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Volt/VAR Control & CVR

PA Fall Engineering Section Meeting

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Terminology

- IVVC: Integrated Volt/VAR Control
  - Operating transformer load tap changers (LTCs), voltage regulators and capacitor installations to control voltage and VAR flow on the distribution system in specific ways to optimize voltage profiles
- CVR: Conservation Voltage Reduction
  - Minimizing end-use voltage within ANSI limits to reduce peak demand and possibly overall energy consumption

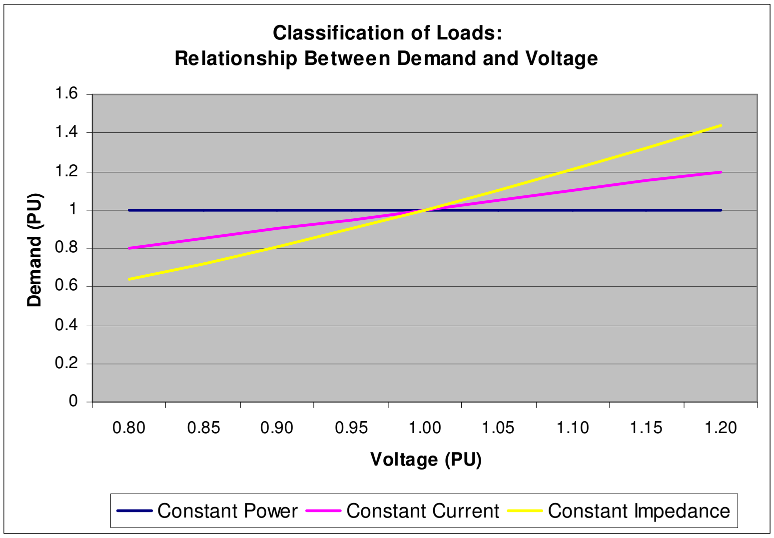
How is CVR Supposed to Work?

- The amp draw of certain electric devices is proportional to the voltage used to energize the device.
  - These devices are called constant impedance or partial constant impedance loads.
- When the overall voltage on a distribution system is reduced, the current (and associated demand) of all constant impedance and partial constant impedance loads will decrease.
- The amount of demand decrease per voltage reduced is called the CVR ratio. (%D/%V)

ZIP Loads

- Loads can be broadly characterized in three categories
  - Constant Impedance (Z)
  - Constant Current (I)
  - Constant Power (P)
- With each load type demand varies differently as a function of voltage

Relationship Between Demand & Voltage



Classification of Typical Loads

Load Type	%Pf	$\%S_{PQ}$	%Z	%I
Resistance heaters, water heaters, ranges	100	0	50	50
Heat pumps, air conditioning, refrigeration	80	15-35	20-40	45
Clothes dryers	99	0	0	100
Televisions	77	0	0	100
Incandescent lighting	100	45	35	20
Fluorescent lighting	90	0	50	50
Pumps, fans, motors	87	40	40	20
Arc furnace	72	0	30	70
Large industrial motors	90	60	40	0
Large agricultural water pumps	84	0	75	25
Power plant auxiliaries	80	40	40	20

Source: State of Washington load research

Constant Impedance Loads

- Demand is proportional to the voltage squared.
- As voltage is decreased, the demand and the current decrease and vice versa
- $P=VI=V^2/Z$
- Beneficial to CVR
- Examples
  - Water Heaters
  - Resistance Heat
  - Incandescent Lighting

The Physics of CVR: Lighting Loads

Lighting:

- Simple incandescent light bulb is resistive load.

  $W \sim V*I = I^{2*}R$.

  » Reduced Voltage = Reduced Demand + Reduced Consumption
- Fluorescent lighting with conventional electromagnetic ballasts will behave almost like incandescent lamps with reduced lumen output.

  » Reduced Voltage = Reduced Demand + Reduced Consumption
- Modern fluorescent lamps with electronic ballasts will continue to draw almost the same power and deliver the same lumens.

  » Reduced Voltage = No significant impact on demand and consumption.

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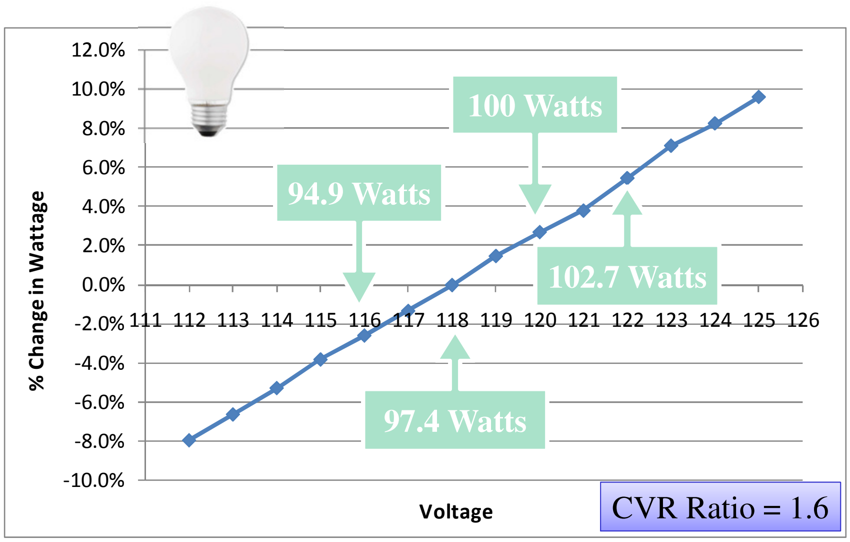
Incandescent Lighting



9

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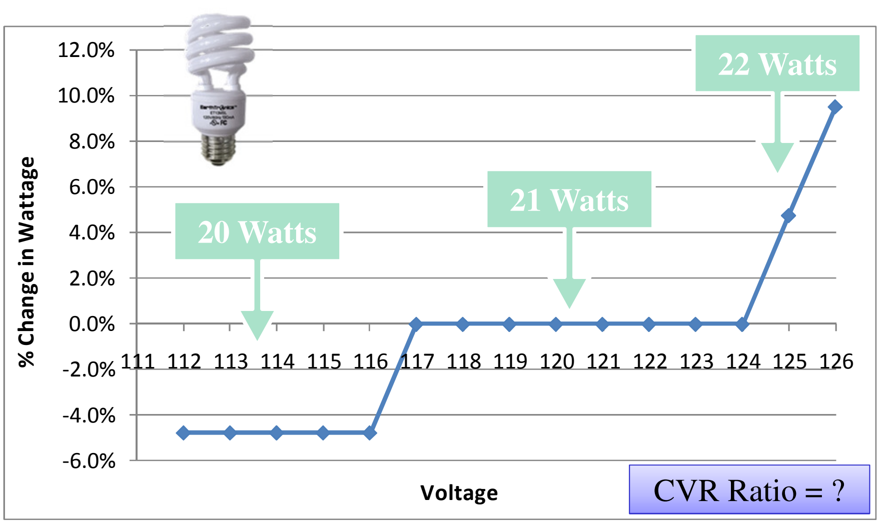
Compact Florescent Lighting



10

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Pertinent Questions

- Why would anyone want to consider CVR?
- How do you know if CVR is right for your utility?
- How do you implement it?
- What operational issues should you be aware of after CVR is implemented?
- How do you measure and verify what is being achieved?

11

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CVR Benefits

- Societal
  - Reduced carbon emissions
  - Improved efficiency
  - Doing the right thing for cooperative members by reducing their usage and bills
- Financial
  - Reduced wholesale/generation capacity costs
  - Reduced energy losses
  - Reduced revenue from energy sales – Not a Benefit

12

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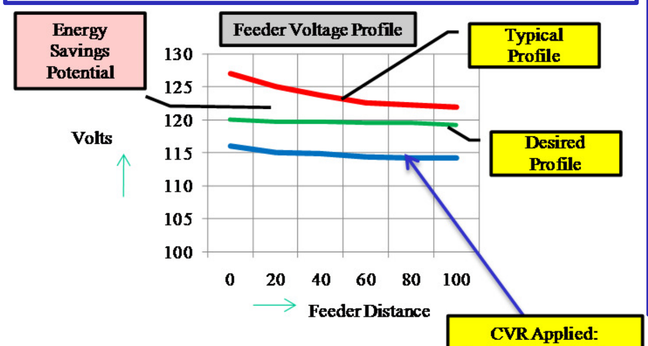
CVR: Key Benefits

CVR for Peak Demand Reduction

- Goal: reduce peak demand and demand costs
- Method: controlling system voltage through advanced DA.
- Result: reduce distribution system coincident peak (MW). Peak demand cost savings.



CVR for Energy Consumption Reduction

- Goal: reduce energy consumption (energy savings)
- Method: controlling system voltage through advanced DA.
- Result: reduced MWH through reduction in consumption and, to a lesser extent, reduction in energy losses.

13

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Voltage Optimization

- To maximize benefits of CVR, cost-effective measures to improve system voltage and efficiency should be considered in advance
  - Feeder load balancing
  - Multi-phasing heavily-loaded single-phase taps
  - Feeder VAR flow control via capacitor placement
  - Voltage Regulators: placement and control settings
- All of these things help to flatten the voltage profile and allow for lowering the voltage further

14

Voltage Optimization

- "Cost-effective" meaning
  - These measures should have a positive return by their own merits without considering CVR
  - Can be justified on their own and should be considered during the normal planning process regardless of CVR
- The financial benefits of voltage optimization in advance of CVR not normally included in the CVR business case

Volt/VAR and CVR

A solid Volt/VAR scheme can improve or alleviate many of these.

Pain Points	Cause	Severity		VAR	CVR
PF Penalties	G&T charges for Lagging Power	$$	Penalties	✓✓	
Lost Capacity	Excess current due to inductive loads uses up line capacity.	$	10-20% Excess Current	✓✓	✓
Line Losses	Resistance in wire uses Real power	$	20-40% Excess Line Losses	✓✓	✓
Voltage Drop	Excess current and line loss leads to excess voltage drop	$	10-20% Excess Voltage Drop	✓	✓
Lost Generation	Customers charged for W but Generation covers VA	$$$	Unbilled Generation	✓✓	
Peak Penalties	Excess energy usage during coincident peak periods	$$$	Peak Rates	✓	✓✓

CVR Financial Benefits - Demand

- Heavily dependent on demand (capacity) costs and how they are incurred
- Utilities that purchase power through wholesale contracts (e.g. all requirements contract with a G&T)
  - Depends on wholesale rate structure
    - Ratcheted peak demand charges
    - Monthly coincident peak charges
  - CVR typically implemented with other DSM programs
  - Frequency of voltage reduction events also depends on wholesale rate structure

CVR Financial Benefits - Energy

- True "CVR"
- CVR operated at all times (not just during peaks)
- Added level of difficulty
  - Energy is demand over time
  - Changes in instantaneous demand do not necessarily yield changes in energy usage
    - Example: Thermostatically controlled loads
  - Realistic level of voltage reduction not as pronounced due to possible power quality concerns

CVR Financial Benefits - Energy

- Most energy reduction comes from reduced consumption (sales)
  - Approximately 90% of reduced energy requirements
  - Lost revenue has to be planned for in financial forecast to insure rates will still collect needed revenues
- The remaining energy reduction experienced (approximately 10%) comes from reduced losses
  - Mostly reduced transformer core losses
  - Some from reduced line losses due to lower current flowing through the lines

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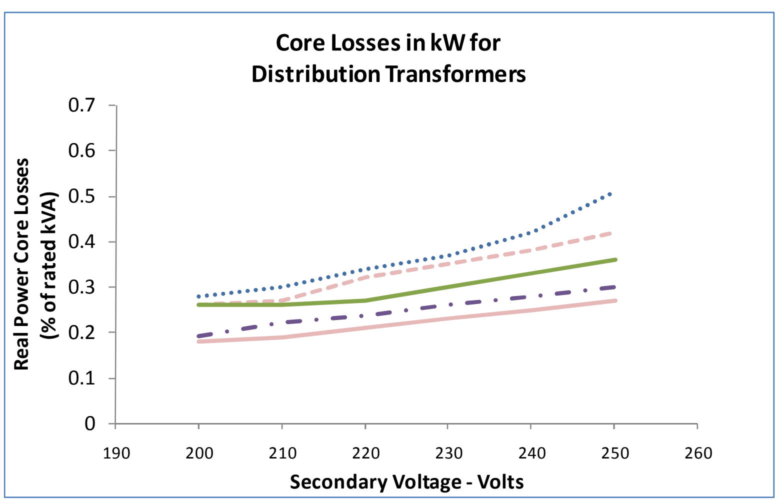
Transformer Core Losses



Energy Reduction Example

WINTER	Change in Voltage (120V Base)	Change in Voltage (%, 120V Base)	Percent Energy Reduction[1]	Percent Loss Reduction
Eaton Substation	2.04	1.7%	1.3%	0.16%
From EPRI Study[2]			*0.9%*	*0.07%*
Oriskany Falls Substation	2.05	1.7%	1.3%	0.16%
From EPRI Study[2]			*1.1%*	*0.13%*
Fenner Substation	1.84	1.5%	1.2%	0.14%

[1] Based on a CVR of 0.8

[2] Note that the EPRI values are annualized, and not directly comparable to the seasonal value indicated.

Can CVR be Effective on Your System?

- Conduct a feasibility assessment
  - What is the load mix on your feeders?
    - Are there feeders where voltage reduction will not work?
    - What is the expected CVR ratio that can be achieved?
  - What are the voltage profiles of your feeders?
    - How much could the voltage on each feeder be reduced today without any additional capital investment?
    - What cost-effective improvements can be made to better optimize voltage profiles to obtain greater levels of voltage reduction (IVVC)?

Can CVR be Effective on Your System?

- Conduct a feasibility assessment (continued)
  - What existing systems are in place that can be utilized? (e.g. SCADA, AMI, DMS, etc.)
  - What is required to actually implement voltage reduction?
    - Control upgrades?
    - Communications to devices?
  - Peak demand reduction or energy reduction?
  - How much benefit in terms of dollars saved is derived?
  - Cost/benefit analysis and business case
  - Conducting a Pilot

CVR Modeling Considerations

- Analysis of CVR for energy reduction requires use of time-series simulations
- Behavior of end use loads is more complicated than generally acknowledged
- Inferring measured peak demand load behavior for the rest of the year is not adequate
- For CVR to be effective, it must be possible to reduce the average voltage along the entire feeder

KP Schneider, FK Tuffner, JC Fuller, R Singh
Evaluation of Conservation Voltage Reduction (CVR) on a National Level
PNNL-19596, Pacific Northwest National Laboratory
US Department of Energy, July 2010

Feasibility Assessment Considerations

- Estimating financial demand/energy savings during peak time periods can be done easily once the amount of demand (kW) that can be reduced through CVR and the number of control events is determined
- Estimating energy savings/costs if operating CVR all the time can be challenging and complex
  - Loads over time react differently to changes in voltage
  - Changes in instantaneous demand do not necessarily yield changes in energy usage (e.g thermostat controlled loads)
  - *Remember that energy reductions are primarily derived from reductions in sales, not losses!*

How Is CVR Implemented?

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Distribution System Voltage Levels

- Voltage on distribution system typically operated between 118 Volts and 126 Volts (on a 120 Volt base)
- Both high and low voltage is a concern
- Voltage regulators at substation and on the lines set around 123 – 126 Volts step the voltage up or down as needed to maintain this set point

27

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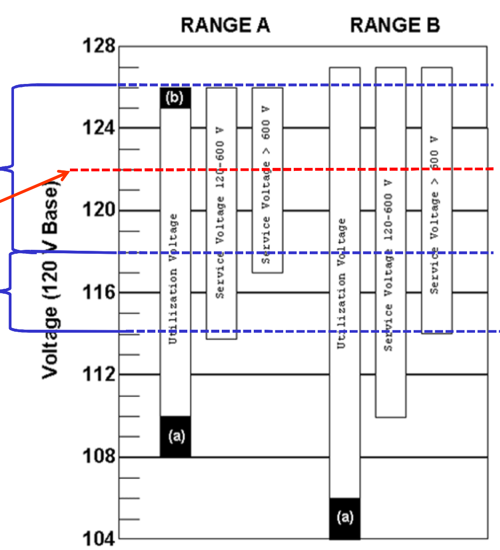
Standard Voltage Range

Typical Planning and Operating Range of Primary System

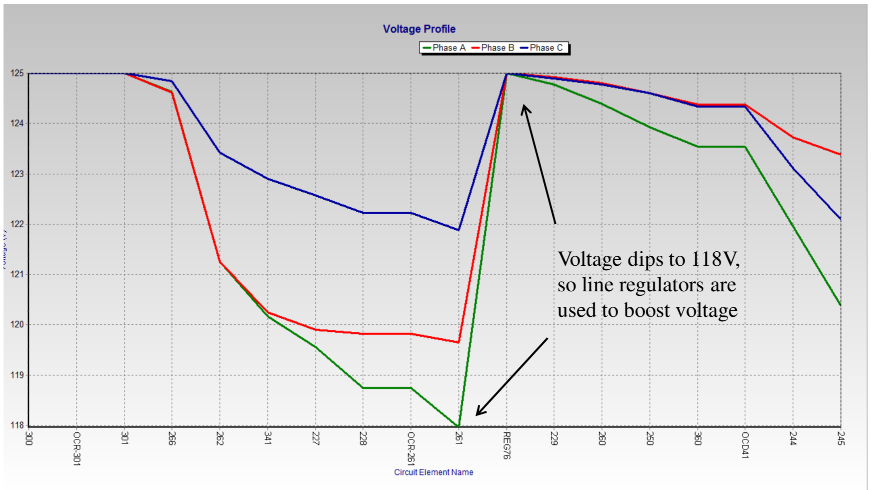
Average System Voltage

Allowed Operating Range of Secondary System



28

Voltage Profile



Efficiency Measures

- To maximize benefits of CVR, cost effective measures to improve system voltage should be considered in advance
  - Feeder load balancing
  - Multi-phasing heavily-loaded single-phase taps
  - Feeder VAR flow control via capacitor placement
  - Voltage Regulators: placement & control settings
- All of these things help to flatten the voltage profile and allow for lowering the voltage further (Voltage Optimization)

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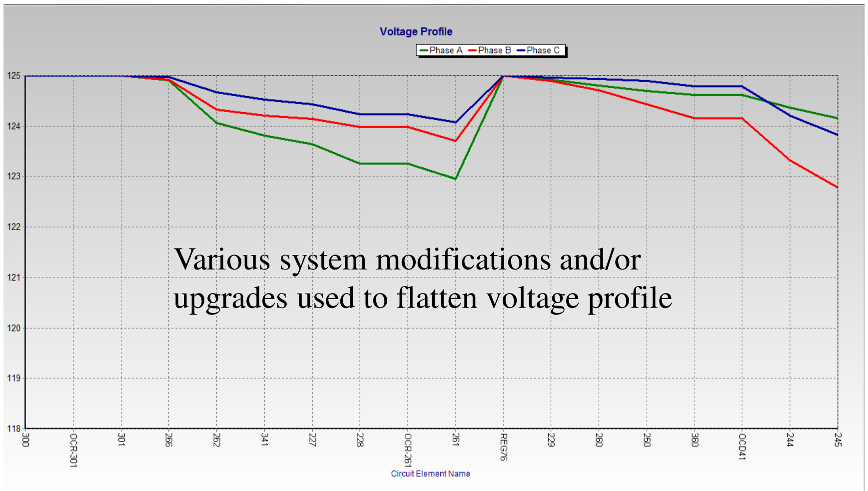
Voltage Profile: Flattened



31

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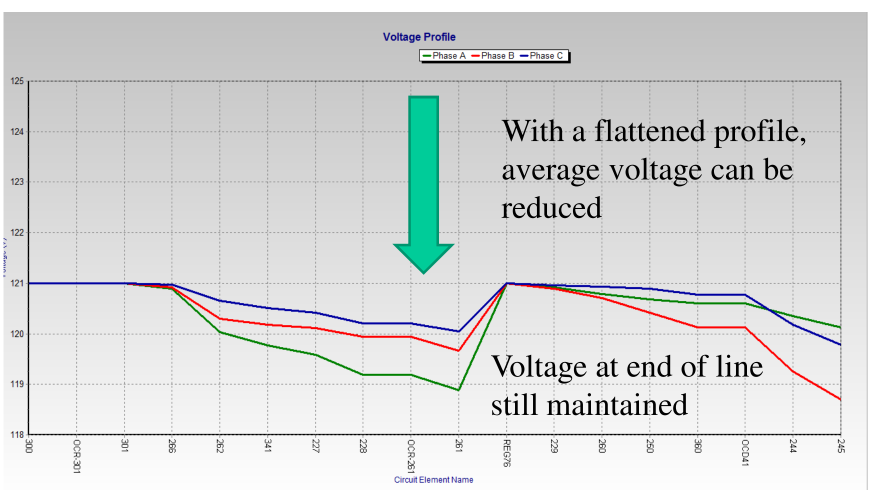
Voltage Profile: Flattened and Lowered



32

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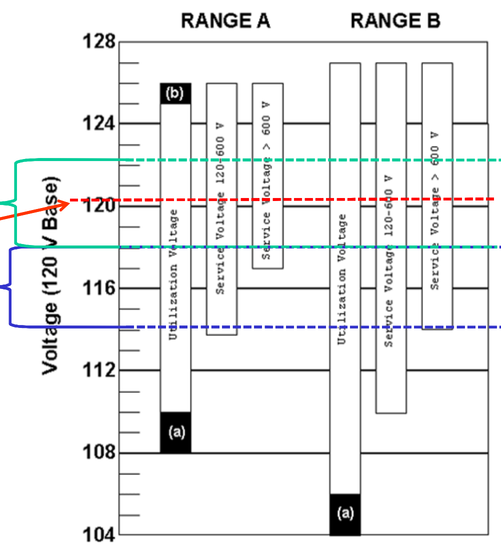
CVR Voltage Range

CVR Planning and Operating Range

Average System Voltage

Allowed Operating Range of Secondary System



33

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Methods of Implementation for CVR

- CVR typically implemented using voltage regulators and Load Tap Changers
- Control settings
  - Manually adjust settings through SCADA
  - Automatically adjust settings through SCADA once a load control event is triggered
  - Line Drop Compensation (LDC)
    - Voltage reduction on a continual basis
    - No real-time feedback so must be conservative
  - Dynamically through SCADA and end of the line voltage monitoring/feedback

34

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Implementing Demand Response

- Changes to regulator settings and capacitor switching can be predetermined based on system modeling
  - Typically must be conservative since do not have real-time data
  - Risk either not lowering voltage as much as possible or giving low voltage to some customers
- Decisions on changes to settings can be made based on real-time data
  - Need end-of-line voltage data
  - If EOL voltage < than desirable, then increase voltage
  - If EOL voltage > than desirable, then lower voltage

35

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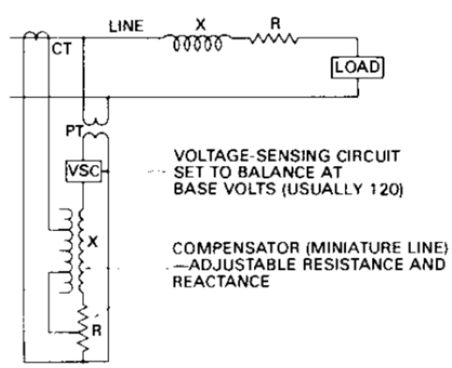
Regulator Line Drop Compensation

- Load current is monitored
- Regulator adjusts output to maintain a desired voltage at some downline point
  - Effectively reduce voltage during lower loading periods
  - Maintain adequate voltage support during peak loading periods

"R" and "X" settings (in volts) represent cumulative resistance and reactance of the downline feeder

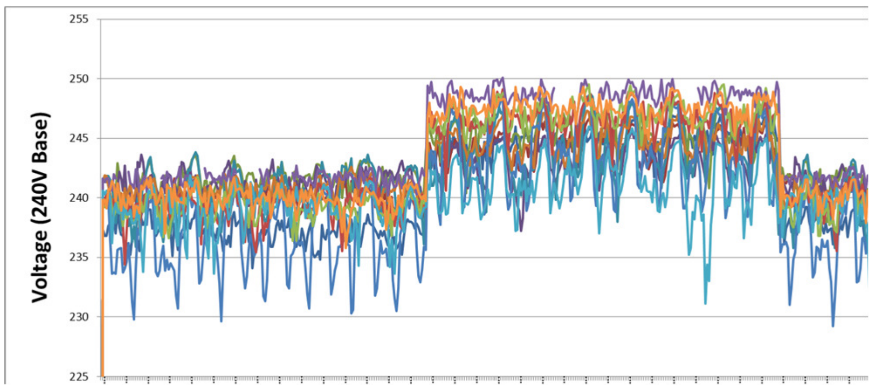


Cooper Power Systems R225-10-1, "Voltage Regulating Apparatus, Determination of Regulator Compensator Settings"

36

LDC Example Results

SUMMER	Change in Voltage (120V Base)	Change in Voltage (%, 120V Base)
Eaton Substation	2.3	1.9%
Oriskany Falls Substation	2.6	2.2%
Fenner Substation	2.0	1.7%



Dynamic CVR

- AMI system can be used to gain access to close to real-time voltage data and provide feedback to SCADA system
  - Need a minimum of 3 points (one for each phase)
  - The more points the better the volte profile can be tweaked (too many points may cause problems)
- SCADA system programmed to poll meters just like any other data point – SCADA and AMI must interface (MultiSpeak)
- Based on voltage readings, SCADA system operates as programmed to operate regulators and capacitor banks

Solution Steps

Implement a Volt/VAR and CVR Program in phases

Step	Description	Phase	Benefit
1	Capacitors in substation	Traditional Starting Point	Avoid PF penalties
	LTC on substation transformer		Periodic adjust substation voltage
	Substation feeder regulators		Independent Feeder adjustment
	Stand-alone fixed & switched feeder capacitors		Basic line loss reduction & voltage/capacity improvement
	Stand-alone feeder regulators		Basic maintenance of voltage
2	Optimize VAR flows with addt'l fixed/switched caps	Integrated Volt/VAR Control	Advanced line loss reduction & voltage/capacity improvement
	Optimize voltage profiles		Advanced control of voltage profiles and system operating efficiency

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Solution Steps (continued)

Implement a Volt/VAR and CVR Program in phases

Step	Description	Phase	Benefit
3	Manual SCADA control of capacitors & regulators	Basic CVR	CVR for peak demand reduction
	LDC settings in regulators not SCADA controlled		CVR for peak demand and energy reduction
	Local capacitor controls for those not SCADA controlled		CVR for peak demand and energy reduction
4	Integrated monitoring with AMI & Feeder DA equipment	Advanced CVR	Continuous feedback for real-time decision-making
	Dynamic CVR through DMS or other DA control software		Continuous CVR for highest optimization

Operational Concerns with CVR

Operational Concerns to Consider

- Obtaining desired voltage reduction
- Contingency and switching
- Seasonal variations in load and potential to reduce voltage
- Sizing transformers and secondary services
- Capacitor operation
- AMI issues related to obtaining end-point voltage
- Low voltage complaints
- Impact of distributed generation

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Obtaining Desired Voltage Reduction

- Simply lowering the voltage setpoint of voltage regulator controls may not achieve the level of voltage reduction desired
- Capacitor switching controls may need alternate switching settings during CVR events to support voltage

43

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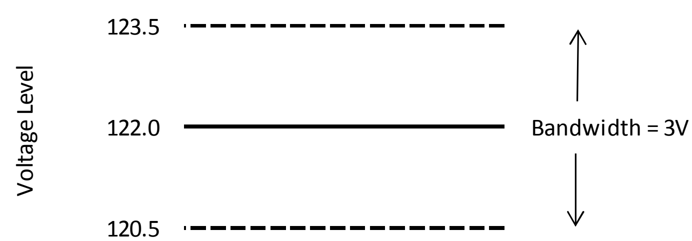
Regulator Settings



- Voltage Setpoint – voltage to hold at point of regulation
- Bandwidth – allowed deviation from the voltage setpoint before the regulator responds with a tap change
- Time Delay – time delay between when the regulator control determines a tap change is required and when the tap change actually occurs

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44

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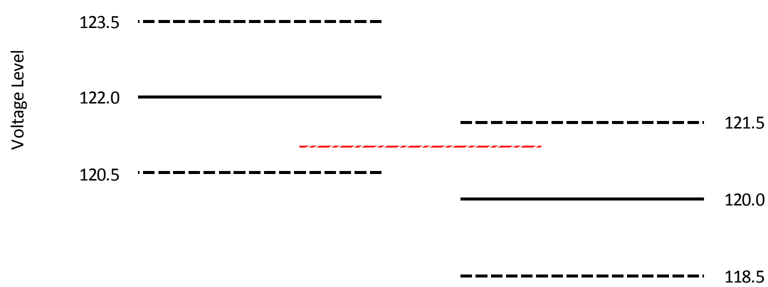
Issues During Voltage Reduction



Before voltage reduction:
- Setpoint = 122.0 V
- Actual Voltage = 121.0 V
- On lower side of band

During voltage reduction:
- Setpoint = 120.0 V
- Actual Voltage = STILL 121.0 V
- On upper side of band

45

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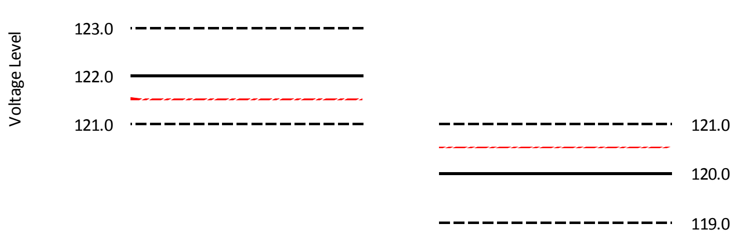
Issues During Voltage Reduction



Before voltage reduction:
- Setpoint = 122.0 V
- Actual Voltage = 121.5 V
- On lower side of band

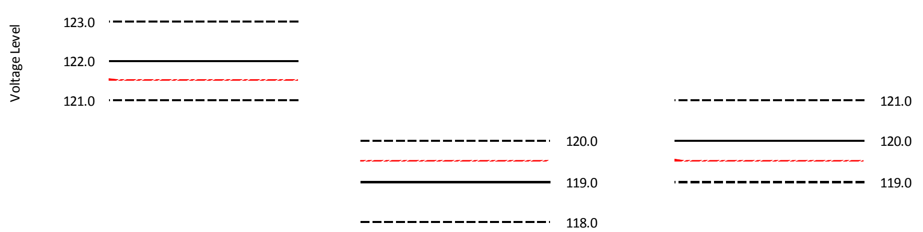
During voltage reduction:
- Setpoint = 120.0 V
- Voltage above upper band, so tap down issued
- Actual Voltage = 120.75 V (asuming 0.75 V/tap)
- DID NOT ACHIEVE DESIRED VOLTAGE REDUCTION
- On upper side of band

46

Possible Solution

- May need to consider different strategies to actually achieve the desired voltage reduction level
  - Initially send a command to lower voltage further than desired
  - Wait appropriate time for tap operations to occur
  - Send a command to set voltage at final desired reduced level
- Some new regulator controls may have methods built in to achieve similar results with less effort
  - Disabling upper band until cross band center

Possible Solution



Before voltage reduction:
Setpoint = 122.0 V
Actual Voltage = 121.5 V
On lower side of band

During voltage reduction (Step 1):
Setpoint = 119.0 V
Voltage above upper band, so 3 tap downs issued
Actual Voltage = 119.25 V (asuming 0.75 V/tap)
On upper side of band

During voltage reduction (Step 2):
Setpoint = 120.0 V
Voltage in band, so no more taps issued
Actual Voltage = 119.25 V
On lower side of band

Capacitor Switching

- Common to have capacitor switching controls set to switch on VARs
- During CVR events, may need to switch capacitors on Volts to flatten voltage profile and maintain acceptable voltage levels along the feeder
  - Power factor may go leading during these times
  - Capacitors may not switch out immediately after the CVR event is over if voltage does not go high enough
  - May need to consider a strategy similar with regulators to temporarily raise the voltage more than desired and then set at normal level to get capacitors to switch out

Contingency and Switching

- During system contingencies and switching, pre-programmed voltage reduction strategies may not be adequate
  - Voltage may be much lower than under normal circumstances
  - LDC settings may not adequately account for the amount of line beyond the regulation point
- Dynamic control strategies may not operate either because meters may be fed by other feeders and now may not necessarily represent the EOL
- May need to turn CVR off during these times

Seasonal Variations in Load

- Level of voltage reduction impacted by season
- Types of loads differ by season
- May need different strategy during different seasons
- Dynamic CVR may be fine all year long

Sizing Transformer and Secondaries

- Low voltage at a few customers due to undersized transformers and secondary services can significantly impact level of voltage reduction allowed
- In addition to reviewing the primary system, must also examine secondary system as well
  - Modeling
  - Billing data - MDM
  - Field measurements

Capacitor Operation

- Concerns with
  - Switching transients
  - Harmonics
  - Noise
  - PLC AMI systems
- Capacitors also often have fuses blow and without specific detection means in controls, will not be aware of part or all of bank being offline

AMI Concerns

- Some AMI systems only allow reading meters on a certain interval
  - TWACS meters can only be read about every 15 minutes
  - May need to monitor more meters
    - Example – 3 meters per phase at end of a feeder can allow 3 meters at a time to be read every 5 minutes
- AMI modules may not have meter class voltage accuracy
- AMI system must be able to interface with SCADA or DMS (MultiSpeak)

Low Voltage Complaints

- Risk that needs to be assessed

Impact of DG

- Distributed Generation not presently allowed to actively regulate voltage, but this requirement will likely be eliminated in the near future
- DG will still change the voltage profile due to reduced load on the feeder
- DG is variable
  - Not always online
  - Output may change considerably over time
- LDC with significant DG may not work properly
- Dynamic CVR control most effective means when significant DG present

Measurement & Verification

Monitoring Voltage

- At a minimum, voltage should be monitored in areas where CVR is being implemented
  - Verify that minimum voltages do not fall below ANSI limits
  - Determine if voltage is being lowered as much as possible
  - Determine the impact of CVR on peak and non-peak voltage profiles
- Monitoring can be real-time (preferred) or after the fact with trending of historical data

Determining Demand/Energy Reduction

- Establish baseline for "similar" days
  - Similar weather
  - Similar day of week
  - Similar load shape prior to CVR
- Establish baseline on some number of recent days
  - Heavily influenced by weather
  - May not be as accurate as similar day approach
- Compare baseline without CVR to days that CVR is implemented

Conclusions

- CVR not a new thing
- Many utilities are considering CVR (some are doing)
- IVVC precursor to CVR
- Determine goals - demand response and/or energy reduction
- Critical to do your homework up front before implementing CVR – **conduct feasibility assessment**
- Consider implementing pilots first
- Consider operational concerns

Thank You!

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