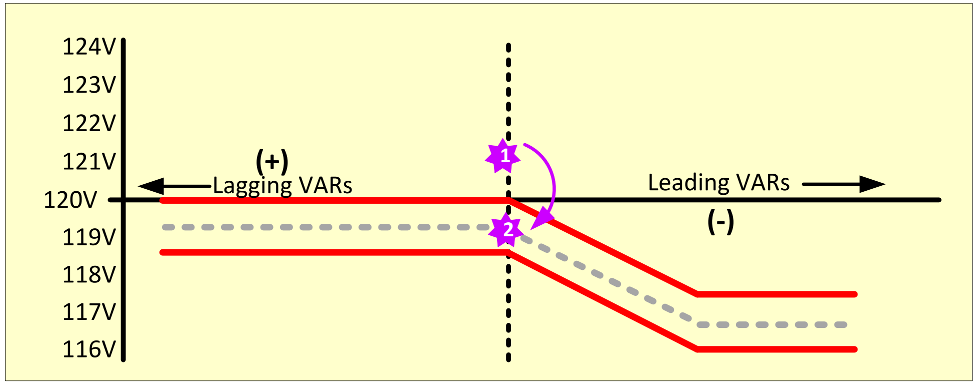
Positive Linear VAR Bias



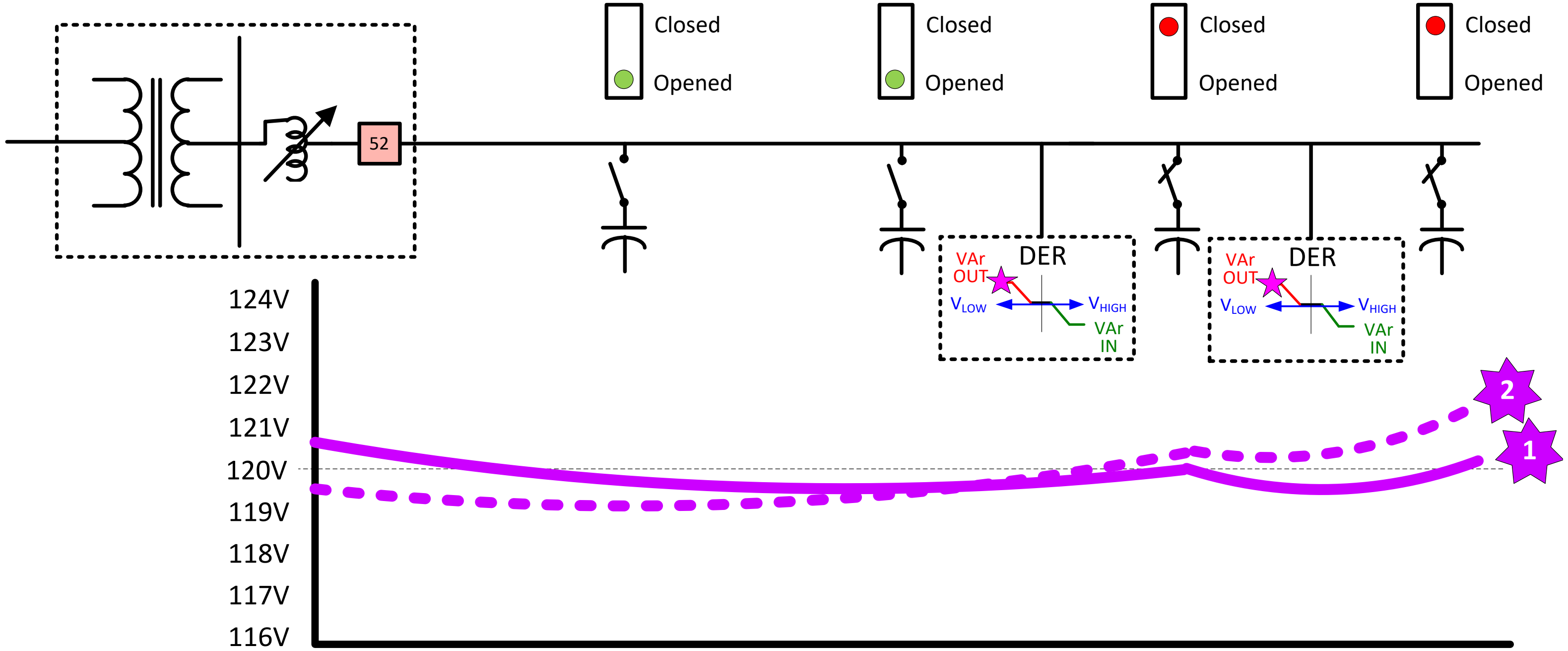
CVR Operation: Positive VAR-Bias

CVR Application

***Positive* Linear VAR Bias**



CVR OPERATION



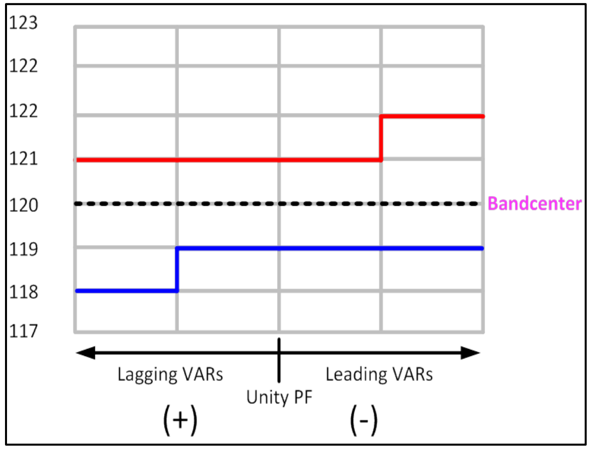
- REG forces voltage lower.
- CAPs begin to switch on.

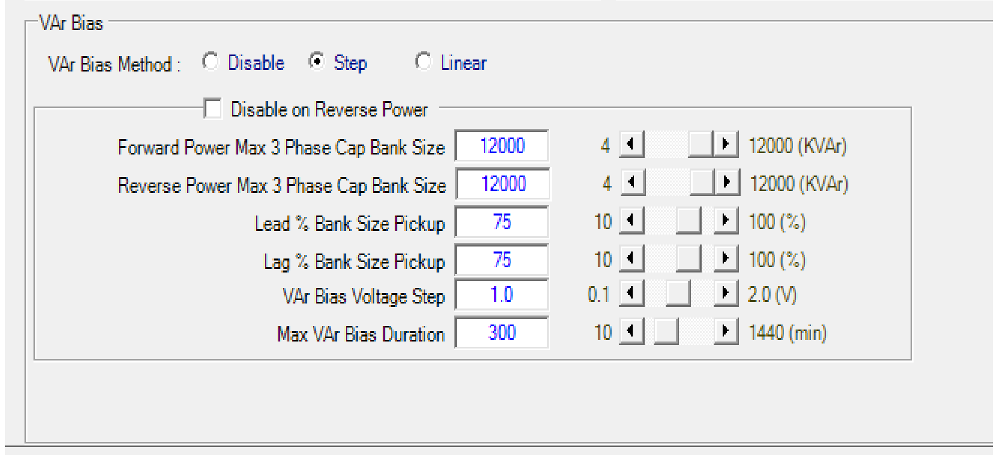
Var Bias for Regulators and LTCs

- The Var flow of the downstream circuit will bias one edge of the regulator/LTC control.
- Use Step Var Bias on only one edge of the Band.
- Allows user to determine the amount the band edge is moved.
- Allows user to determine at what Var flows the band edge is moved to obtain desired power factor on the circuit.
- Allows capacitors to regulate the voltage as long as the circuit stays within desired pf and therefore reduces operations on the regulators/LTC.
- Remove the Bias after a pre-determined amount of time if Var flow is still out of band.

Settings for Step Var Bias

- Forward Power Max 3 Phase Cap Bank Size – The largest capacitor bank size in the forward (downline) direction from the tapchanger in its regulation zone.
- Reverse Power Max 3 Phase Cap Bank Size – The largest capacitor bank size in the reverse (upline) direction from the tapchanger in its regulation zone.
- Lead % Bank Size Pickup – Leading VArs as a percentage of the Max 3 Phase Cap Bank Size, above which the upper band edge will be increased by the VAR Bias Voltage Step.
- Lag % Bank Size Pickup – Lagging VArs as a percentage of the Max 3 Phase Cap Bank Size, below which the lower band edge will be decreased by the VAR Bias Voltage Step.
- Timer – Turns off VAR Bias settings if capacitors do not react.





Bob McFetridge –Hubbell Utility Solutions – Beckwith Electric

919-675-3372

910-777-4910
bmcfetridge@hubbell.com

www.BeckwithElectric.com

(727) 544-2326