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

Voltage	LVM Circuits	Total Circuits	LVM Subs	Total Subs
34.5kv	58	62	21	22
12.47kv	476	556	148	153
4.16kv	0	161	0	72
totals	534	779	169	247

Volt/var Circuit Exceptions:

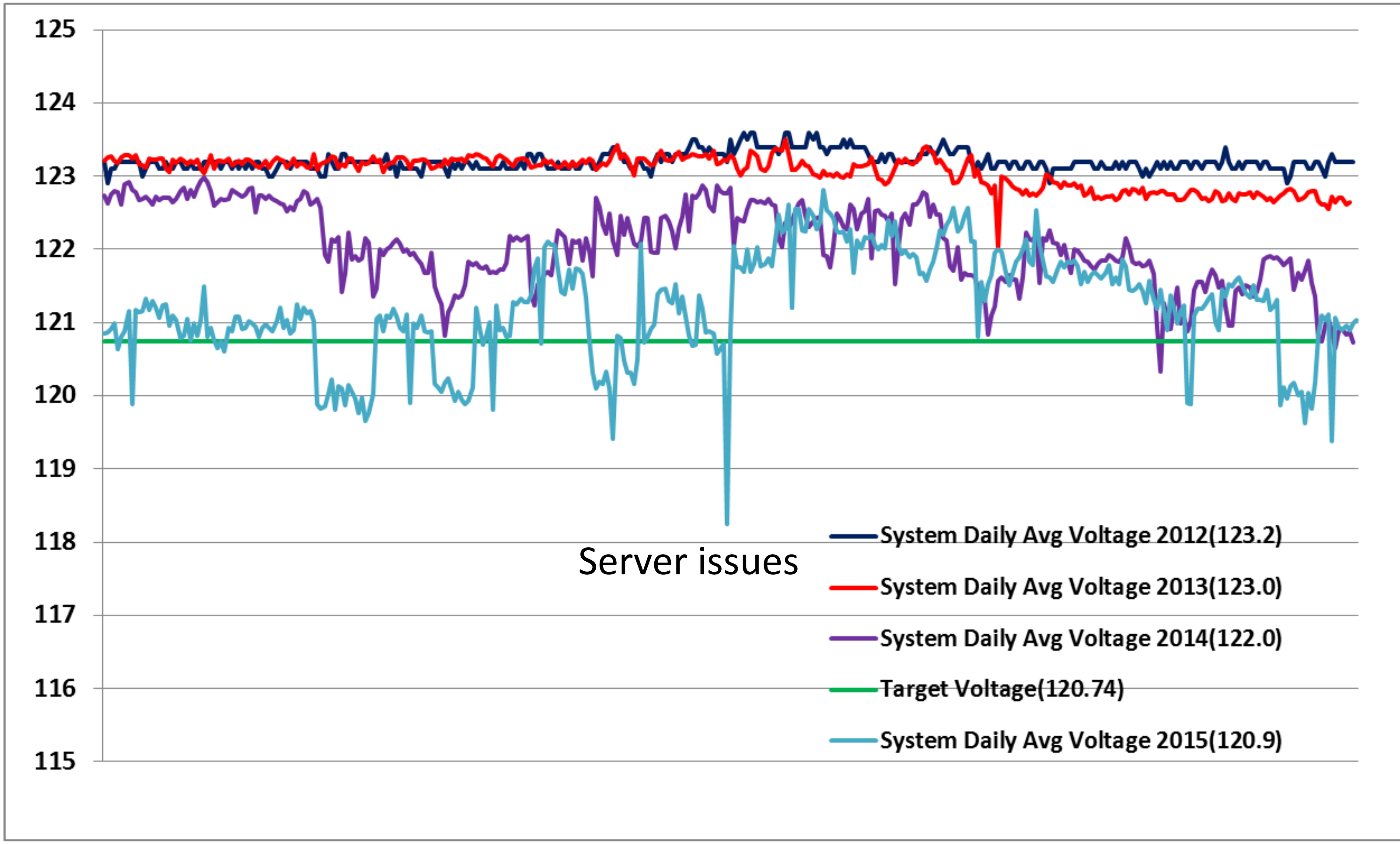
4kV circuits
Sub Transmission
Secondary Network
Dedicated customer circuits

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

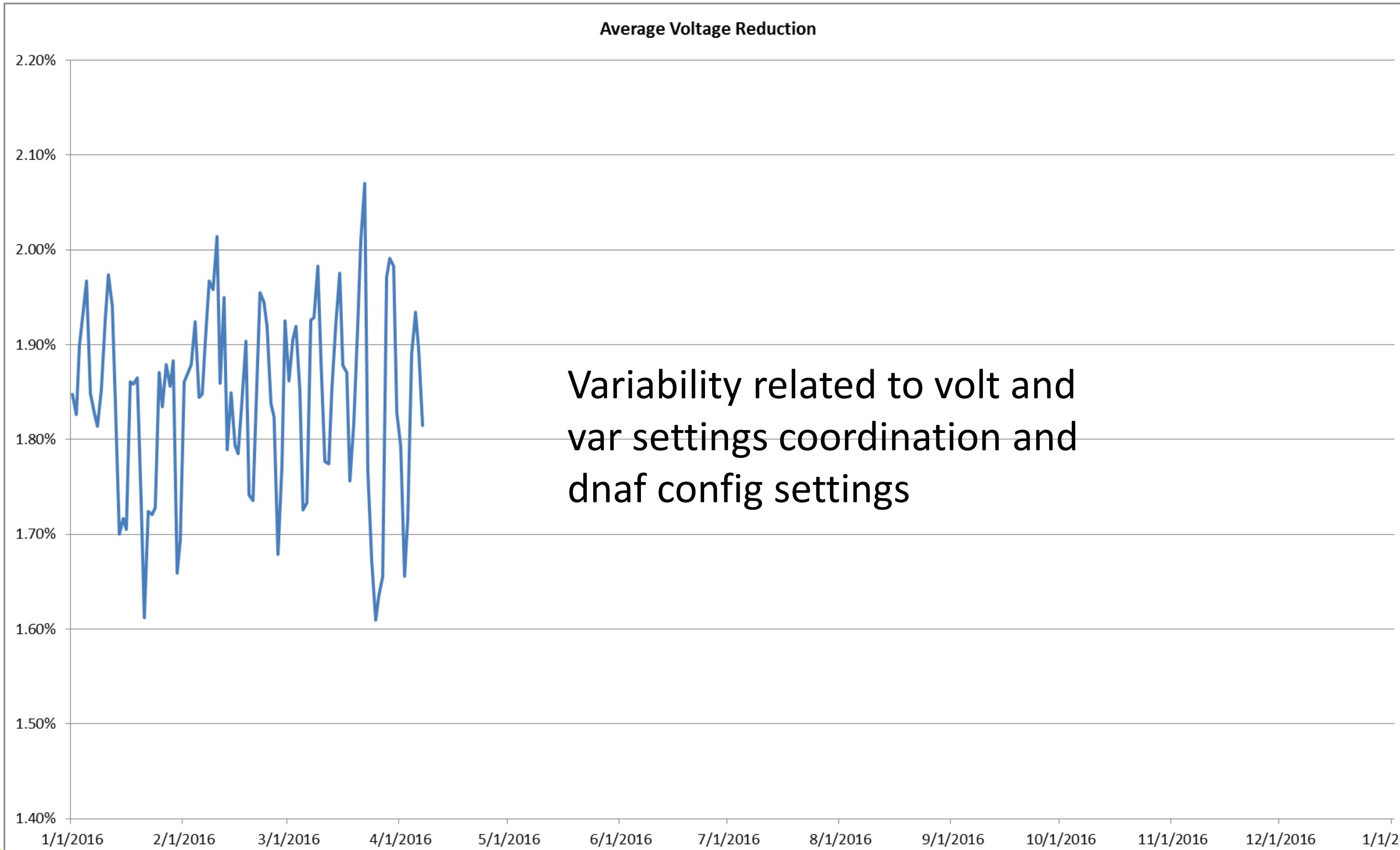
Volt/Var System Performance/Operational Enhancements

DEO-Volt/var Average System Voltage Reduction



2016 Volt/var Average % Voltage Reduction

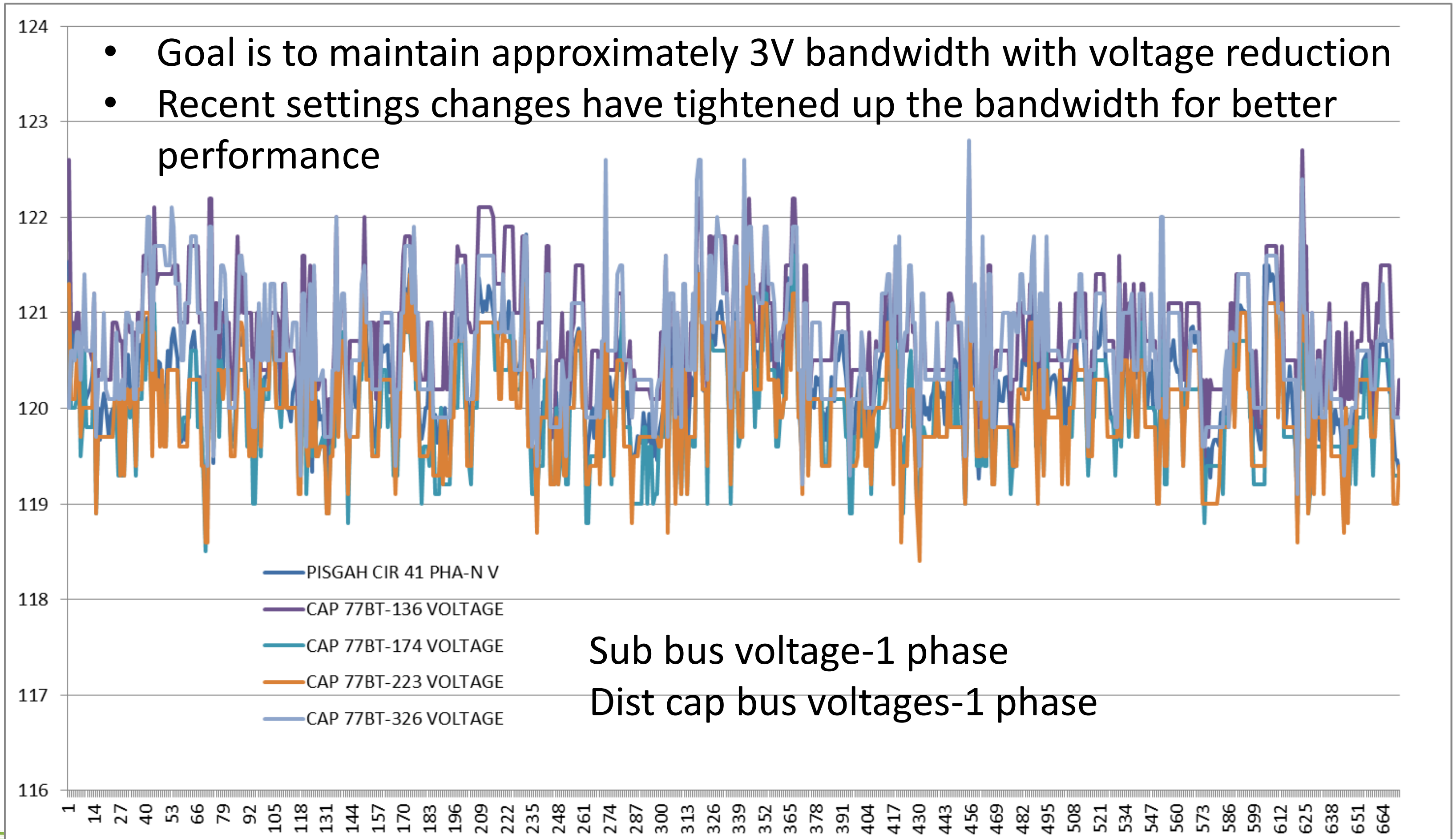
2016 System Average System % Voltage Reduction



Volt/var Voltage Flatness-Circuit voltage profiles

Single xfmr/circuit w/LTC control-1 month time period

- 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

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Volt/var Performance Metrics-MWh Reduction

- **Calculated Energy Reduction=**

  Measured Energy X **Measured Voltage Reduction** X **CVR factor**

  - Assumed CVR factor 0.5 to 0.79

Avg System Voltage Baseline(2012)	123.2					
	Avg System Voltage(2014)	Avg Circuit Voltage Reduction% with IVVC	MWh under IVVC Control	MWh Reduction with IVVC	CVR Factor	Circuits under IVVC Control
IVVC Operation as of 10/31/14	121.1	1.72%	4,411,976	37,943	0.5	365
IVVC Operation as of 10/31/14	121.1	1.72%	4,411,976	59,949	0.79	365
	Avg System Voltage(2014)	Avg Circuit Voltage Reduction% with IVVC	MWh under IVVC Control	MWh Reduction with IVVC	CVR Factor	Circuits under IVVC Control
IVVC Operation as of 12/31/14	121.1	1.71%	5,951,744	51,185	0.5	417
IVVC Operation as of 12/31/14	121.1	1.71%	5,951,744	80,402	0.79	417
	Avg System Voltage(2015)	Avg Circuit Voltage Reduction% with IVVC	MWh under IVVC Control	MWh Reduction with IVVC	CVR Factor	Circuits under IVVC Control
IVVC Operation as of 4/16/15	120.7	2.03%	7,554,230	76,646	0.5	500
IVVC Operation as of 4/16/15	120.7	2.03%	7,554,230	121,101	0.79	500
Avg System Voltage Baseline(2012)	123.2					
	Avg System Voltage(2015)	Avg Circuit Voltage Reduction% with IVVC	MWh under IVVC Control	MWh Reduction with IVVC	CVR Factor	Circuits under IVVC Control
IVVC Operation as of 6/29/15	120.8	1.95%	9,565,145	93,167	0.5	511
IVVC Operation as of 6/29/15	120.8	1.95%	9,565,145	147,204	0.79	511
	Avg System Voltage(2015)	Avg Circuit Voltage Reduction% with IVVC	MWh under IVVC Control	MWh Reduction with IVVC	CVR Factor	Circuits under IVVC Control
IVVC Operation as of 8/31/15	121.1	1.70%	12,701,685	108,253	0.5	511
IVVC Operation as of 8/31/15	121.1	1.70%	12,701,685	171,040	0.79	511
	Avg System Voltage(2015)	Avg Circuit Voltage Reduction% with IVVC	MWh under IVVC Control	MWh Reduction with IVVC	CVR Factor	Circuits under IVVC Control
IVVC Operation as of 12/31/15	120.95	1.83%	14,521,502	132,603	0.5	511
IVVC Operation as of 12/31/15	120.95	1.83%	14,521,502	209,513	0.79	511

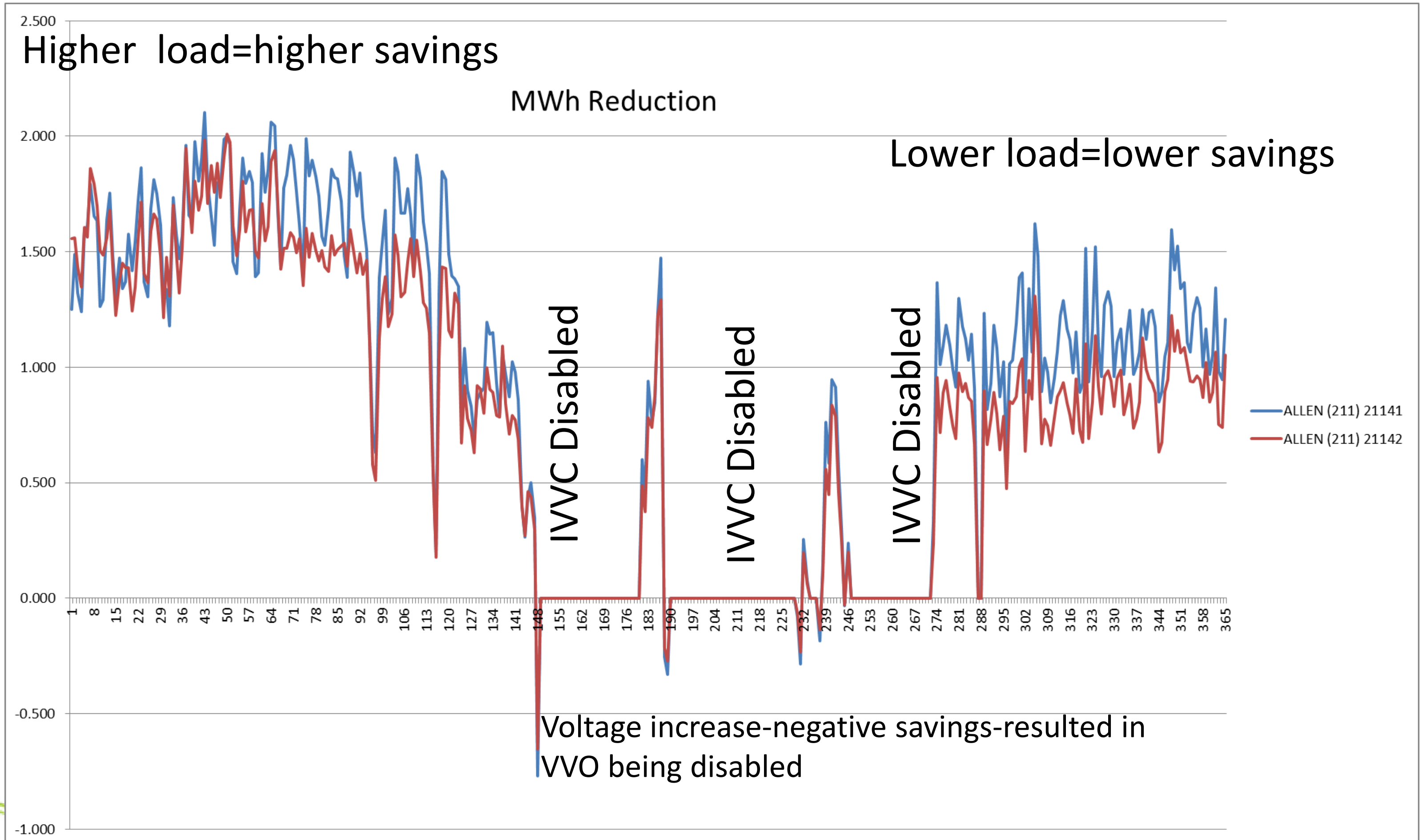
Deployment Completed

Software/Server Issues

Tuning Phase

Volt/var Circuit Performance variance-Circuit MWh Reduction

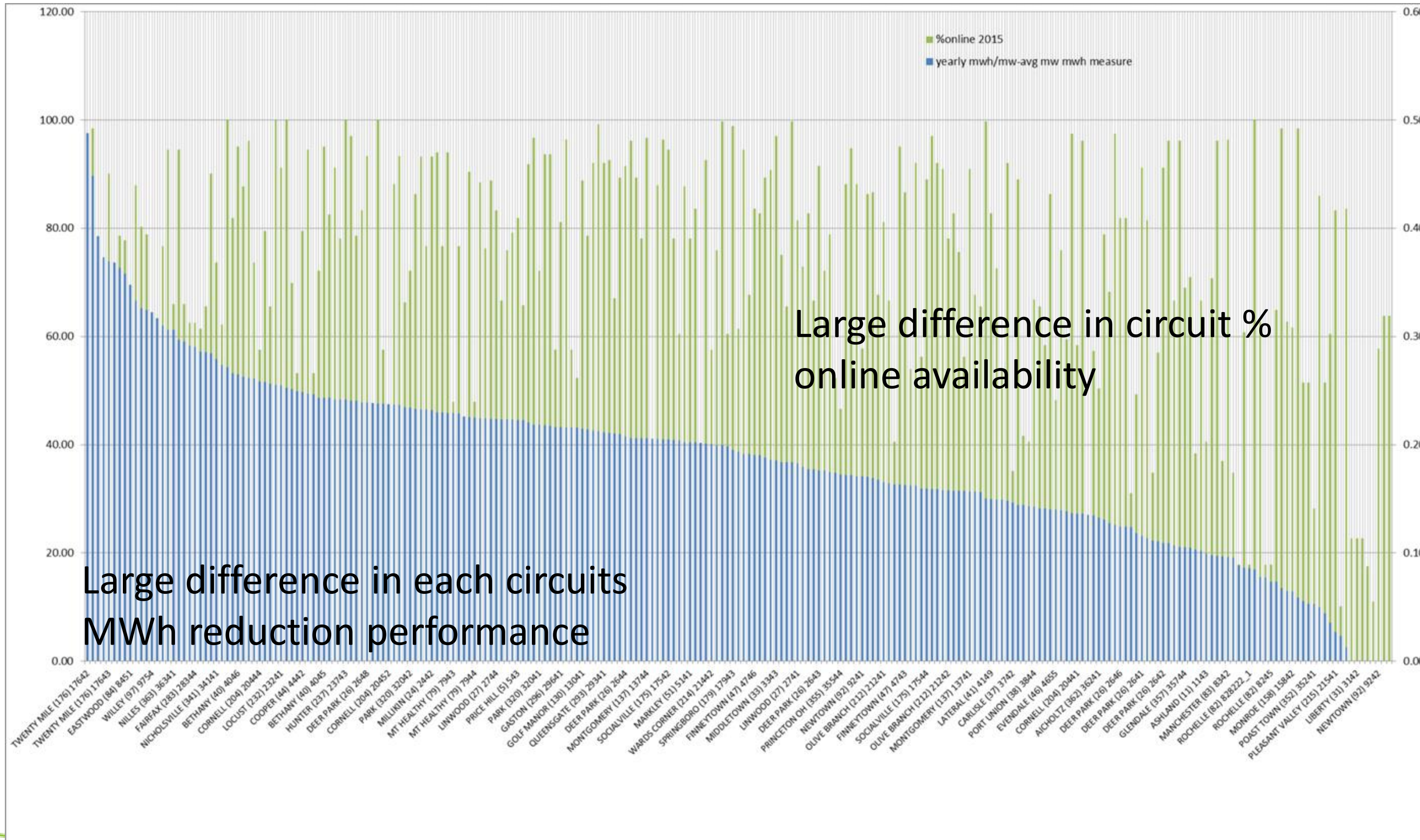
MWh Savings Variance- 2015 Period



Volt/var Circuit online % & MWh savings Performance Variance

% Online

Normalized Energy Reduction



Volt/Var - Day in the life of DNAF/VVO-Plan Overview

What does the system look like over the same day

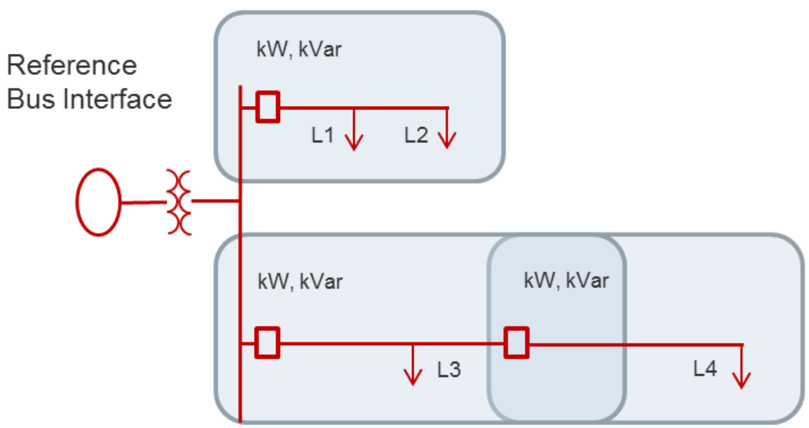
- DPF runs 2254
- VVO Runs 2962
- VVO Accepted Periodic plans 1747
- VVO Accepted Backbone plans 97
- VVO Accepted Voltage Quality plans 1100
- VVO Circuits enabled 317
- VVO MWh reduction 334
- VVO Voltage reduction 1.93%

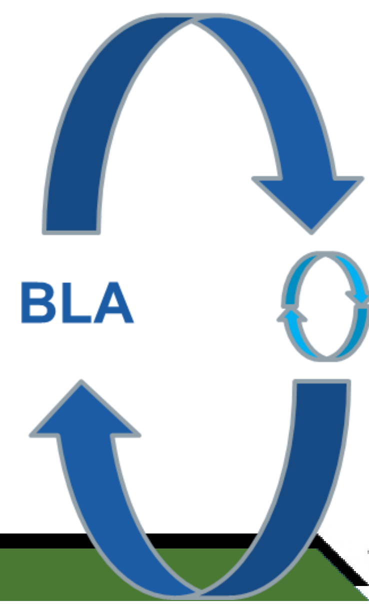
VOLT/VAR LOAD ALLOCATION AND POWER FLOW OVERVIEW AND MEASUREMENT ENHANCEMENTS

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

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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

Volt/Var Load Flow Improvement-Measurement Strategy

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 <u>voltage and current sensing</u>
- 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
  - **<u>Minimizes need for current only line sensors</u>**

	Time	Fault	W23-54(6283A)	RCL 21953(ABB OVR)	Montg 45 relay(SEL 351)	
6/29/2015	23:08:30	B-G	1471A	1493A	1533A	
6/30/2015	5:51:49	B-G	1453A	1451A	1496A	

VOLT/VAR OPTIMIZATION OPTIONS

Heuristic Volt/Var Option

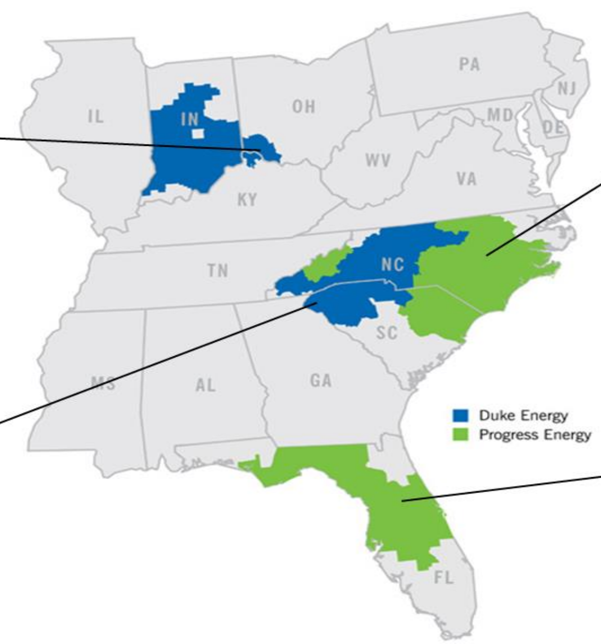
- In order to obtain high quality results, a good power flow model is required. The model must have an accurate impedance model and a solid load model.
- In some cases, obtaining an accurate power flow model capable of generating high quality VVO results is not a simple task.
- Heuristic-based VVO solution developed as alternate optimization method
- Measurement based optimization

VOLT/VAR MODELING AND CVR FACTORS

Volt/Var Duke Energy CVR Factors?

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

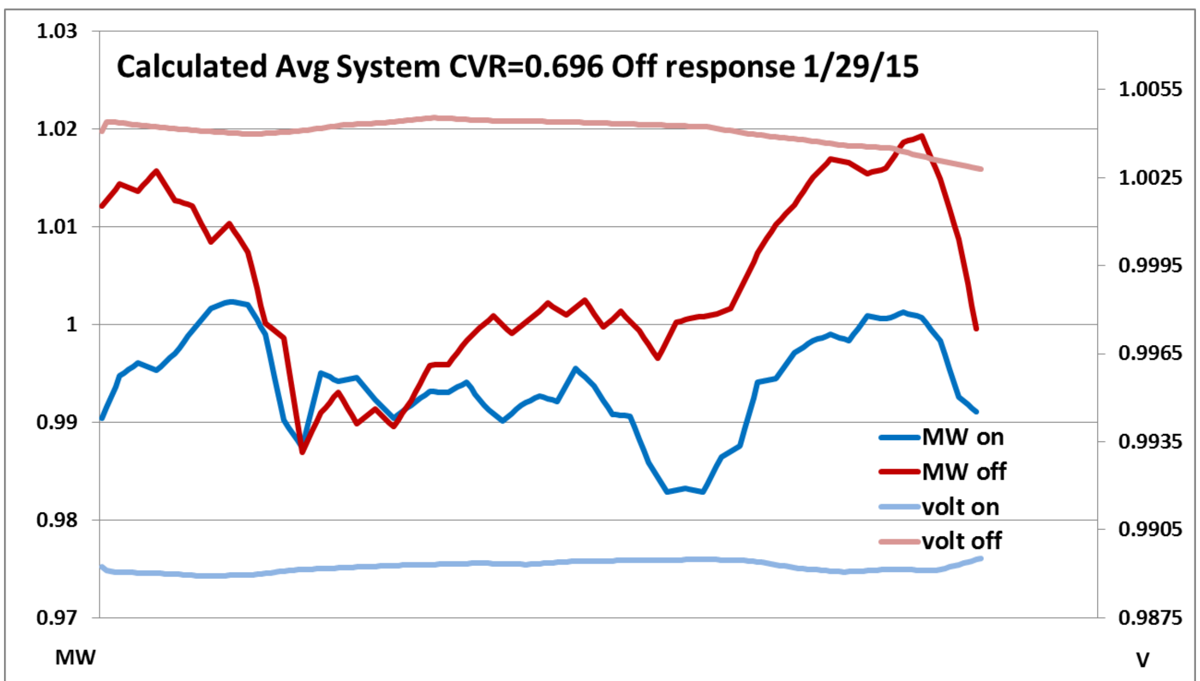
Area	Mean CVR
DEC	1.02
DEF	1.15
DEM	2.92
DEP	1.67

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

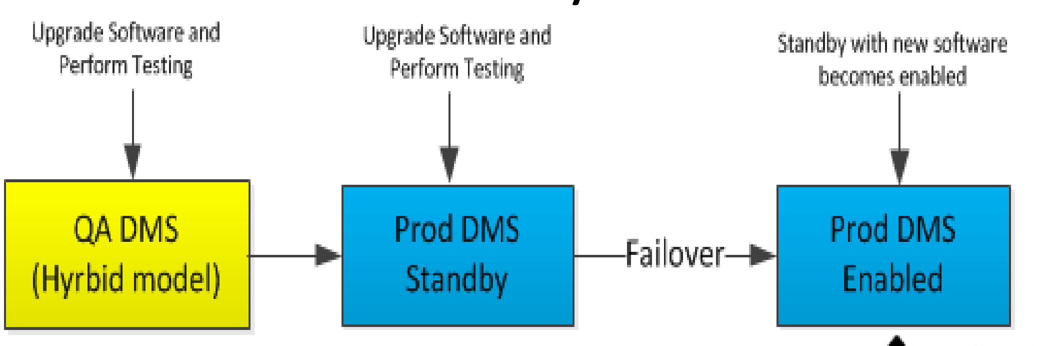
- Measured CVR
- A common rule of thumb in the industry is that 80-90 percent of CVR savings accrue to the customer and 10-20 percent to the utility.
- Inadvertent Off/On testing
- Load models affect power flow calculated values
- **CVR Factors estimated for most areas around 0.7**



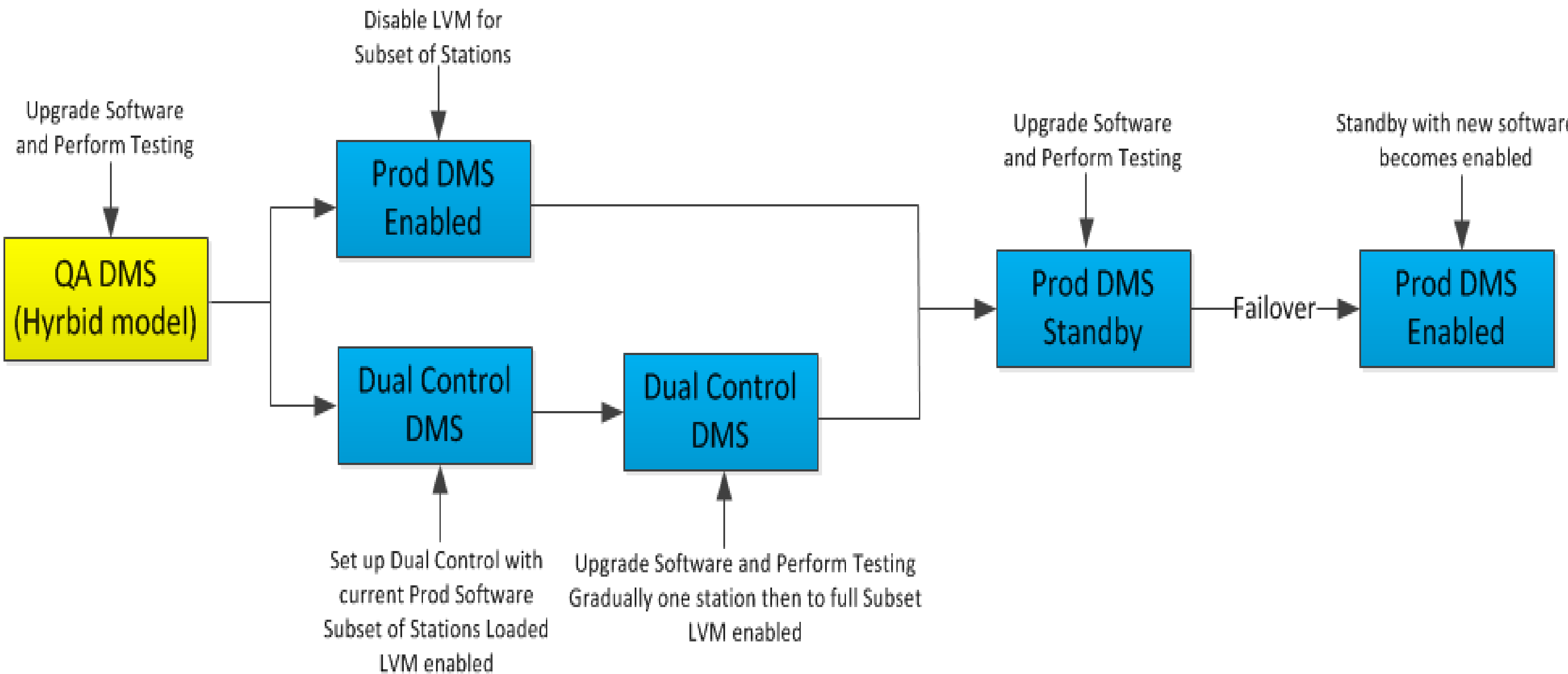
VOLT/VAR SOFTWARE TESTING

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

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