Leveraging AMI Solutions with DA Applications to Enhance Volt/Var Optimization

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Leveraging AMI solutions with DA applications to enhance Volt/Var Optimization

- Volt-Var Fundamentals
  - Benefits and Optimization Strategies
- VVO Application Requirements
  - Data Flow - Hardware, Communication, and Software
- Case Study Results
  - Validation of CVR and VVO applications
VVO Benefits

- Conservation Voltage Reduction - (Reduction in Losses + Reduction in End-use Load MWh) x ($/MWh to generate or purchase the next MWh)
  - Decoupling Rates/Green initiatives - Capacity release (MW) due to reduced losses (typically a very sizable $ benefit)
- Energy purchase savings – Reduction in Energy (MWh) to serve losses and end-use load (can be a very sizable $ benefit)
- Power Quality and Reliability Improvement
  - Regulation imposes new requirements with the overall goal of reducing energy consumption and demand - (Reduction in peak load MW) x ($/MW to add capacity or demand charges)
- Public and Employee Safety
Fundamentals: Power Factor

All loads draw apparent power:
VA, kVA, MVA

Two components of apparent power
Real Power: W, kW, MW
Reactive Power: var, kvar, Mvar

Power Factor = \( \frac{\text{Real Power}}{\text{Apparent Power}} \)

\[
pf = \frac{kW}{kVA} = \frac{16 - 4}{16} = 0.75 = 75\%
\]
Volt/Var Fundamentals

- Change in voltage leads to a corresponding change in power consumption:
  - a 1% change in voltage causes a change in kW
  - usually ranging from 0.2% to 1.5%

- Effect of change of voltage on reactive power is even more significant:
  - 1% change in voltage causes a change in kvar
    - usually ranging from 2% to 6%

*The change in load will decay over time, but not to the value before the change in voltage. The amount and time constant of decay depend on the characteristics of the circuit.*

What is Volt/VAR Optimization

- A Flat Feeder Voltage Profile. (improved voltage profile)
- Near Unity Power Factor (minimize losses)
- The ability change the voltage on demand
  - Demand Response - conservation voltage reduction
- The ability to define roles where Voltage or Power Factor are the primary metric based on advance algorithms, real-time data, power flow, constraints and system dynamic needs.
Voltage Optimization

Average Voltage Standard Practice

Volts

126

120

114

Feeder Length

Normal Voltage Operating Range in Current Practice by Utilities

Normal Voltage Operation

124  123  121  120  118  117
Voltage Optimization

Average Voltage
Standard Practice

Average Voltage
VO Practice

ΔV

Feeder Length

System improvements:
- Flattens voltage profile and allows additional voltage reduction; and
- Mitigates/prevents risk of low voltage and customer power quality issues.
Distribution Efficiency

- Voltage optimization
  - Combination of distribution efficiency and CVR
- Why distribution efficiency?
  - Improves the efficiency of the distribution system – that is, reduces system losses
  - More distribution systems can take advantage of CVR.
  - Ensures a certain level of distribution system stability
  - Reduces risk of supplying low voltage to customers.

CVR = conservation voltage reduction
Distribution Efficiency Improves

- Phase balancing
  - At peak and average loads
  - Based on phase AMP and voltage levels
  - Reduces losses and flattens voltage profile

- VAR management
  - At peak and average loads
  - Reduces losses and flattens voltage profile

- Load balancing between feeders and substations
  - Losses should be same on each feeder/substation.

- Balance voltage between phases/feeders in same voltage control zone (area of influence by a voltage control device, such as load-tap changer or voltage regulator).

AMP = ampere  VAR = volt-ampere reactive
Volt/Var Optimization Strategies

- **VAR Optimization - Power Factor Correction**
  - Distribution feeder capacitor bank control provide energy loss reduction by coordinating capacitor banks control.
  - Helps utility’s with avoiding costly power factor penalties

- **Conservation Voltage Reduction (CVR)**
  - Coordinating voltage regulator and LTC controls to reduce feeder voltage levels provide load reduction on substations and feeders.
  - Reduces losses associated with higher voltage profile

- **Volt/VAR Optimization (VVO)**
  - Coordinated Control of substation load tap changers, feeder voltage regulators and capacitor banks ensure VAR and voltage profiles optimize these benefits.
  - Coordination of power factor optimization and reduced losses
Field Hardware

- Communication Enabled – Multi-Vendor Controls for voltage, Var, and substation current/watts (bias)
  - Substation Regulators
  - Substation Capacitor Banks Controls
  - Down-line (Feeder) Regulators
  - Feeder Capacitor Bank Controls
  - Medium Voltage Sensors
  - Customer Meters
Example Architecture - VVO

SCADA / EMS / DMS

Field Commands

VVO SERVER

Database

Field Commands

Regulator/LTC

Cap Control

Recloser

DNP 3.0/WAN

DNP 3.0

Measurement data

AMI

C12.22

Meter/Voltage

VVO SERVER
CVR: NW Energy Efficiency Alliance

- Controlled Voltage at Substation
  - Used Line Drop Compensation
  - Used End of Line voltage feedback loop
- 6 Utilities, 10 Substations, 31 Feeders
- Performed System Improvements
  - Installed Feeder Meters
  - Phase Balancing
  - Voltage Regulators
  - Capacitors
CVR: NW Energy Efficiency Alliance - Results

<table>
<thead>
<tr>
<th>Project</th>
<th>Voltage Reduction (ΔV)</th>
<th>CVRf (%ΔE/%ΔV)</th>
<th>Energy Savings (MWh)</th>
<th>Energy Savings (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load Research</td>
<td>5.20V - 4.3%</td>
<td>0.569</td>
<td>87</td>
<td>2.15%</td>
</tr>
<tr>
<td>Pilot Demonstration</td>
<td>3.03V - 2.5%</td>
<td>0.690</td>
<td>8,476</td>
<td>2.07%</td>
</tr>
</tbody>
</table>

- 345 kWh per residential home annualized (Load Research project)
- Cost for majority of pilots of less than 5 Mills ($0.005 per kWh)

ΔV – change in voltage
ΔE – change in energy
MW – megawatt
kWh - kilowatt hour
MWh – megawatt hour
Case Study

Northwest Energy Efficiency Alliance
Distribution Efficiency Initiative

- Load research
  - 11 utilities – 395 homes
  - Multiple strata – electric space/hot water heating, heat pumps, non-electric space/hot water heating, air conditioning
  - End-use CVR factor end-use load dependent

- Pilot demonstration projects
  - Six utilities, 10 substations, and 31 feeders
  - Line drop compensation and voltage feedback

CVR = conservation voltage reduction
Load Research Driving CVR

NEEA DEI End-Use Load Research Study

Load Research CVR Factor by Weekday and by Season

With 90 Percent Error Bounds

CVR = conservation voltage reduction

CVRf

Summer Fall Winter Spring

Weekdays Weekends
Load Research Driving CVR

NEEA DEI End-Use Load Research Study

Overall \( V_O_f \) of End-Use Load by Heating and Cooling Types Weighted to Northwest

- Electric Hot Water Heating and Electric Space Heating
- Electric Hot Water Heating OR Electric Space Heating
- Non-Electric Hot Water Heating and Non-Electric Space Heating

\( V_O_f \) values for different heat and cooling types have been calculated and are illustrated in the bar chart.
“In general, when CVR is in operation, 98 percent to 99 percent of the change in energy consumption occurs in the end use loads, while only one percent to two percent of the reduction in energy consumed can be attributed to losses.”

*Evaluation of Conservation Voltage Reduction (CVR) on a National Level*

Pacific Northwest National Laboratory – July 2010
KP Schneider, FK Tuffner, JC Fuller, R Singh
Conservation Voltage Regulation (CVR)

- Normal operating range for voltage is 114-126 Volts per ANSI 84.1
- End of feeder is target control point
- Reduces energy consumption, demand and reactive power requirements (kWh, kW, and KVAr) by lowering average delivery voltage

kW – kilowatt  
kWh - kilowatt hour  
KVAr – kilovolt-amperes reactive  
ANSI – American National Standards Institute  
AMI – advanced metering infrastructure
Voltage Profile of Four Feeders Where the Voltage Control Is Bus-regulated

Typical Voltage Settings

At Substation

End of Feeder

VO = voltage optimization

Minimum Allowable Voltage on Primary Line

Maximum Secondary Voltage Drop

Distance from Substation
Voltage Profile of Four Feeders Where the Voltage Control Is Bus-regulated Voltage Reduction ONLY (CVR)

At Substation

End of Feeder

\[ \Delta V = 1.5V \]

VO = voltage optimization
CVR = conservation voltage reduction
Implementing VO (System Improvements & Voltage Reduction)

- Phase Balancing
- Capacitors
- Load Balancing
- Multi-Phasing
- Voltage Reduction

VO = voltage optimization

Voltage Profile of Four Feeders Where the Voltage Control Is Bus-regulated

At Substation

Minimum Allowable Voltage on Primary Line

End of Feeder

Maximum Secondary Voltage Drop

Distance from Substation
Case Study

**Bonneville Power Administration**
**Energy Smart Utility Efficiency Program**

- Five Utilities
  - 17 substations
  - ~50 feeders
- Detailed power flow model simulations
  - Detailed data and metering, 50% had 8,760 data (hourly)
- Performed high-level Scoping Studies
  - Determined potential savings and costs
- Performed detail system study
  - Refines implementation strategies, costs, and savings

CVR = conservation voltage reduction
<table>
<thead>
<tr>
<th>Case Study</th>
<th>Project Energy Savings (MWhs)</th>
<th>Number of Substation/Feeders With Savings</th>
<th>Average Cost per Substation</th>
</tr>
</thead>
<tbody>
<tr>
<td>CVR Only</td>
<td>6,571</td>
<td>9/35</td>
<td>$40,000</td>
</tr>
<tr>
<td>VO</td>
<td>11,880</td>
<td>17/62</td>
<td>$194,614</td>
</tr>
<tr>
<td>Increase Savings</td>
<td>4,802</td>
<td>8/27</td>
<td></td>
</tr>
</tbody>
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- Benefit of VO (results from 5 scoping studies)
  - Increases total energy savings by 80.8 percent
  - Increases savings from losses 1 to 2 percent for CVR to more than 9.8 percent with VO
  - Benefit/Cost ratio ranges from 0.8 to 13.53 with weighted average at 4.45

VO = voltage optimization  
CVR = conservation voltage reduction
CVR: Voltage Optimization

- Accurate measurement of customer voltage
- Accurate measurement of energy savings from voltage shift
- Precise circuit voltage design

AMI – advanced metering infrastructure
VO = voltage optimization

Voltage Profile of Four Feeders Where the Voltage Control Is Bus-regulated
Implementing VO (System Improvements & Voltage Reduction)

• AMI data

At Substation

End of Feeder

ΔV = 2.6V

Minimum Allowable Voltage on Primary Line

Distance from Substation
### Midwest Utility CVR Savings (3,000 capacitor banks)

#### MW Savings with 5,000 MW Peak Load

<table>
<thead>
<tr>
<th>Voltage Reduction</th>
<th>MW Reduction at CVR Factor</th>
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<tbody>
<tr>
<td></td>
<td>0.5</td>
</tr>
<tr>
<td>0.5%</td>
<td>12.5</td>
</tr>
<tr>
<td>1%</td>
<td>25</td>
</tr>
<tr>
<td>2%</td>
<td>50</td>
</tr>
</tbody>
</table>

With a CVR factor of 0.7 and a 0.5% voltage reduction, could spend up to roughly $2900 per capacitor to break even.

#### Generation Capital Savings (assuming $500/kW)

<table>
<thead>
<tr>
<th>Voltage Reduction</th>
<th>Millions of Capital at CVR Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.5</td>
</tr>
<tr>
<td>0.5%</td>
<td>6.24</td>
</tr>
<tr>
<td>1%</td>
<td>12.5</td>
</tr>
<tr>
<td>2%</td>
<td>25</td>
</tr>
</tbody>
</table>
OpenWay supports VVO Enterprise Requirements

- **Real Time Measurement Data:** Volts, Amps, Watts and Vars at each control device and each meter location

- **Utility integration with:** AMI, SCADA, OMS, DMS and database systems to support operational objectives for application status and control positions

- **Sectionalizing Switch Positions:** Support automated device re-coordination of feeder cap banks and regulators to the appropriate feeder and substation bus after feeder switching