IEEE SDWG 2016

Duke Energy Production Experience with CVR

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DUKE ENERGY OHIO SMART GRID
BUSINESS CASE REVIEW
Ohio Smart Grid Business Case
Overview

• DMS-enabler of most operational benefits
• Volt/var Optimization-45% of benefits
• AMI-45% of benefits
• Reliability(Self healing, sectionalization, etc.)- customer minutes saved
• Avoided O&M-Inspections, Shortened billing cycles, vehicle management, efficiency improvements, continuous voltage monitoring, outage detection
## Ohio Volt/var Deployment Summary

<table>
<thead>
<tr>
<th>Voltage</th>
<th>LVM Circuits</th>
<th>Total Circuits</th>
<th>LVM Subs</th>
<th>Total Subs</th>
</tr>
</thead>
<tbody>
<tr>
<td>34.5kv</td>
<td>58</td>
<td>62</td>
<td>21</td>
<td>22</td>
</tr>
<tr>
<td>12.47kv</td>
<td>476</td>
<td>556</td>
<td>148</td>
<td>153</td>
</tr>
<tr>
<td>4.16kv</td>
<td>0</td>
<td>161</td>
<td>0</td>
<td>72</td>
</tr>
<tr>
<td>totals</td>
<td>534</td>
<td>779</td>
<td>169</td>
<td>247</td>
</tr>
</tbody>
</table>

**Volt/var Circuit Exceptions:**
- 4kV circuits
- Sub Transmission
- Secondary Network
- Dedicated customer circuits
DMS/DA/Volt/var Business Case

- Ohio VVO Business Case – Energy Reduction
  - No prior circuit conditioning work performed
  - Assumed there was a 1:1 correlation between demand reduction and energy reduction
  - Targeted 2% system volt reduction
  - Assumed 0.5-0.79 CVR factor range-Industry accepted values
  - System energy reduction 1-1.58% with 24/7/365 operation
  - Reduced Energy Purchases Ohio deregulated Generation
Volt/Var System
Performance/Operational Enhancements
DEO-Volt/var Average System Voltage Reduction

Server issues

- System Daily Avg Voltage 2012(123.2)
- System Daily Avg Voltage 2013(123.0)
- System Daily Avg Voltage 2014(122.0)
- Target Voltage(120.74)
- System Daily Avg Voltage 2015(120.9)
2016 Volt/var Average % Voltage Reduction

Variability related to volt and var settings coordination and dnaf config settings
Goal is to maintain approximately 3V bandwidth with voltage reduction.

Recent settings changes have tightened up the bandwidth for better performance.

Sub bus voltage-1 phase

Dist cap bus voltages-1 phase
# Volt/var Performance Metrics - MWh Reduction

## Calculated Energy Reduction

\[
\text{Calculated Energy Reduction} = \text{Measured Energy} \times \text{Measured Voltage Reduction} \times \text{CVR factor}
\]

- Assumed CVR factor 0.5 to 0.79

<table>
<thead>
<tr>
<th>Avg System Voltage Baseline (2012)</th>
<th>Avg System Voltage (2014)</th>
<th>Avg Circuit Voltage Reduction% with IVVC</th>
<th>MWh under IVVC Control</th>
<th>MWh Reduction with IVVC Control</th>
<th>CVR Factor</th>
<th>Circuits under IVVC Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>IVVC Operation as of 10/31/14</td>
<td>121.1</td>
<td>1.72%</td>
<td>4,411,976</td>
<td>37,943</td>
<td>0.5</td>
<td>365</td>
</tr>
<tr>
<td>IVVC Operation as of 10/31/14</td>
<td>121.1</td>
<td>1.72%</td>
<td>4,411,976</td>
<td>59,949</td>
<td>0.79</td>
<td>365</td>
</tr>
<tr>
<td>IVVC Operation as of 12/31/14</td>
<td>121.1</td>
<td>1.71%</td>
<td>5,951,744</td>
<td>51,185</td>
<td>0.5</td>
<td>417</td>
</tr>
<tr>
<td>IVVC Operation as of 12/31/14</td>
<td>121.1</td>
<td>1.71%</td>
<td>5,951,744</td>
<td>80,402</td>
<td>0.79</td>
<td>417</td>
</tr>
<tr>
<td>IVVC Operation as of 4/16/15</td>
<td>120.7</td>
<td>2.03%</td>
<td>7,554,230</td>
<td>76,646</td>
<td>0.5</td>
<td>500</td>
</tr>
<tr>
<td>IVVC Operation as of 4/16/15</td>
<td>120.7</td>
<td>2.03%</td>
<td>7,554,230</td>
<td>121,101</td>
<td>0.79</td>
<td>500</td>
</tr>
<tr>
<td>Avg System Voltage Baseline (2012)</td>
<td>123.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IVVC Operation as of 6/29/15</td>
<td>120.8</td>
<td>1.95%</td>
<td>9,565,145</td>
<td>93,167</td>
<td>0.5</td>
<td>511</td>
</tr>
<tr>
<td>IVVC Operation as of 6/29/15</td>
<td>120.8</td>
<td>1.95%</td>
<td>9,565,145</td>
<td>147,204</td>
<td>0.79</td>
<td>511</td>
</tr>
<tr>
<td>IVVC Operation as of 8/31/15</td>
<td>121.1</td>
<td>1.70%</td>
<td>12,701,685</td>
<td>108,253</td>
<td>0.5</td>
<td>511</td>
</tr>
<tr>
<td>IVVC Operation as of 8/31/15</td>
<td>121.1</td>
<td>1.70%</td>
<td>12,701,685</td>
<td>171,040</td>
<td>0.79</td>
<td>511</td>
</tr>
<tr>
<td>IVVC Operation as of 12/31/15</td>
<td>120.95</td>
<td>1.83%</td>
<td>14,521,502</td>
<td>132,603</td>
<td>0.5</td>
<td>511</td>
</tr>
<tr>
<td>IVVC Operation as of 12/31/15</td>
<td>120.95</td>
<td>1.83%</td>
<td>14,521,502</td>
<td>209,513</td>
<td>0.79</td>
<td>511</td>
</tr>
</tbody>
</table>
Volt/var Circuit Performance variance - Circuit MWh Reduction

MWh Savings Variance - 2015 Period

- Higher load = higher savings
- Lower load = lower savings
- Voltage increase - negative savings - resulted in VVO being disabled
Volt/var Circuit online % & MWh savings Performance Variance

% Online

Normalized Energy Reduction

Large difference in circuit % online availability

Large difference in each circuits MWh reduction performance
Volt/Var - Day in the life of DNAF/VVO-Plan

Overview

What does the system look like over the same day

- DPF runs 2254
- VVO Runs 2962
- VVO Accepted Periodic plans 1747
- VVO Accepted Backbone plans 97
- VVO Accepted Voltage Quality plans 1100
- VVO Circuits enabled 317
- VVO MWh reduction 334
- VVO Voltage reduction 1.93%
VOLT/VAR LOAD ALLOCATION AND POWER FLOW OVERVIEW AND MEASUREMENT ENHANCEMENTS
Volt/Var/DMS Load Allocation - Utilizing the Data

**Bus Load Allocation (BLA): Islands**

- Scales loads to match real-time measurements
- Iterates with DPF in an outer loop
- Measurements are grouped according to location and used to form measurement islands
- Uses a priority order for processing measurements.
Volt/Var/DMS Load Allocation - Utilizing the Data

• A “measurement island” is a collection of components bounded by a common set of measurements with the purpose of allocating load.

• **With no distribution line data only one measurement island formed from sub data**

• Measurement island is bounded by a reference bus interface object, an upstream measurement island, a downstream measurement island, or feeder ends.

• All loads inside of a measurement island are scaled up or down based on the island’s kW or kVA measurement.

• The more measurement islands generally the better the load allocation and power flow

• **This leads us to revised device sensing strategies to deliver more data**
Volt/Var/DMS Measurements Implemented

Accuracy requirements not fully developed in Ohio prior to deployment - consider this the minimum requirements

- Substation/Circuit relays
  - Measurements - phase amps, watts, volts, vars
    - Estimated 1-5% accuracy
- Three phase caps
  - Measurements - single phase voltage only
    - Estimated 0.75% accuracy
- Line reclosers
  - Measurements - phase amps, watts, volts, vars
  - Variable accuracy - not quantified
- Line sensors (not used in load allocation or power flow)
  - Measurements - phase amps
    - Estimated 5-10% accuracy
Volt/Var Tested Device Accuracy

• Line post combination voltage and current sensors
  – Voltage and current accuracy as spec’d around 1% or less
  – Watt and var accuracy not quite as good
  – Installation geometry
  – Ice/Moisture impacts
• Line post voltage sensors
  – Accurate as spec’d around 1% or less
• Capacitor controls
  – Voltage and current accuracy as spec’d around 0.25%.
  – Watt and var accuracy dependent on sensor and device accuracy
• Stick based voltage sensor
Three Phase Cap with Line post sensors & With Capacitor control

- High accuracy voltage and current sensing
- Avg of 3-5 cap locations per circuit could be leveraged for measurements
- Three Line post sensors for single phase voltage and current sensing
- Fault detection/magnitude
- Voltage, current, power data for operations
- DMS-DPF/BLA integration for improved power flow, load allocation and VVO operation
Volt/Var Load Flow Improvement-Side Benefits-Fault Data

- Three Phase cap with Post Sensors/Capacitor Control Fault Detection Capability
  - Cap control records overcurrent value via DNP
  - Data from scada to PI
  - Compared event to SEL and Recloser fault data
  - **Minimizes need for current only line sensors**

<table>
<thead>
<tr>
<th>Time</th>
<th>Fault</th>
<th>W23-54(6283A)</th>
<th>RCL 21953(ABB OVR)</th>
<th>Montg 45 relay(SEL 351)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6/29/2015</td>
<td>23:08:30</td>
<td>1471A</td>
<td>1493A</td>
<td>1533A</td>
</tr>
<tr>
<td>6/30/2015</td>
<td>5:51:49</td>
<td>1453A</td>
<td>1451A</td>
<td>1496A</td>
</tr>
</tbody>
</table>
VOLT/VAR OPTIMIZATION OPTIONS
Heuristic Volt/Var Option

• In order to obtain high quality results, a good power flow model is required. The model must have an accurate impedance model and a solid load model.

• In some cases, obtaining an accurate power flow model capable of generating high quality VVO results is not a simple task.

• Heuristic-based VVO solution developed as alternate optimization method

• Measurement based optimization
VOLT/VAR MODELING AND CVR FACTORS
Volt/Var Duke Energy CVR Factors?

<table>
<thead>
<tr>
<th>Area</th>
<th>Mean CVR</th>
</tr>
</thead>
<tbody>
<tr>
<td>DEC</td>
<td>1.02</td>
</tr>
<tr>
<td>DEF</td>
<td>1.15</td>
</tr>
<tr>
<td>DEM</td>
<td>2.92</td>
</tr>
<tr>
<td>DEP</td>
<td>1.67</td>
</tr>
</tbody>
</table>

**DEM**
- Data: ~75 Substations, ~400 Feeders
- 6 Events
- Results For: 12 Feeders

**DEC**
- Data: 4 Substations, 29 Feeders
- 1 Event
- Results For: 12 Feeders

**DEP**
- Data: ~400 Substations, ~1500 Feeders
- 25 Events
- Results For: 12 Feeders

**DEF Analysis**
- Data: ~250 Substations, ~500 Feeders
- 9 Events
- Results for: 8 Feeders
Volt/Var CVR Factors Published Industry Studies

- Georgia Power 0.3 to 2.0
- EPRI/Alabama Power 0.4 to 0.7
- EPRI SMUD 0.6
- NEEA DEI 0.6
- Hydro Quebec 1.0 summer-0.7 winter
- Navigant Avista 0.7 to 0.9
- PNNL 0.7
Volt/Var CVR Measurements Ohio

- Measured CVR
- A common rule of thumb in the industry is that 80-90 percent of CVR savings accrue to the customer and 10-20 percent to the utility.
- Inadvertent Off/On testing
- Load models affect power flow calculated values
- CVR Factors estimated for most areas around 0.7

![Calculated Avg System CVR=0.696 Off response 1/29/15](image)
VOLT/VAR SOFTWARE TESTING
Volt/Var Testing of New Software Versions

- Load new software on QA DMS server
- Hybrid model on QA DMS
- Most station’s points are being fed from Production SCADA to QA SCADA
  - A few station’s points are being simulated with DOTS
- Go through a round of Technical and Business Testing on QA
- Load new software on Production standby DMS server
- Failover DMS to Standby DMS server with new software
- There is a big risk with this method when you have 500 VVO circuits enabled
Volt/Var Dual Production Control

Utilized for software update in 2016
Utilizing for system optimization tuning
Utilizing for problem formulation testing, heuristic testing
Utilizing for FME update testing
## Volt/Var Secondary Regulation-SVC/IPR

<table>
<thead>
<tr>
<th>Unit</th>
<th>Transformer rating</th>
<th>Installation details</th>
<th>Delta V</th>
<th>20kVAR boost</th>
</tr>
</thead>
<tbody>
<tr>
<td>11600 Thistle Hill</td>
<td>25 kVA</td>
<td>170ft split wire from xfmr</td>
<td>0.49V/kVAR</td>
<td>9.8V</td>
</tr>
<tr>
<td>11649 Thistle Hill</td>
<td>50 kVA</td>
<td>Same pole as xfmr</td>
<td>0.13V/kVAR</td>
<td>2.6V</td>
</tr>
<tr>
<td>9386 Greenhedge</td>
<td>50 kVA</td>
<td>70ft split wire from xfmr</td>
<td>0.15V/kVAR</td>
<td>3V</td>
</tr>
<tr>
<td>9358 Greenhedge</td>
<td>25 kVA</td>
<td>Same pole as xfmr</td>
<td>0.14V/kVAR</td>
<td>2.8V</td>
</tr>
<tr>
<td>8740 Arcturus</td>
<td>50 kVA</td>
<td>170ft split wire from xfmr</td>
<td>0.29V/kVAR</td>
<td>5.8V</td>
</tr>
</tbody>
</table>

![Graph showing voltage over time for 11600 Thistle Hill]