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Relion. Thinking beyond the box.

Designed to seamlessly consolidate functions, Relion relays are smarter, more flexible and more adaptable. Easy to integrate and with an extensive function library, the Relion family of protection and control delivers advanced functionality and improved performance.

ABB Protective Relay School Webinar Series

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ABB Protective Relay School Webinar Series

Volt-VAR Optimization

Stephen Trachian and Aroldo Couto

November 4, 2014

Presenter

- Stephen graduated from the University of Tennessee at Chattanooga with a Bachelor of Science in Engineering in 2001.
- He began his career in the electric utility industry as a Design Engineer with the Tennessee Valley Authority.
- While at the TVA, Stephen worked in the Protection and Control, Substation Communications, and Communications Planning and Architecture groups.
- Stephen is currently a System Architect for the ABB Smart Grid Center of Excellence in Raleigh, North Carolina

Presenter

- Aroldo Couto has spent over 15 years as an applications engineer delivering automation and control systems solutions for both manufacturing and electrical industry.
- During his career, he has worked on a variety of automation and controls projects including transmission and distribution substation automation, machine vision and control systems providing feedback for product development and process improvements.
- He holds a Master in Electrical and Computer Engineering from Auburn University and Bachelors in Electrical and Computer Engineering from UFG Brazil.
- Aroldo is currently a “System Verification Engineer” for “Smart Grid Distribution Automation” in ABB for the North America Region.

Learning objectives

- Overview : Business Case
- Overview : Volt-VAR Optimization
  - Power Factor Correction
  - Conservation Voltage Reduction
- Implementation Concepts
  - Project Phases and Technical Considerations
  - Simple VVO Example
- System Integration /Architecture
- Measurement & Verification
- Q&A

Key acronyms

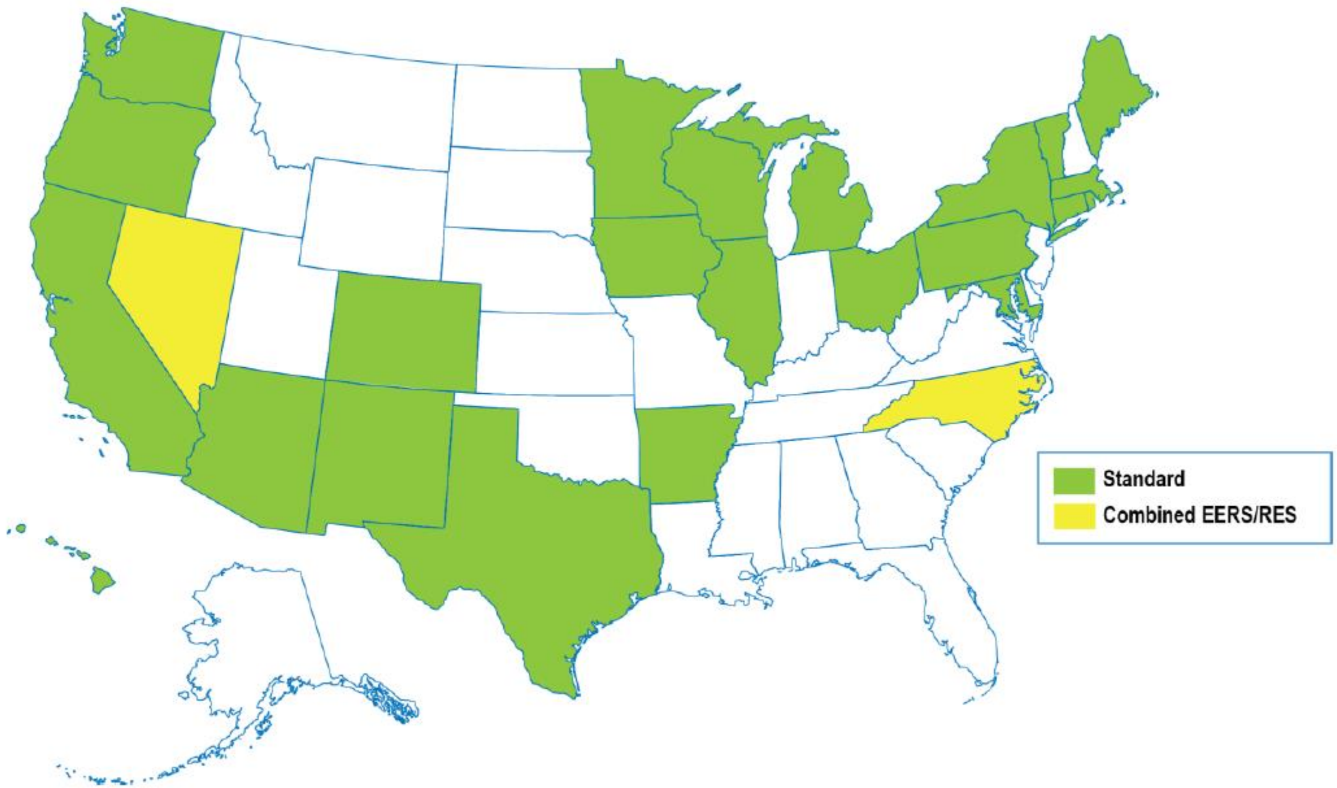
- VVC – Volt-VAR Control
- PFC – Power Factor Correction
- CVR – Conservation Voltage Reduction
- CVRf – CVR Factor
- VVO – Volt-VAR Optimization
- M&V – Measurement & Verification

- SCADA – Supervisory Control and Data Acquisition
- DMS – Distribution Management System
- IED – Intelligent Electronic Device
- RTU – Remote Terminal Unit
- EOL – End Of Line (Voltage Monitoring Point)

Business Case
Potential Benefits

- Loss reduction
- Demand reduction
- Wear and Tear reduction
- CO_2 reduction
- Cost effective due to leverage existing equipment
- Leverage benefits without any customer interface
- 25 US states with Energy Efficiency Resource Standards

Energy Efficiency Resource Standards (EERS)
Policy approaches by state (as of April 2014)



Source: American Council for an Energy-Efficient Economy

Business Case
Power Factor Correction ONLY

Simple VAR Support Calculator

12/16/20MVA Transformer - Average Load 8.5MWh

Variable	Utility
Number of Substations	1
Number of Feeder Circuits	4
Annual Load [MWh]	74,555
Starting Power Factor	0.980
Ending Power Factor	0.998
Percentage Reduction [%] in System Load due to Power Factor Improvement	1.8%

Calculations		Volt/VAR
Total Annual Load Savings (MWh)	[Percentage Reduction * Annual Load]	1,342
Average rate [$/kwh]		$0.098
Value of Annual Load Savings [$]	[Average rate * Total Annual Load Savings]	131,515

First Year - Implementation Cost	125,000
Annual Savings (Starting in Year 2)	131.515
Simple Payback [years]	2.08

Business Case
Power Factor Correction ONLY

Simple VAR Support Calculator

12/16/20MVA Transformer - Average Load 8.5MWh

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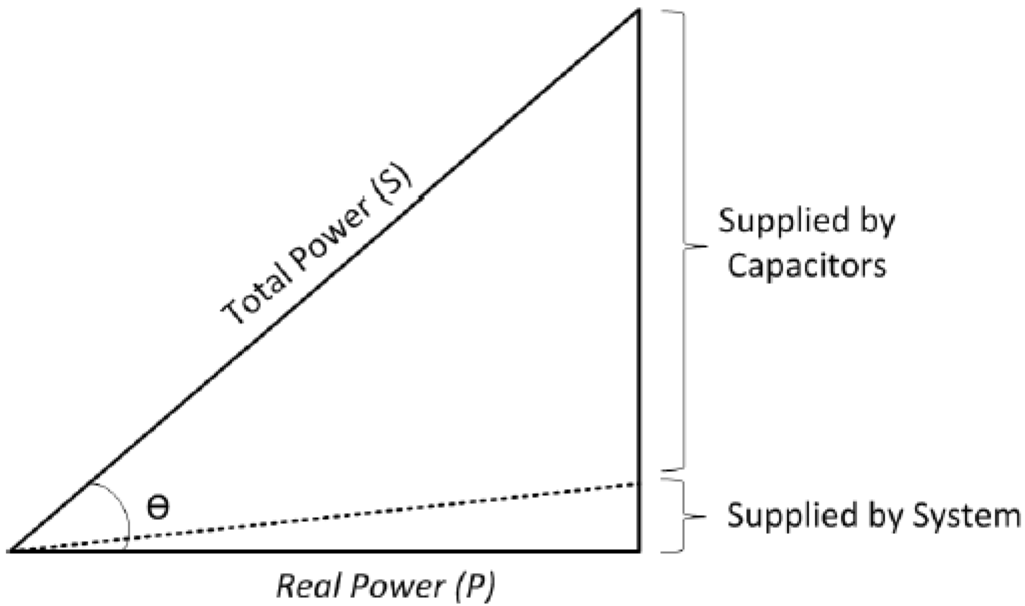
Number of Substations	1
Number of Feeder Circuits	4
Annual Load [MWh]	74,555
Starting Power Factor	0.970
Ending Power Factor	0.998
Percentage Reduction [%] in System Load due to Power Factor Improvement	2.8%

Calculations		Volt/VAR
Total Annual Load Savings (MWh)	[Percentage Reduction * Annual Load]	2,088
Average rate [$/kwh]		$0.098
Value of Annual Load Savings [$]	[Average rate * Total Annual Load Savings]	204,579

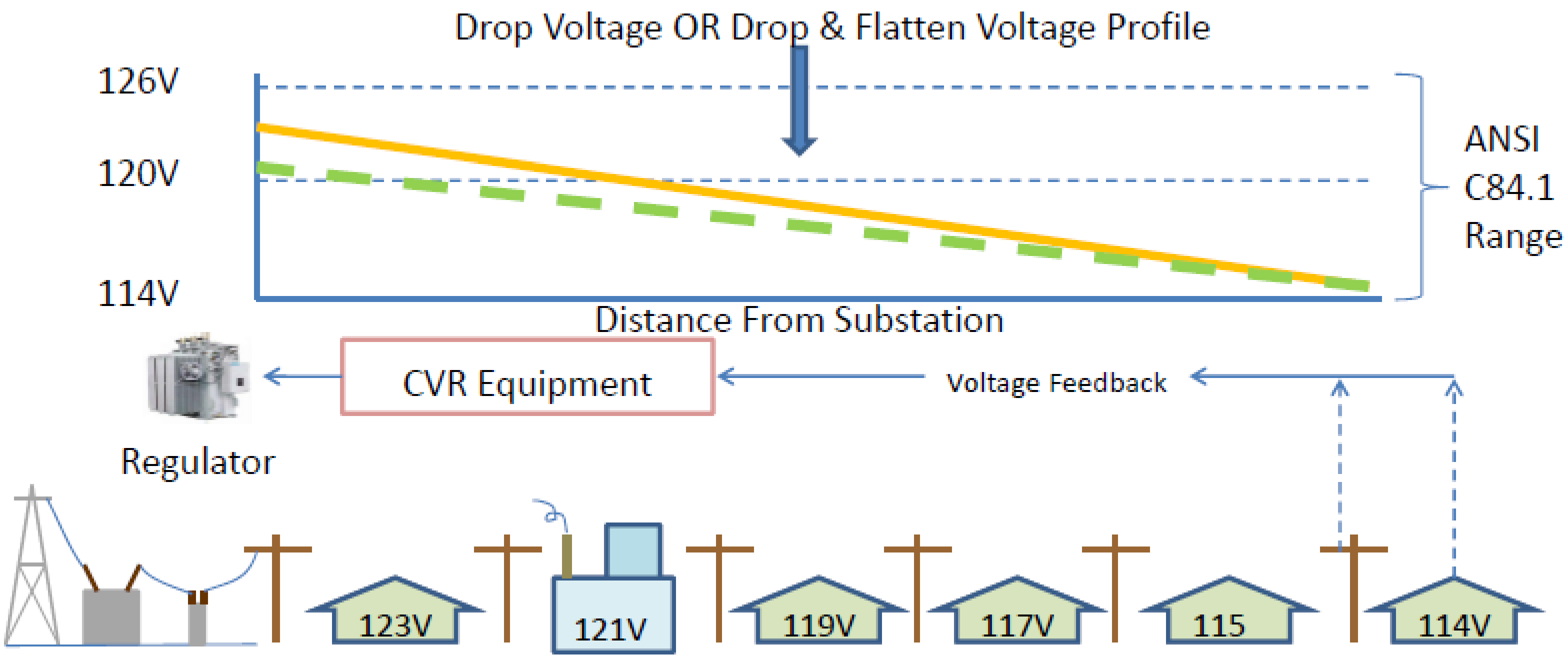
First Year - Implementation Cost	**125,000**
Annual Savings (Starting in Year 2)	**204,579**
Simple Payback [years]	**1.70**

Power Factor Correction
Brief Overview

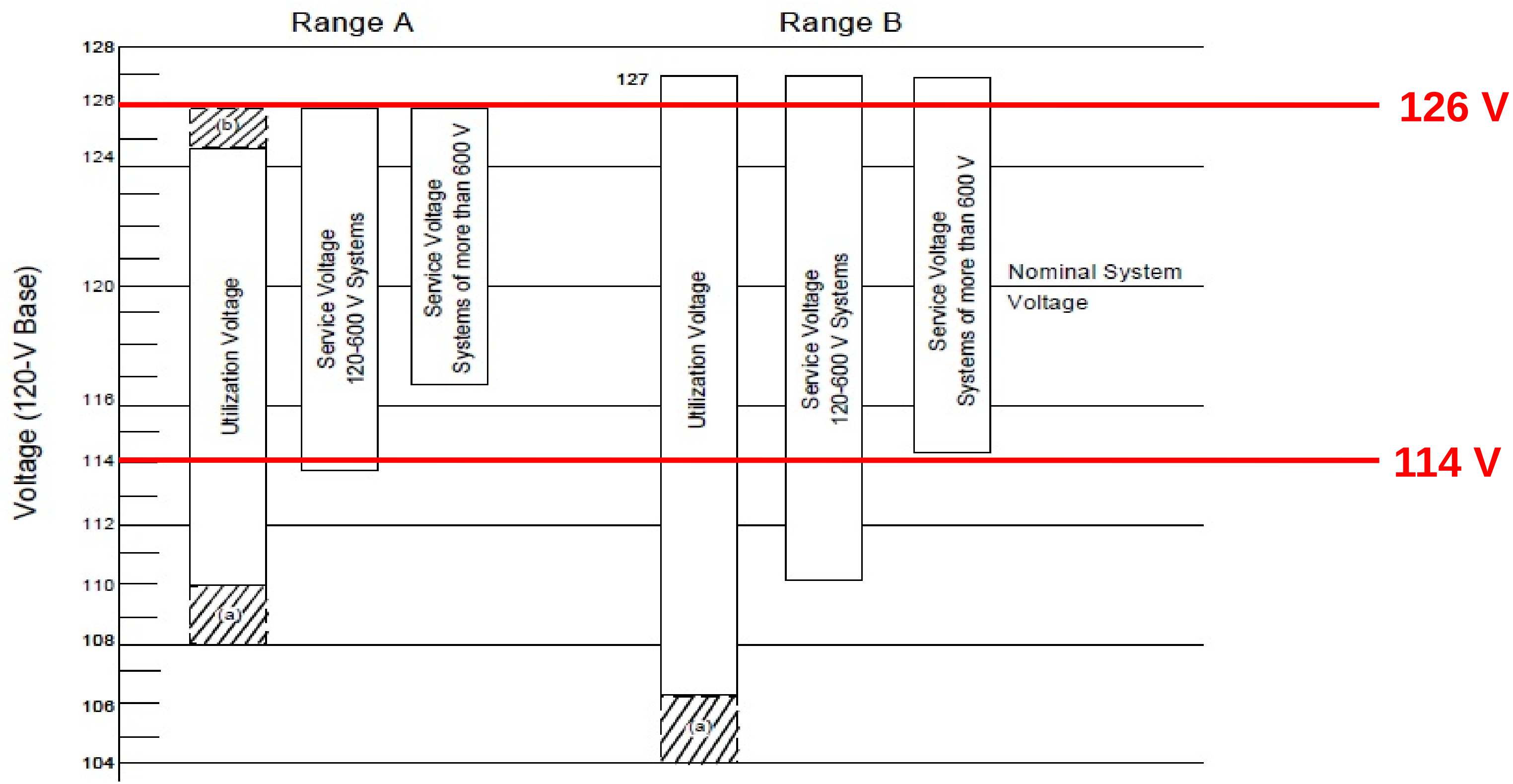


Conservation Voltage Reduction
Brief Overview

$$\boldsymbol{CVR\ Factor} = \frac{\%\ demand\ reduction}{\%\ voltage\ reduction}$$



Conservation Voltage Reduction
ANSI C84.1 Voltage Limits



Implementation Concepts
Automation & Control Systems Strategies

Rule-Based Volt/VAR Control

Model-Based Volt/VAR Optimization

Local Controls

- Based on Local measurements
- No coordination at system level
- Minimal visibility into performance

Regional One-Way Communication Control System

- Rule-based
- Considers only few or several points often just capacitor banks, not regulators
- Thermal and voltage constraints not modeled

Regional Two-Way Communication Control System

- Provided asset status
- Measured values at devices now visible

- Reduced ownership costs through shared Infrastructure with SCADA, OMS, DMS Applications
- Maximizes CVR and Loss Reduction through mathematical optimization
- Uses present “as operated” network model
- Accounts for change feeder configurations
- Model loads and their voltage sensitivity

Implementation Concepts
Technical Considerations

Traditional power factor correction solutions are able to solve simple power factor problems at local levels

- How do you know the capacitor bank is online and functioning properly?
- How do you know the overall power factor is being optimally corrected?

Traditional CVR correction techniques involve lowering LTC/regulator tap positions at feeder/bus heads to implement demand response

- How do you know the utilization/service voltages are within acceptable ANSI C84.1 limits?
- How do you know the voltage level has been optimized without closed loop voltage monitoring on the system?

Centralized VVO automation applications can help solve all of these challenges, while providing better optimization at a system wide level.

Implementation Concepts
VVO Control Objectives

- The control objectives of VVO are :
  - MW loss reduction via feeder power and/or substation PFC
  - Demand reduction via CVR
  - Voltage violation correction

Implementation Concepts
VVO Control Problem

- The control problem of VVO is to determine :
  - if a capacitor’s switching status should be changed
  - If the tap setting of a voltage regulator should be raised or lowered
  - If the reactive power of controllable Distributed Generation should be changed and by how much

Implementation Concepts
VVO Technical Challenges

- A few properties of the VVO make it a technically difficult problem :
  - The discrete nature of the controls
  - Limitation on switching operations

Implementation Concepts
System Components

- Automation application
  - Software (eg ABB MicroSCADA Pro)
  - Hardware : hardened computer or a traditional server
- Distribution circuit components
  - Equipment (cap banks, reg banks, LTCs, reclosers, EOL sensors, etc.)
  - Intelligent electronic devices (IEDs)
- Telecommunications equipment
  - Typically wireless radios for telemetry to distribution circuit devices
  - Fiber can also be integrated where feasible, such as station backhaul

Implementation Concepts
Project Steps

Planning

Model circuits to determine optimum equipment layout and investment requirements based upon project budget

Identify EOL monitoring locations to ensure ANSI C84.1 compliance

Telecommunications site survey for any wireless infrastructure

Engineering/Procurement

Circuit engineering for new equipment (no different than “traditional” engineering)

System engineering for automation application (VVO)

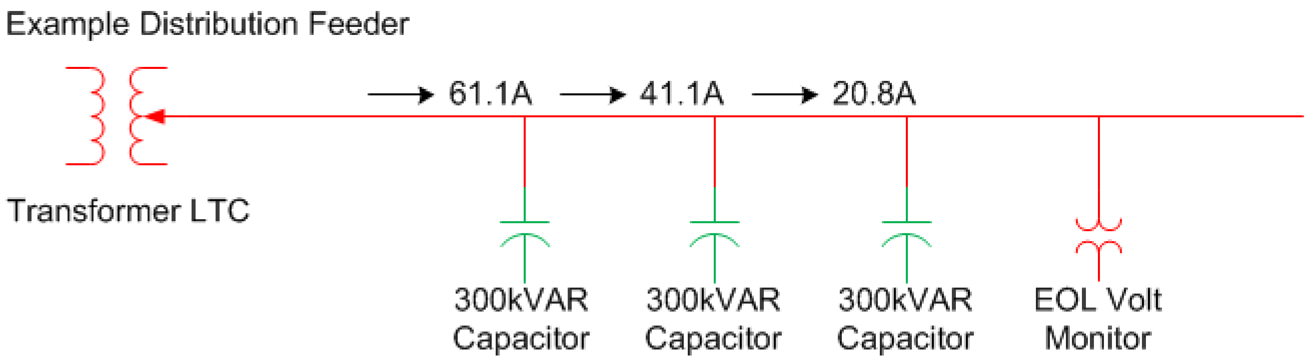
Telecommunications engineering for wired/wireless infrastructure

Integration (may be associated with factory acceptance testing)

Ensure all distribution/telecommunications/automation applications function together as one congenial system!

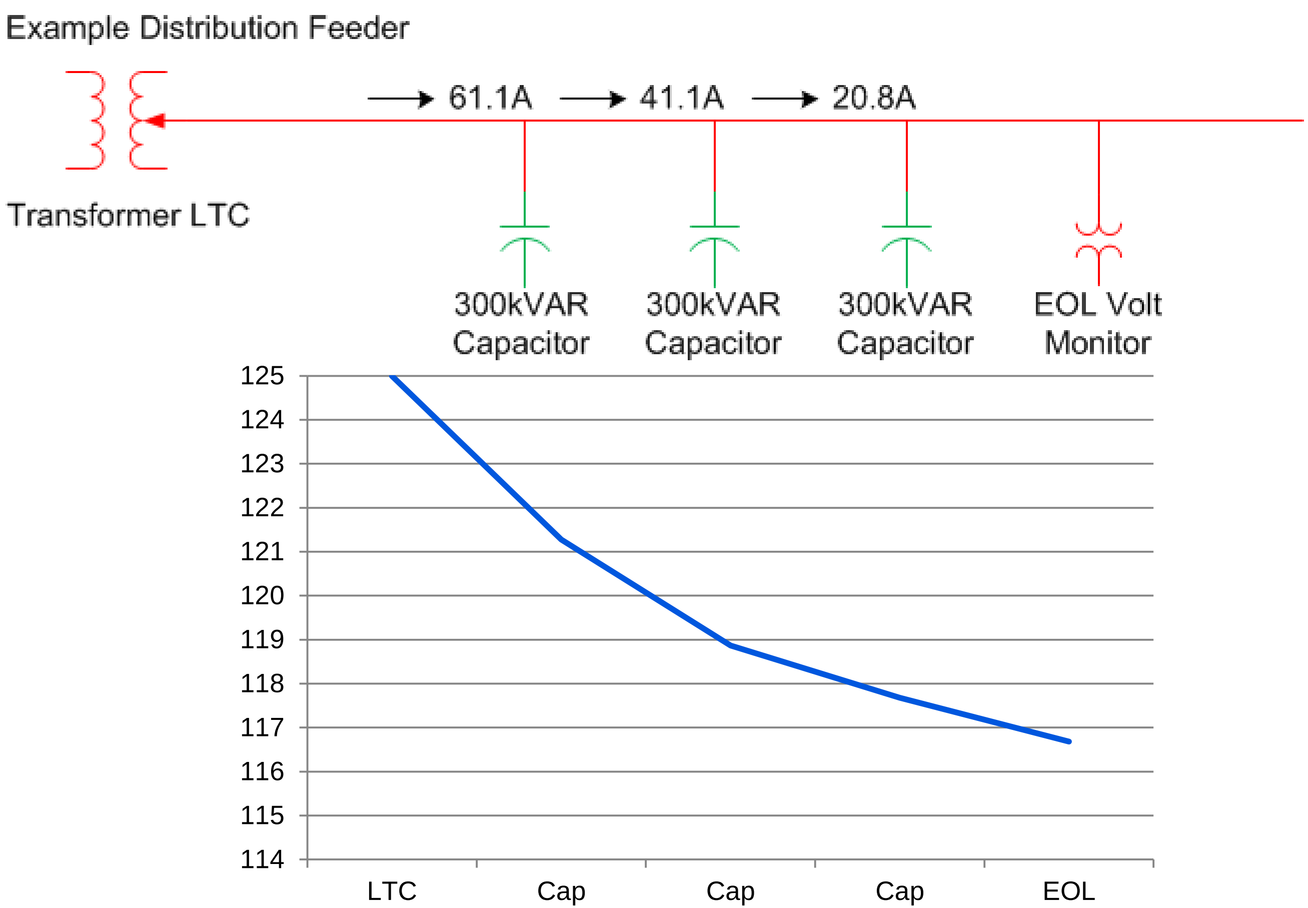
Testing/Commissioning (typically associated with site acceptance testing)

Implementation Concepts
Example Feeder Scenario - Base Case



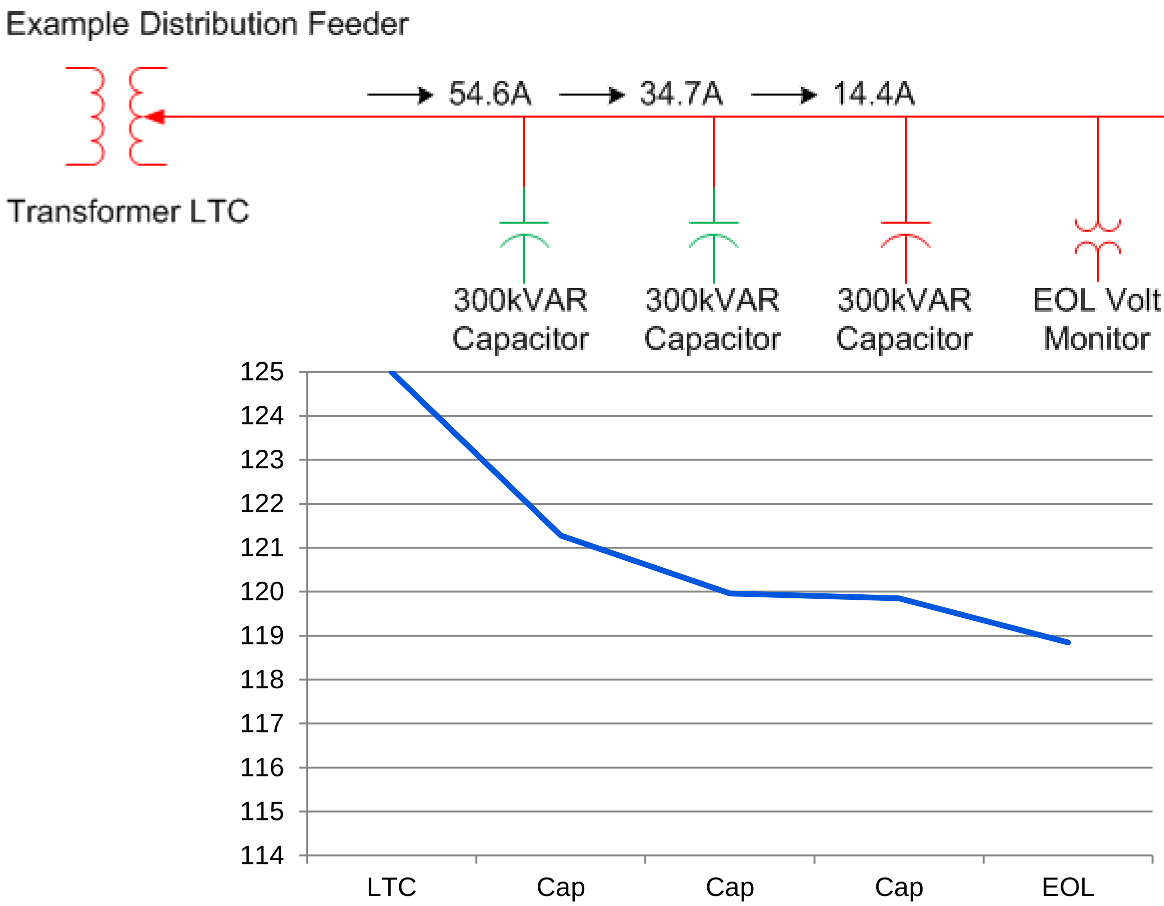
- 12.47kV feeder w/ LTC on transformer regulating to 125V secondary at feeder head (120V base)
- Base power factor of .7 with no power factor correction implemented
- Line impedance of .4 + j.6 ohms per mile, each line section is 5 miles
  - .4 ohms is the “real” resistance, j.6 ohms is the “imaginary” reactance
- CVRf = 1.0 (1% drop in demand for each 1% drop in voltage)

Implementation Concepts
Example Feeder Scenario - Base Case

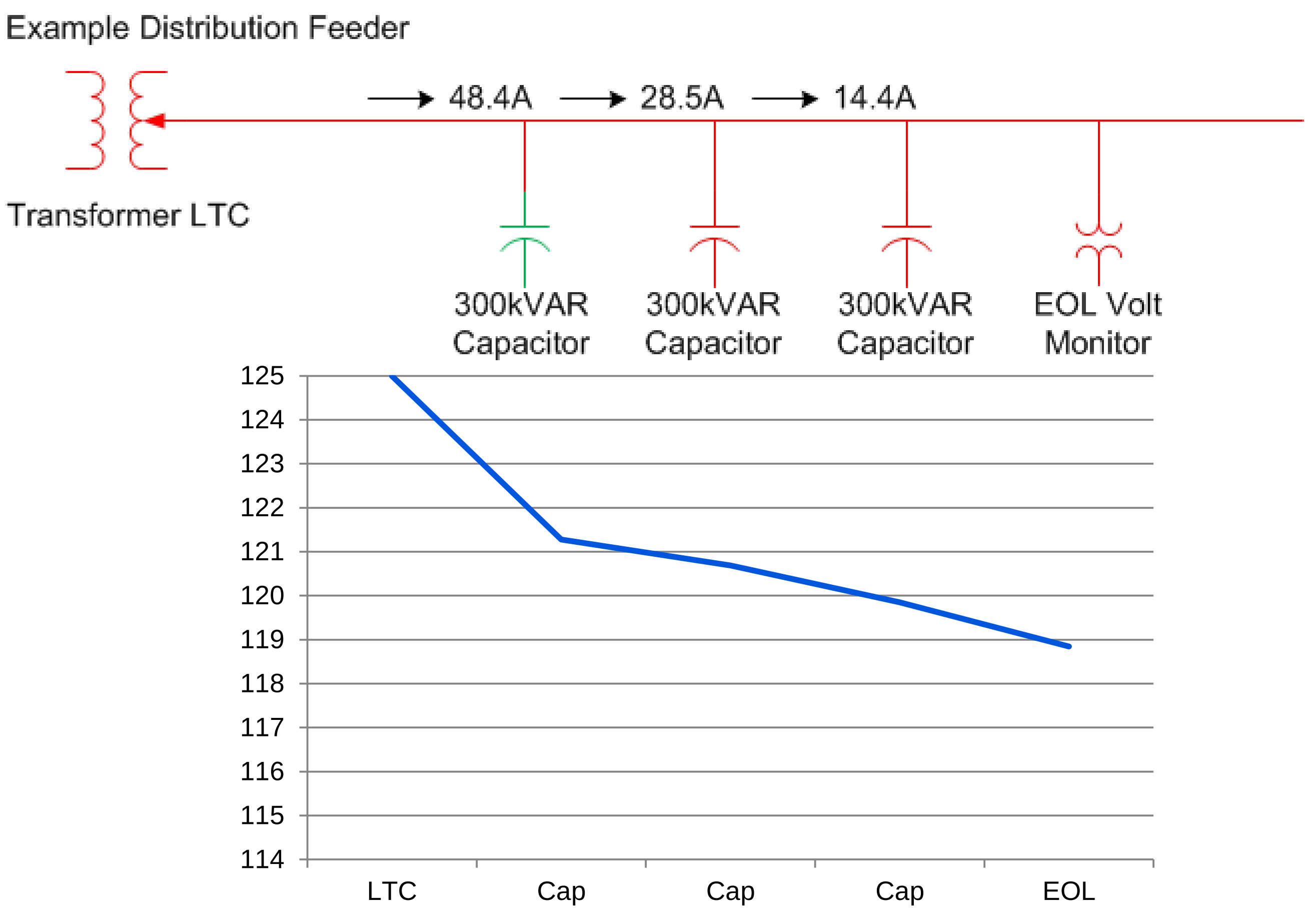


Implementation Concepts

Example Feeder Scenario – First Cap Switched

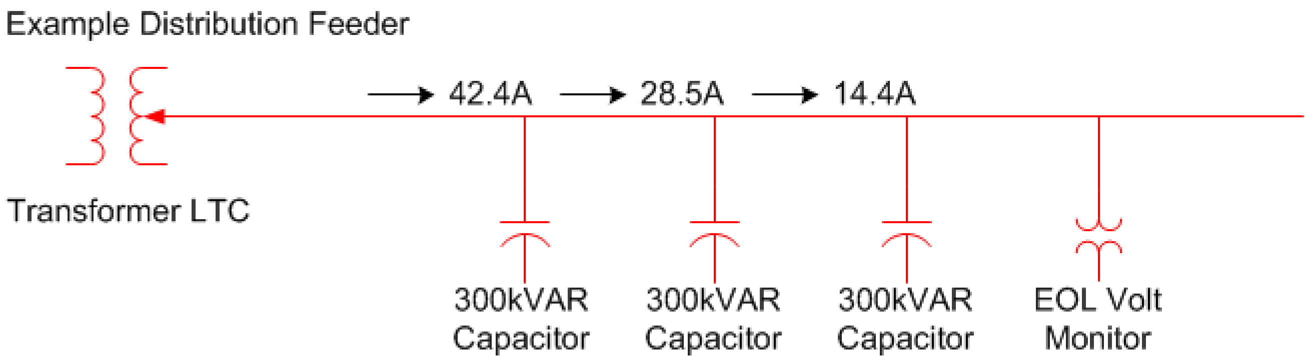


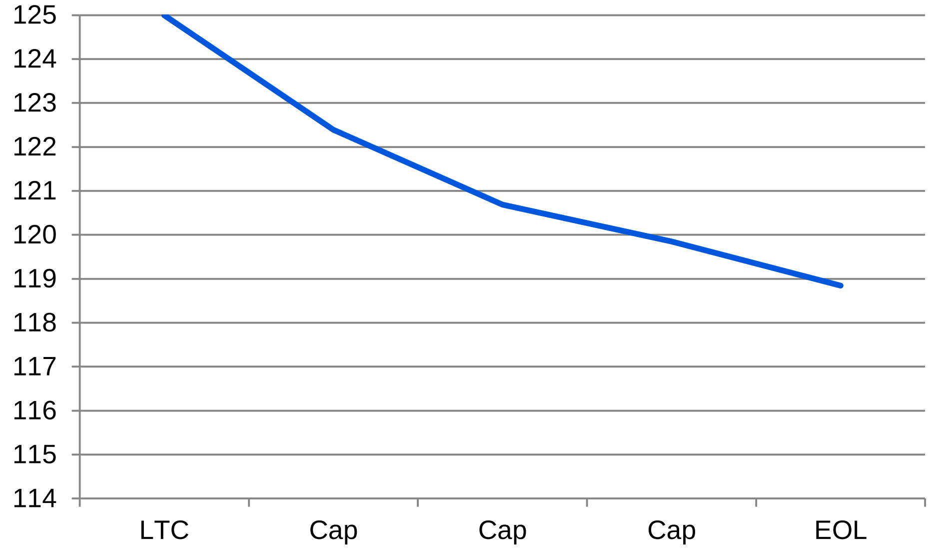
Implementation Concepts
Example Feeder Scenario – Second Cap Switched



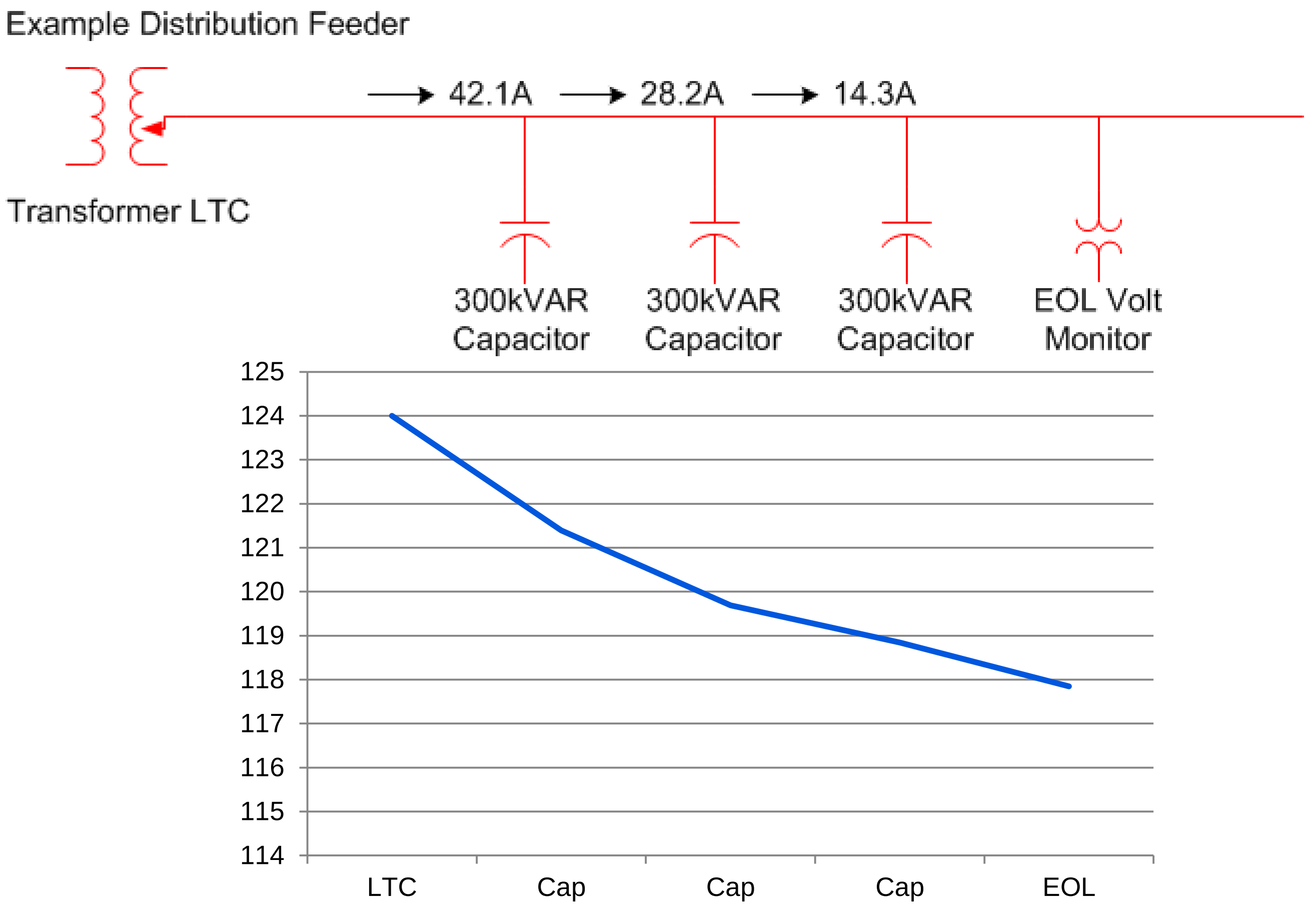
Implementation Concepts

Example Feeder Scenario – Third Cap Switched



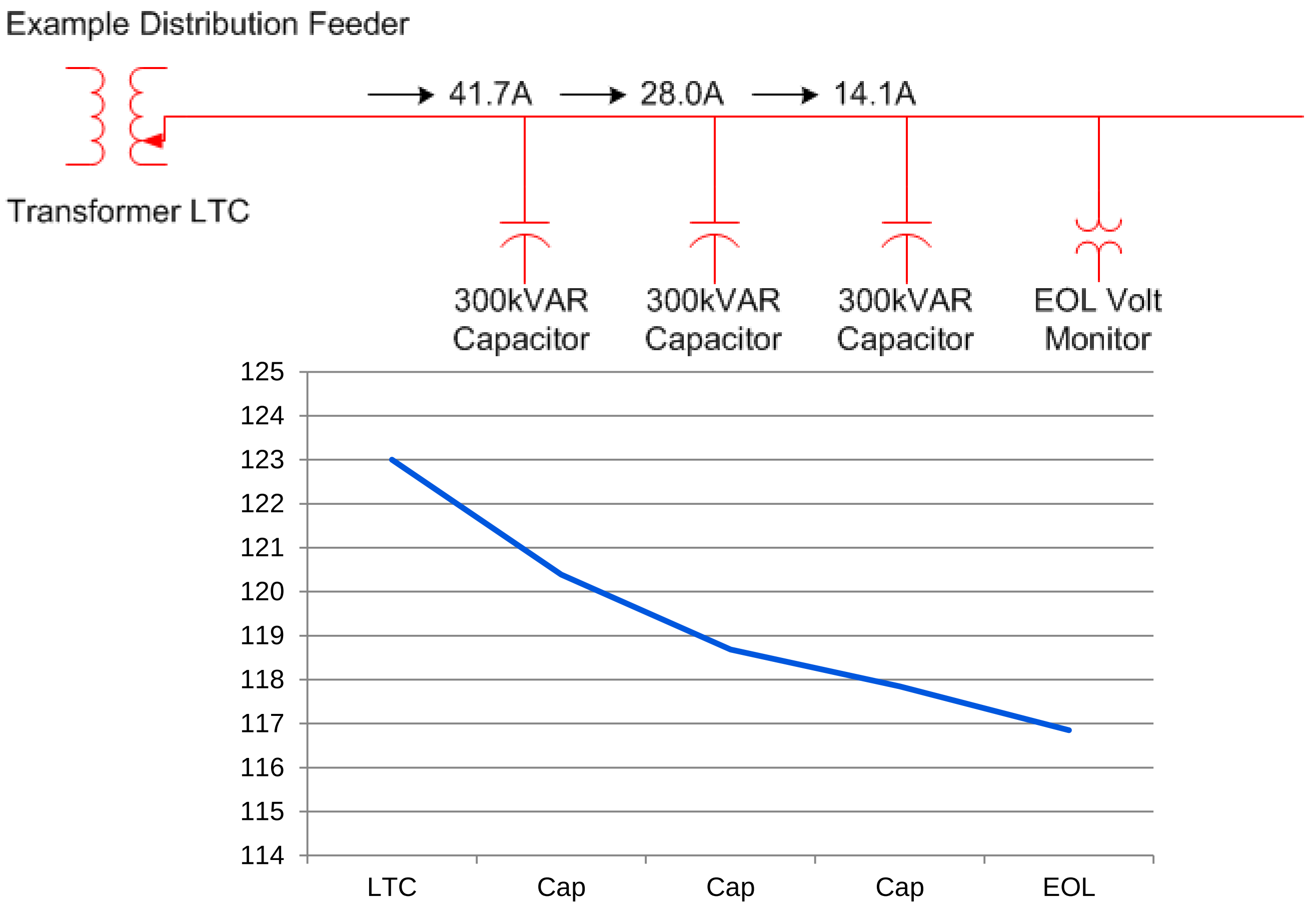


Implementation Concepts
Example Feeder Scenario – First LTC Tap Down

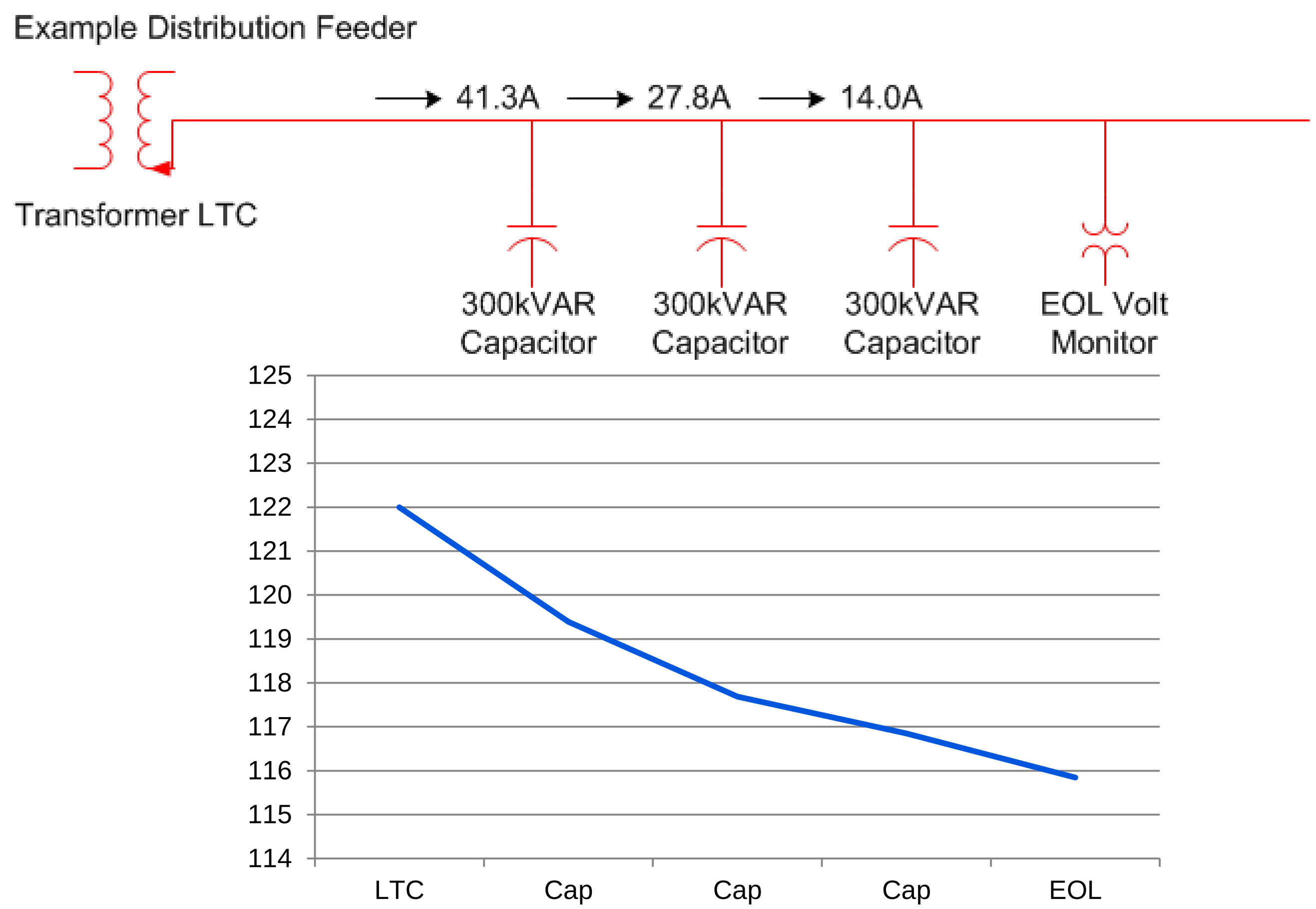


Implementation Concepts

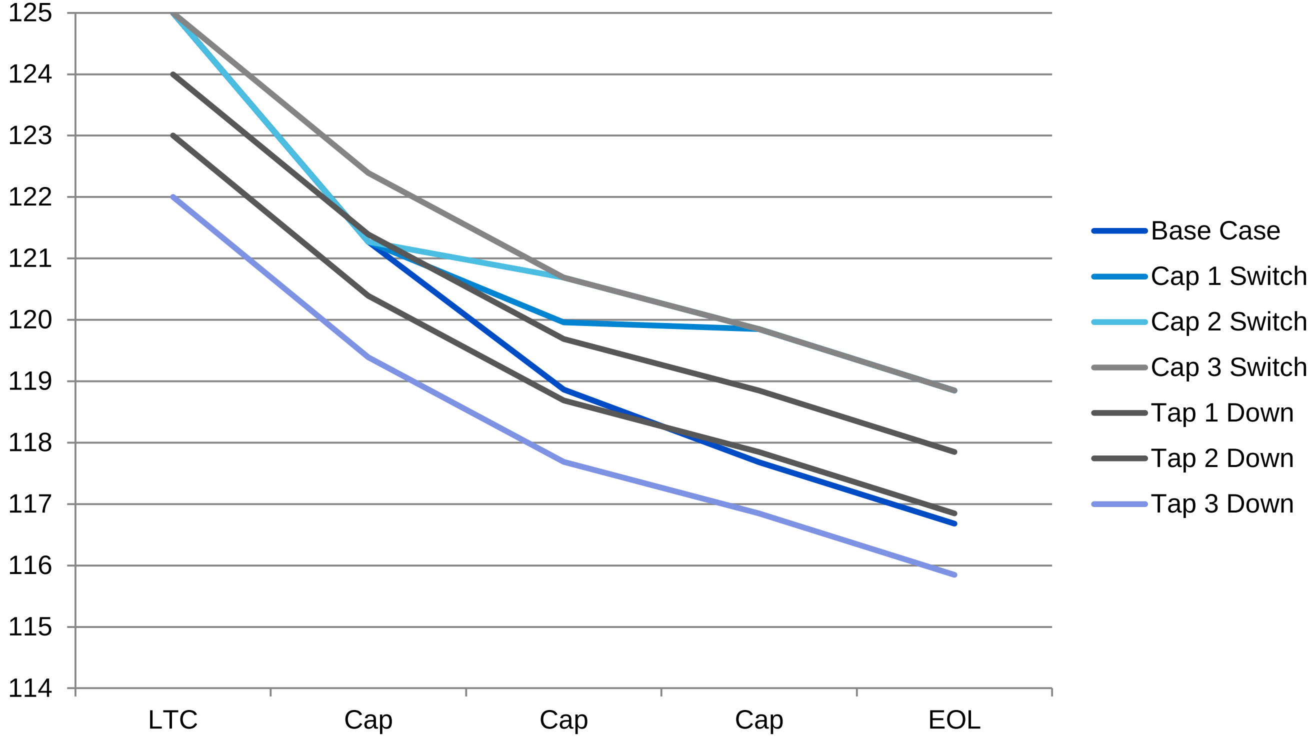
Example Feeder Scenario – Second LTC Tap Down



Implementation Concepts
Example Feeder Scenario – Third LTC Tap Down



Implementation Concepts
Example Feeder Scenario – Stage Comparison



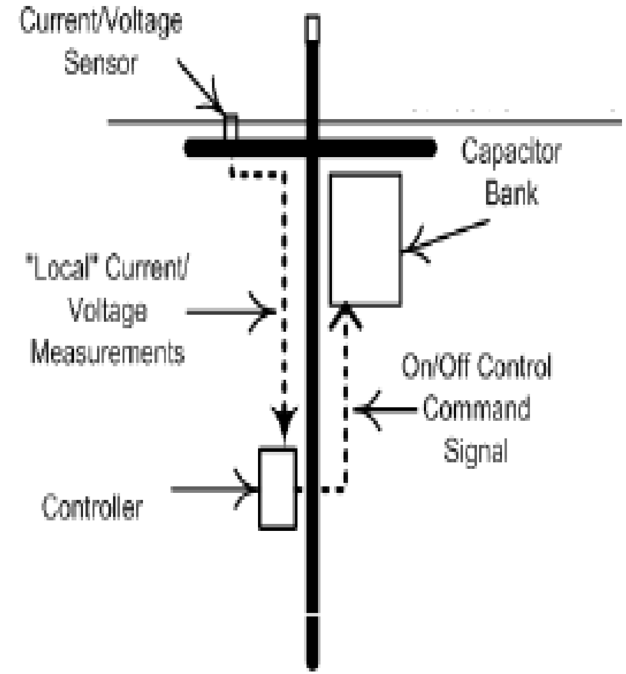
Implementation Concepts
Example Results

- Feeder power factor corrected from .7 to near unity
- Feeder current reduced from 61A/phase to 43A/phase
- Feeder load reduced from 1.3MVA to .9MVA (33%)
  - 2.5 % demand reduction from CVR (assume CVRf of 1%)
- Savings due to reduction in reactive power requirements provided by utilizing shunt capacitors for power factor correction
- Loss reduction also evident through reduced line currents

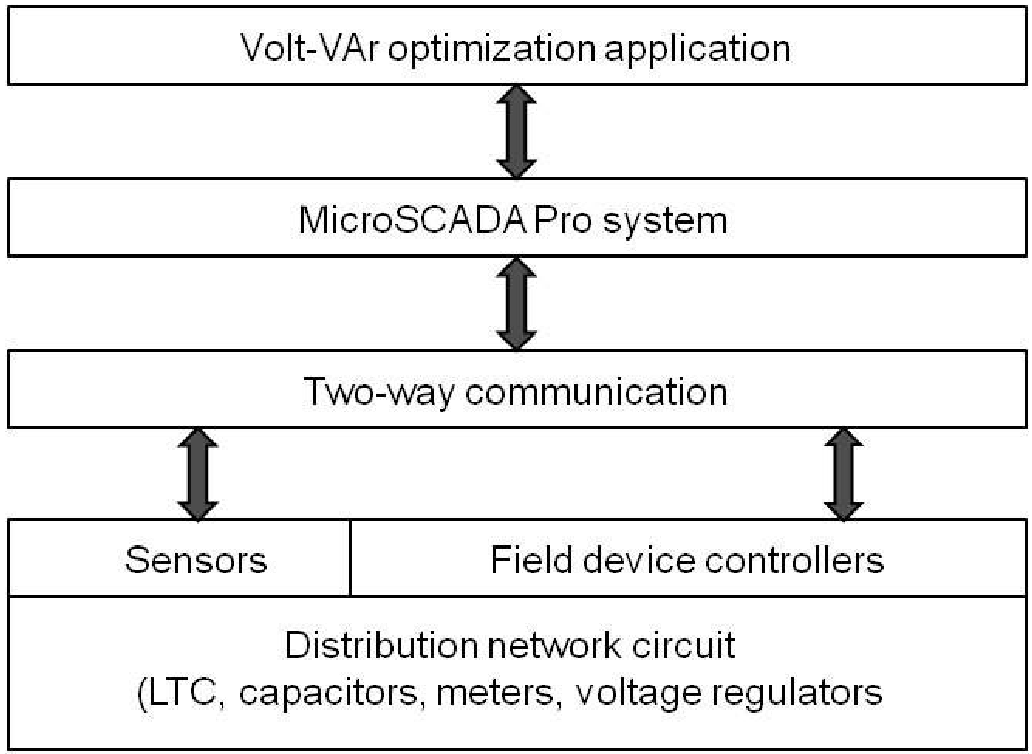
Implementation Concepts
Example Takeaways

- Power Factor Correction provides the most “bang for your buck”
- Leverage existing equipment
- Ancillary benefit of VVO : integrating telecommunications network with IEDs facilitates distribution SCADA system operational efficiency
- Capacitor banks help to flatten the load profile, allowing true voltage optimization
- CVR benefits seem small in comparison to power factor correction; however, when combine across multiple feeders/stations the benefits are rather large

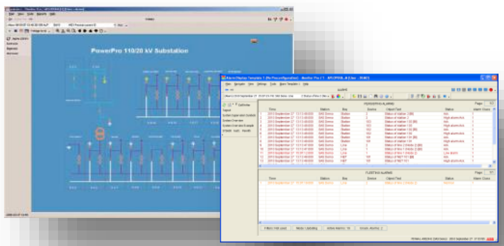
System Integration /Architecture
VVO System Field Devices

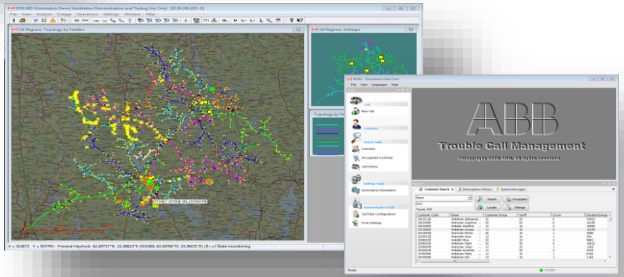


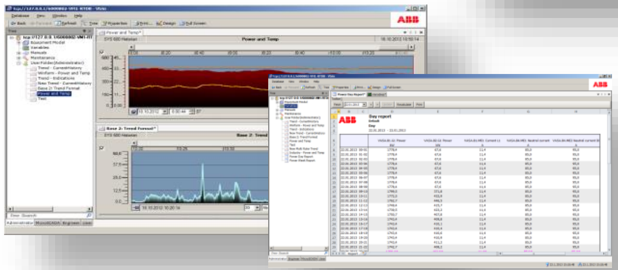
System Integration /Architecture
VVO System Architecture Overview



System Integration /Architecture
MicroSCADA Pro Family

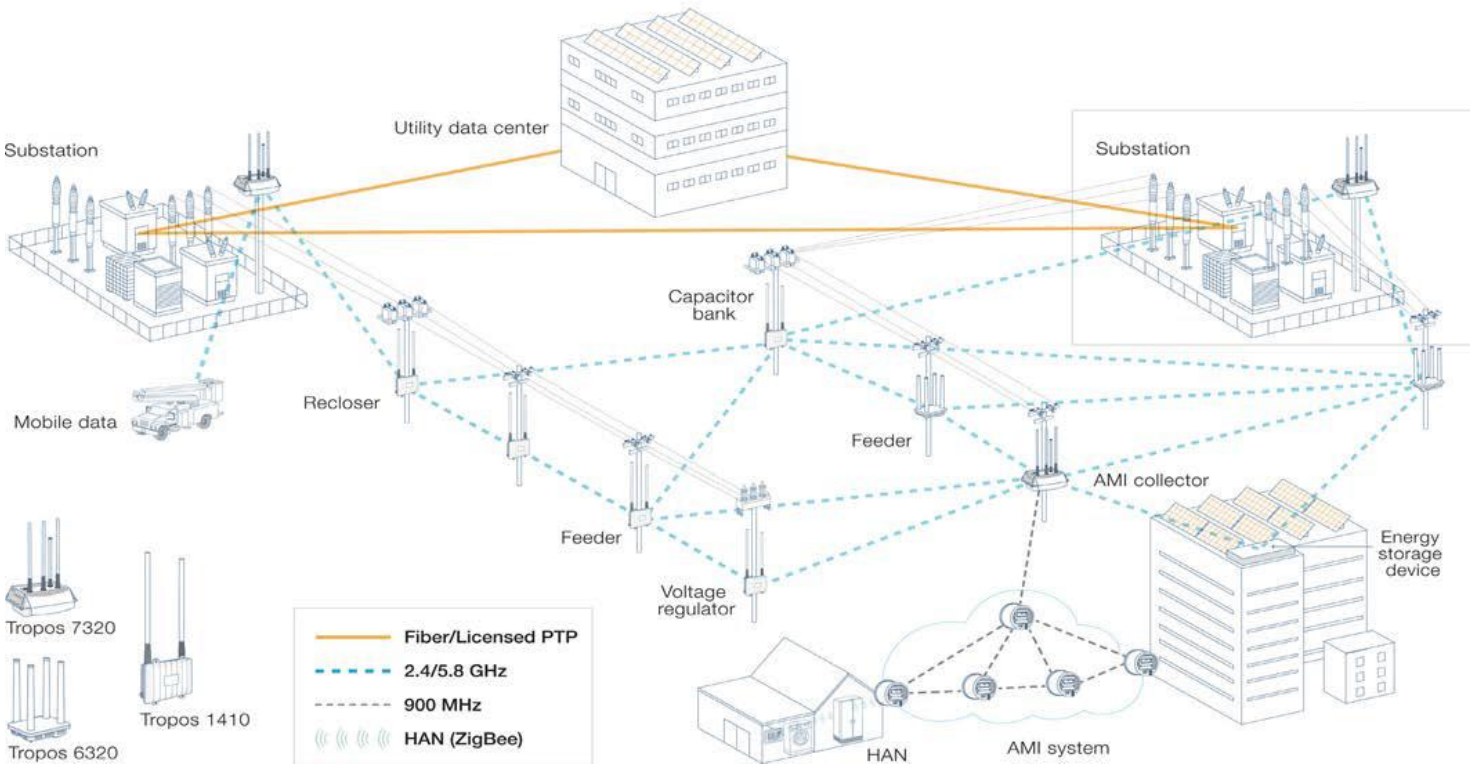






- **SYS 600 -** SCADA functionality
  - Collection and Storage of Real time data
  - Control
  - HMI
  - Communication
  - Trends & Measurement Reports
- **DMS 600 -** Distribution Management System
  - Network model
  - Background maps
  - Outage Management
  - Fault Detection, Isolation & Restoration
  - Auto-Restoration
  - Network Analysis
  - Field Crew Management
  - Trouble Call Management
  - Volt/VAR Optimization
- **Historian** – Advanced Data Analysis & Reporting
  - High capacity data logging
  - Flexible reporting and trending
  - Flexible architecture

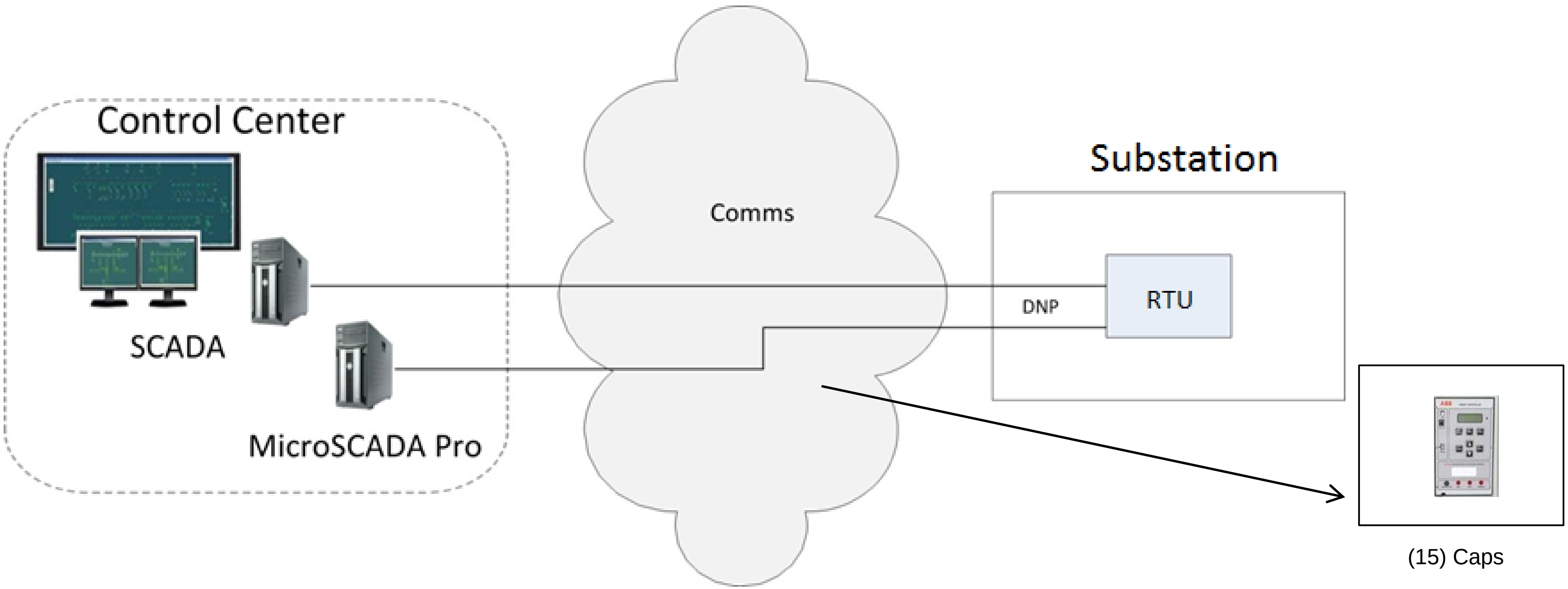
System Integration /Architecture
Network Architecture



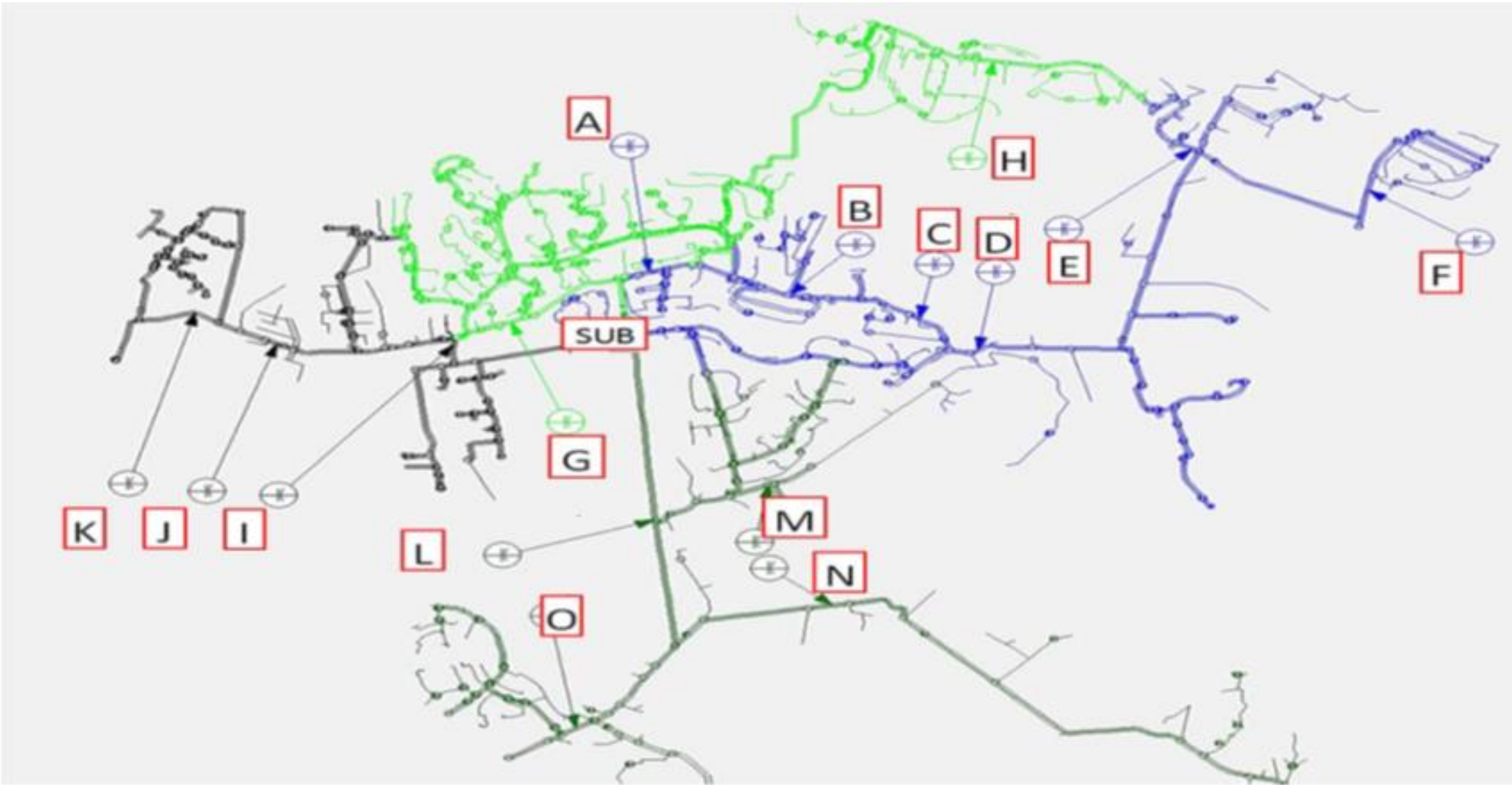
Power Factor Correction
System Objectives

- Real-time monitoring and control of distribution capacitors through integration with their corresponding controllers.
- Real-time monitoring of substation feeder metrology through integration with SCADA system.
- Advanced analytic and control software that directs the switching of distribution line capacitors to achieve the desired levels of regulation.
- Real time status displays of the entire feeder network from the substation down to end of the feeder lines.

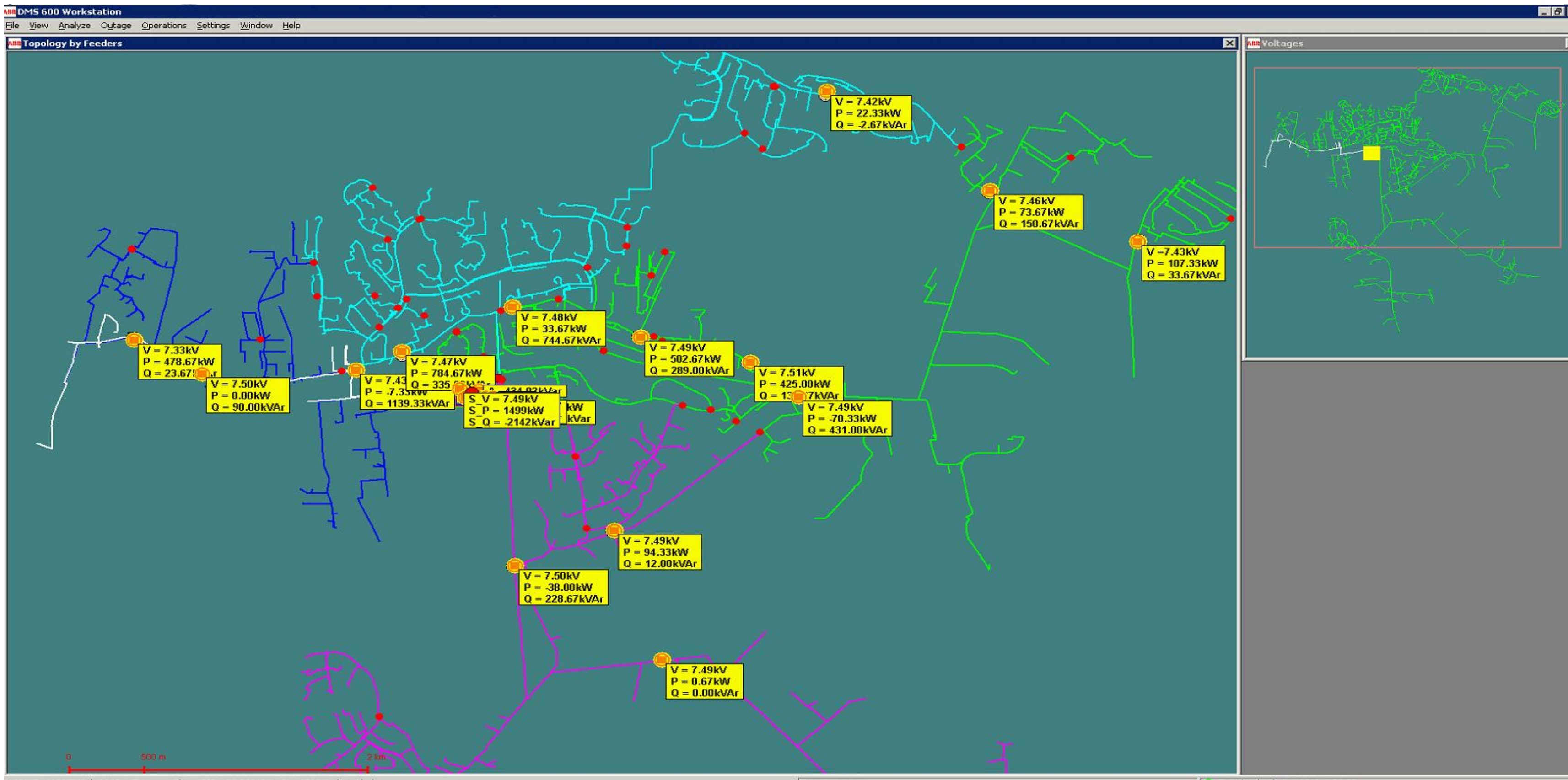
Power Factor Correction
System Architecture



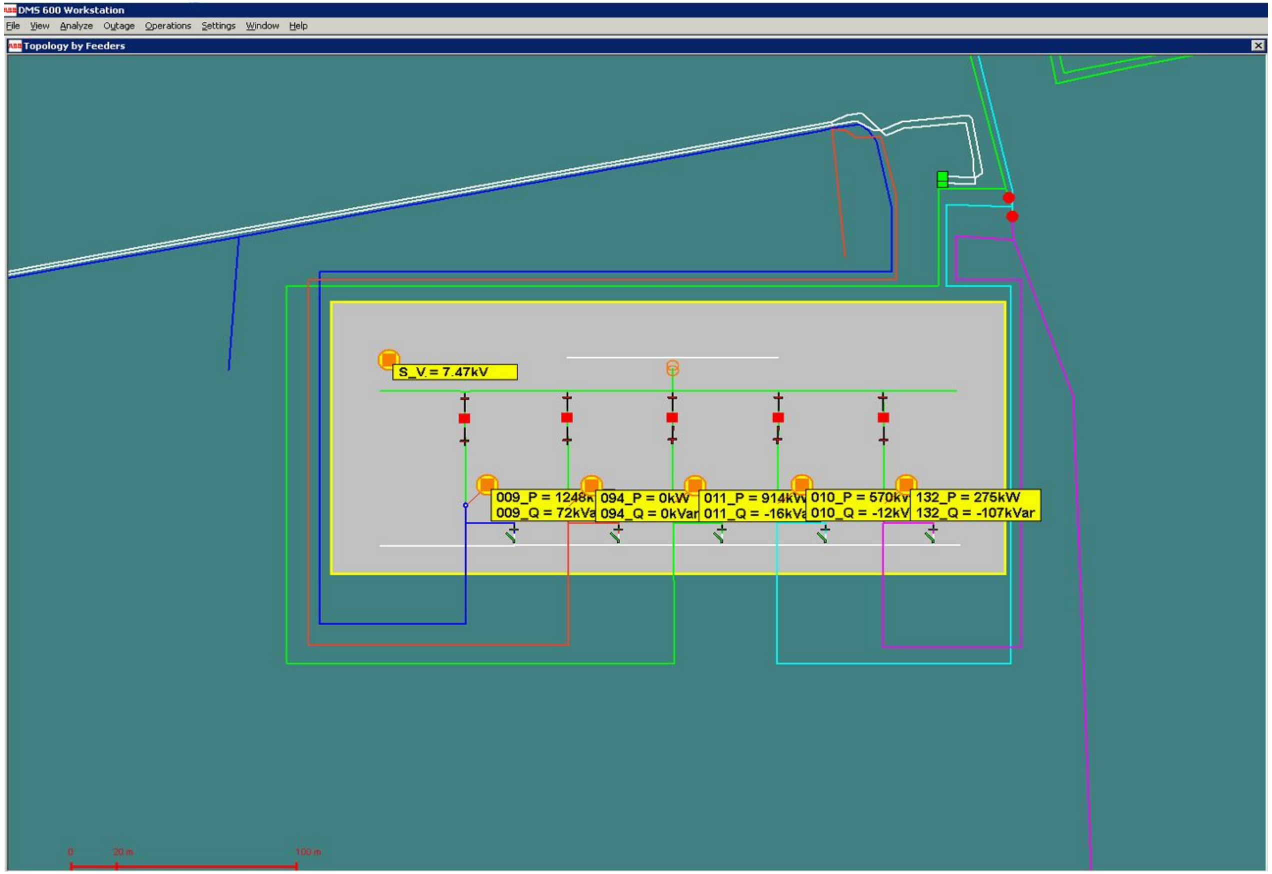
Power Factor Correction
Field Device Locations



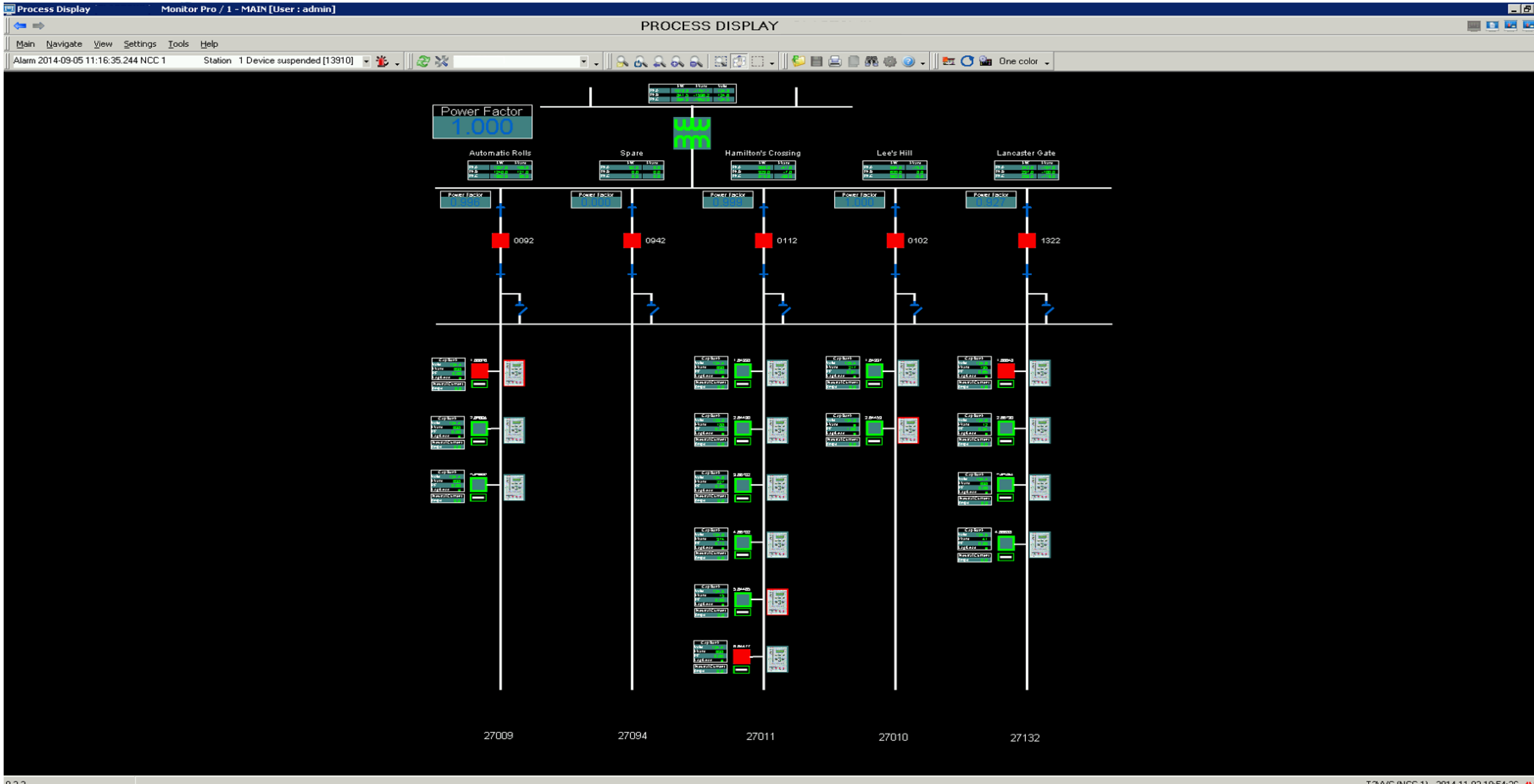
Power Factor Correction
Geographic Representation



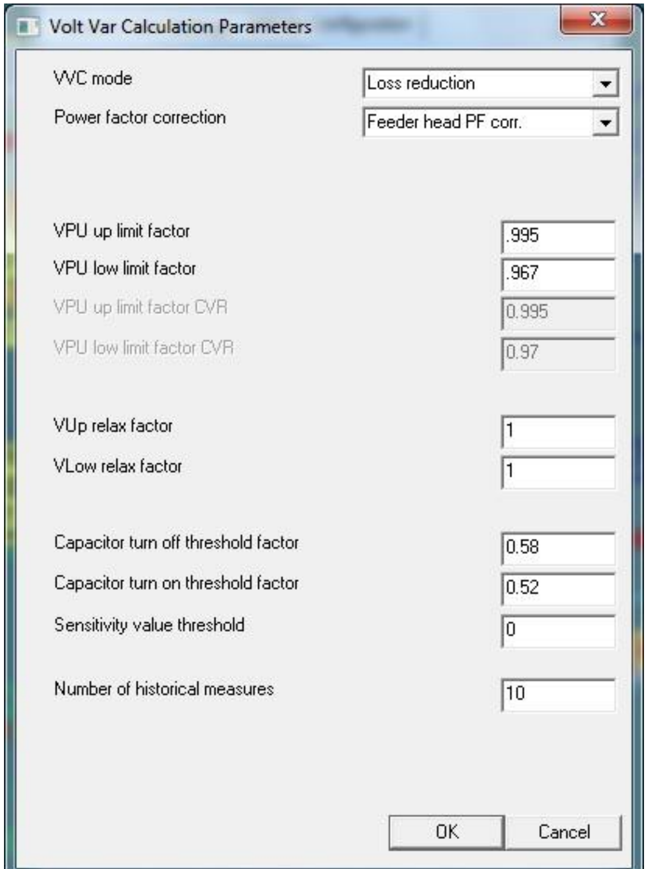
Power Factor Correction
Station Layout

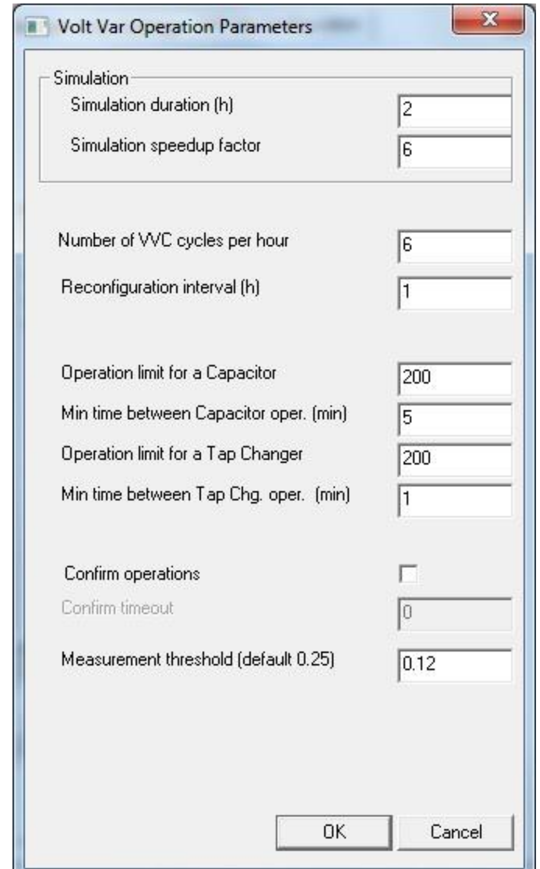


Power Factor Correction
One Line Representation



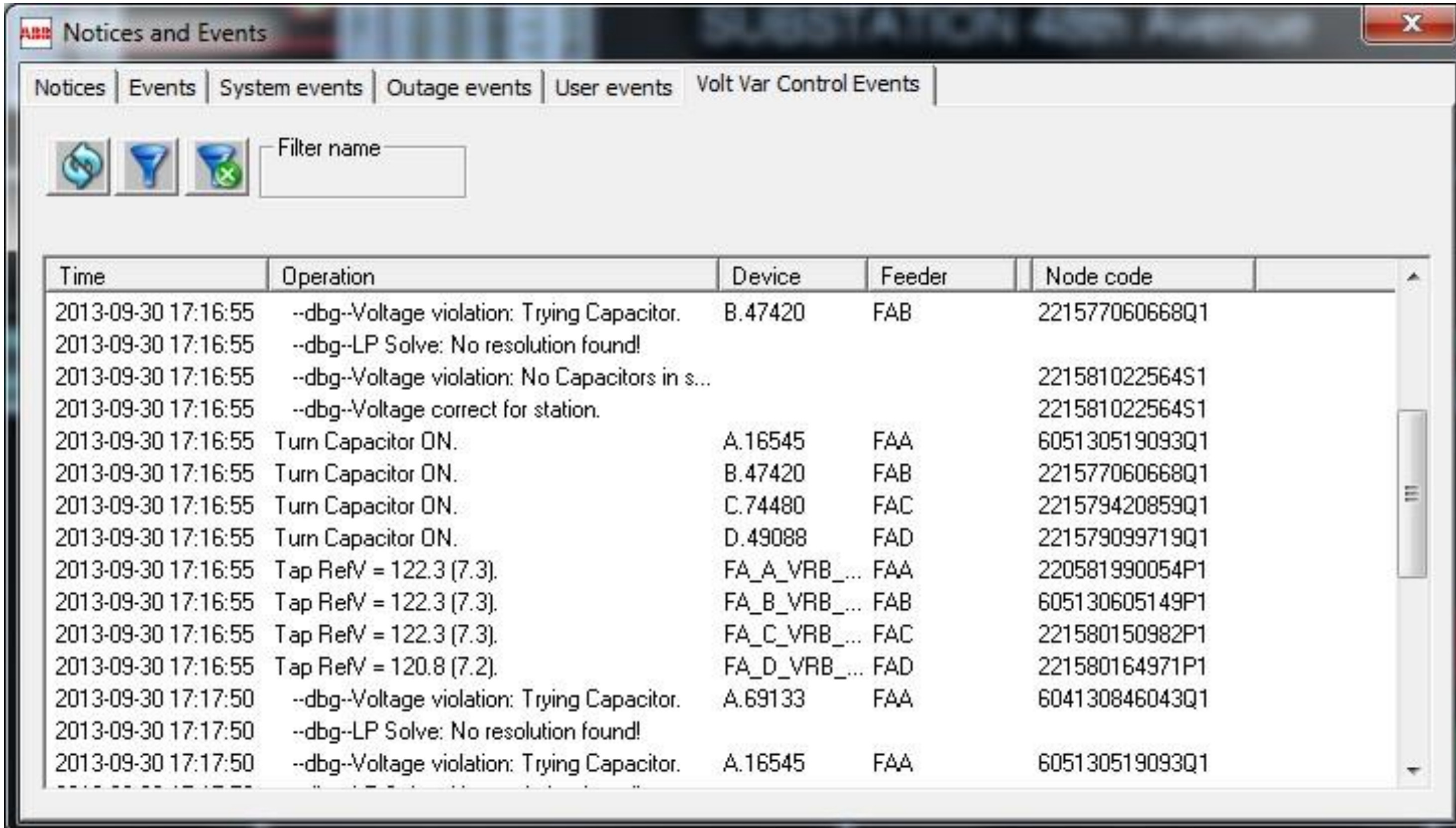
Power Factor Correction
Volt/VAR Parameters





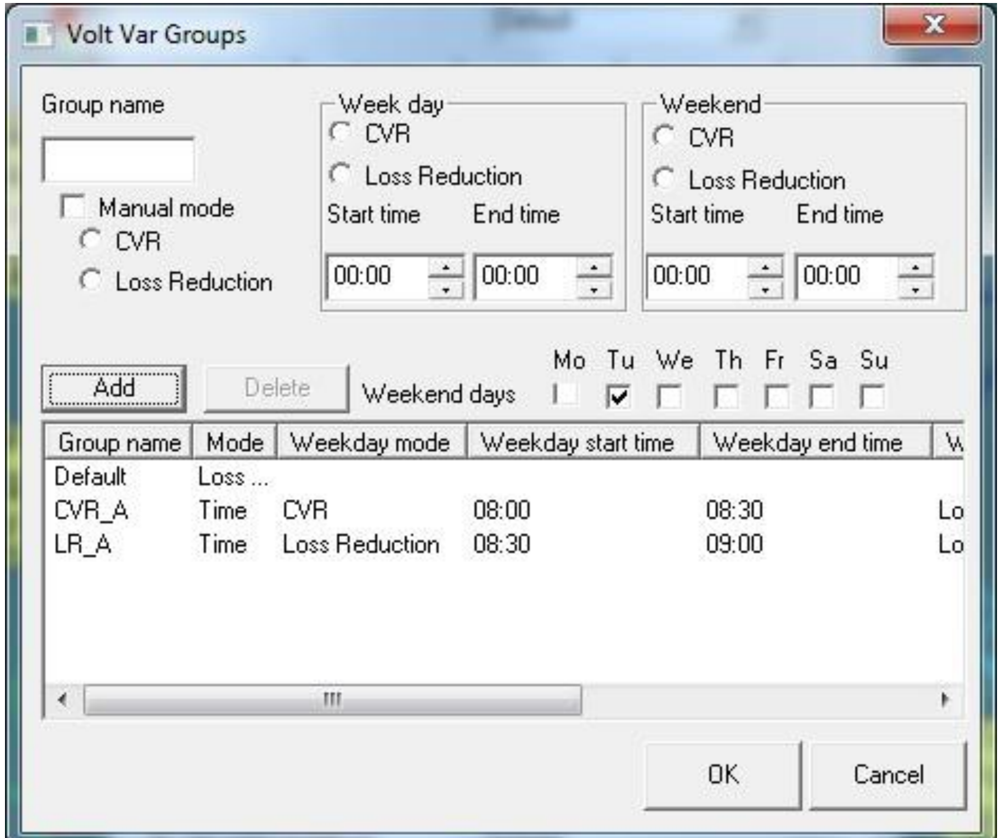
Power Factor Correction

Notices and Events

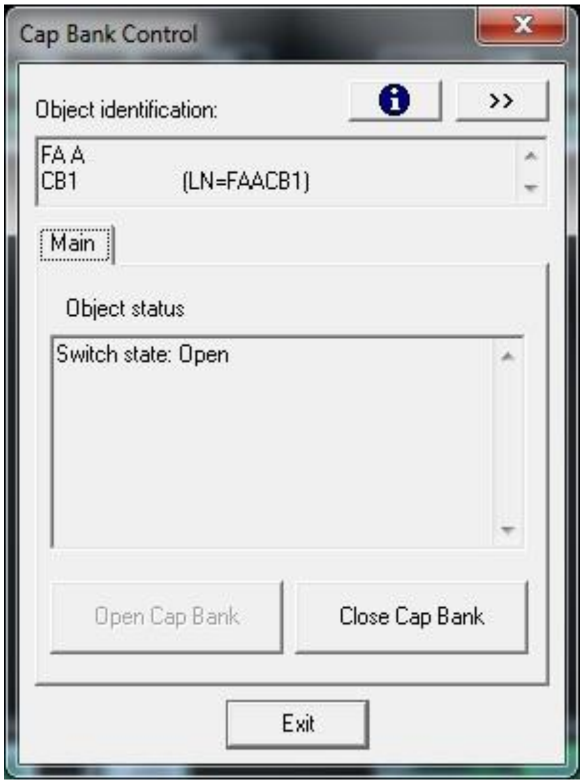


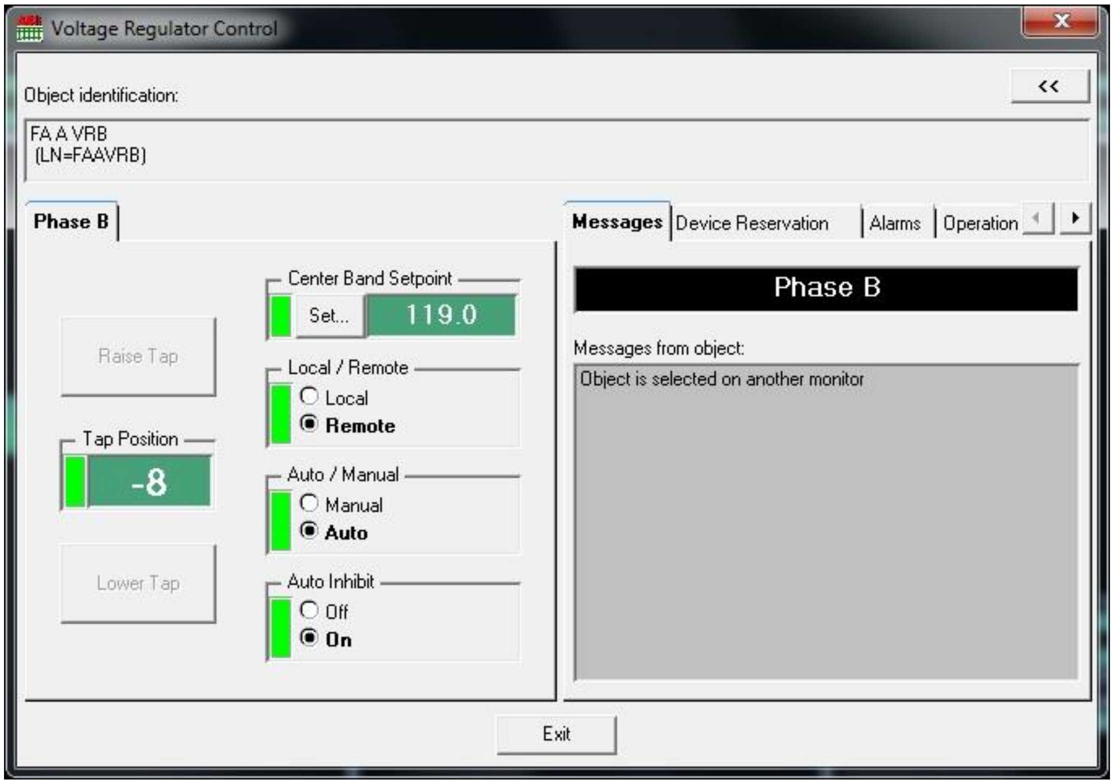
Time	Operation	Device	Feeder	Node code
2013-09-30 17:16:55	--dbg--Voltage violation: Trying Capacitor.	B.47420	FAB	221577060668Q1
2013-09-30 17:16:55	--dbg--LP Solve: No resolution found!			
2013-09-30 17:16:55	--dbg--Voltage violation: No Capacitors in s...			221581022564S1
2013-09-30 17:16:55	--dbg--Voltage correct for station.			221581022564S1
2013-09-30 17:16:55	Turn Capacitor ON.	A.16545	FAA	605130519093Q1
2013-09-30 17:16:55	Turn Capacitor ON.	B.47420	FAB	221577060668Q1
2013-09-30 17:16:55	Turn Capacitor ON.	C.74480	FAC	221579420859Q1
2013-09-30 17:16:55	Turn Capacitor ON.	D.49088	FAD	221579099719Q1
2013-09-30 17:16:55	Tap RefV = 122.3 (7.3).	FA_A_VRB_...	FAA	220581990054P1
2013-09-30 17:16:55	Tap RefV = 122.3 (7.3).	FA_B_VRB_...	FAB	605130605149P1
2013-09-30 17:16:55	Tap RefV = 122.3 (7.3).	FA_C_VRB_...	FAC	221580150982P1
2013-09-30 17:16:55	Tap RefV = 120.8 (7.2).	FA_D_VRB_...	FAD	221580164971P1
2013-09-30 17:17:50	--dbg--Voltage violation: Trying Capacitor.	A.69133	FAA	604130846043Q1
2013-09-30 17:17:50	--dbg--LP Solve: No resolution found!			
2013-09-30 17:17:50	--dbg--Voltage violation: Trying Capacitor.	A.16545	FAA	605130519093Q1

Power Factor Correction
Volt/VAR Scheduler

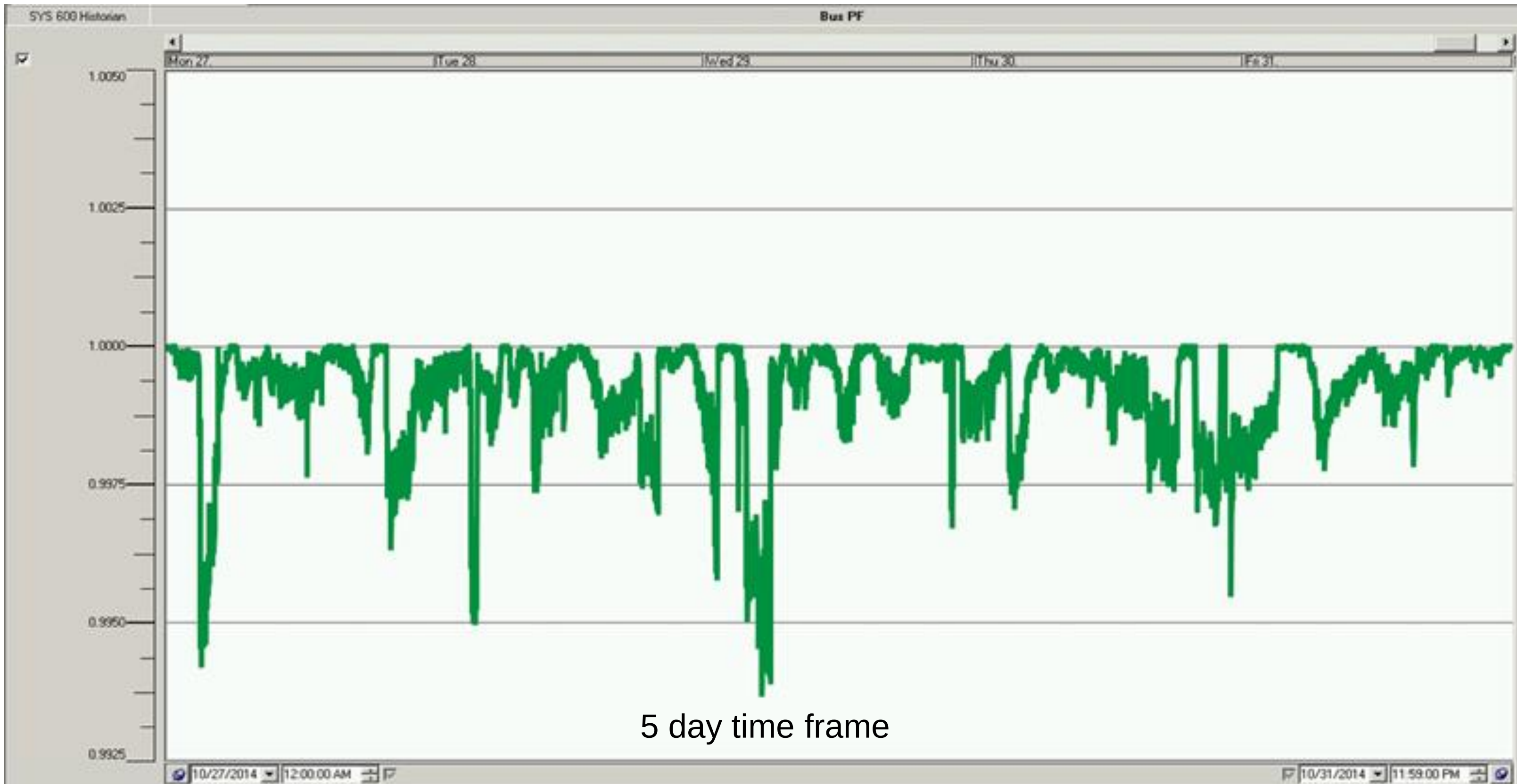


Power Factor Correction
Full SCADA Control



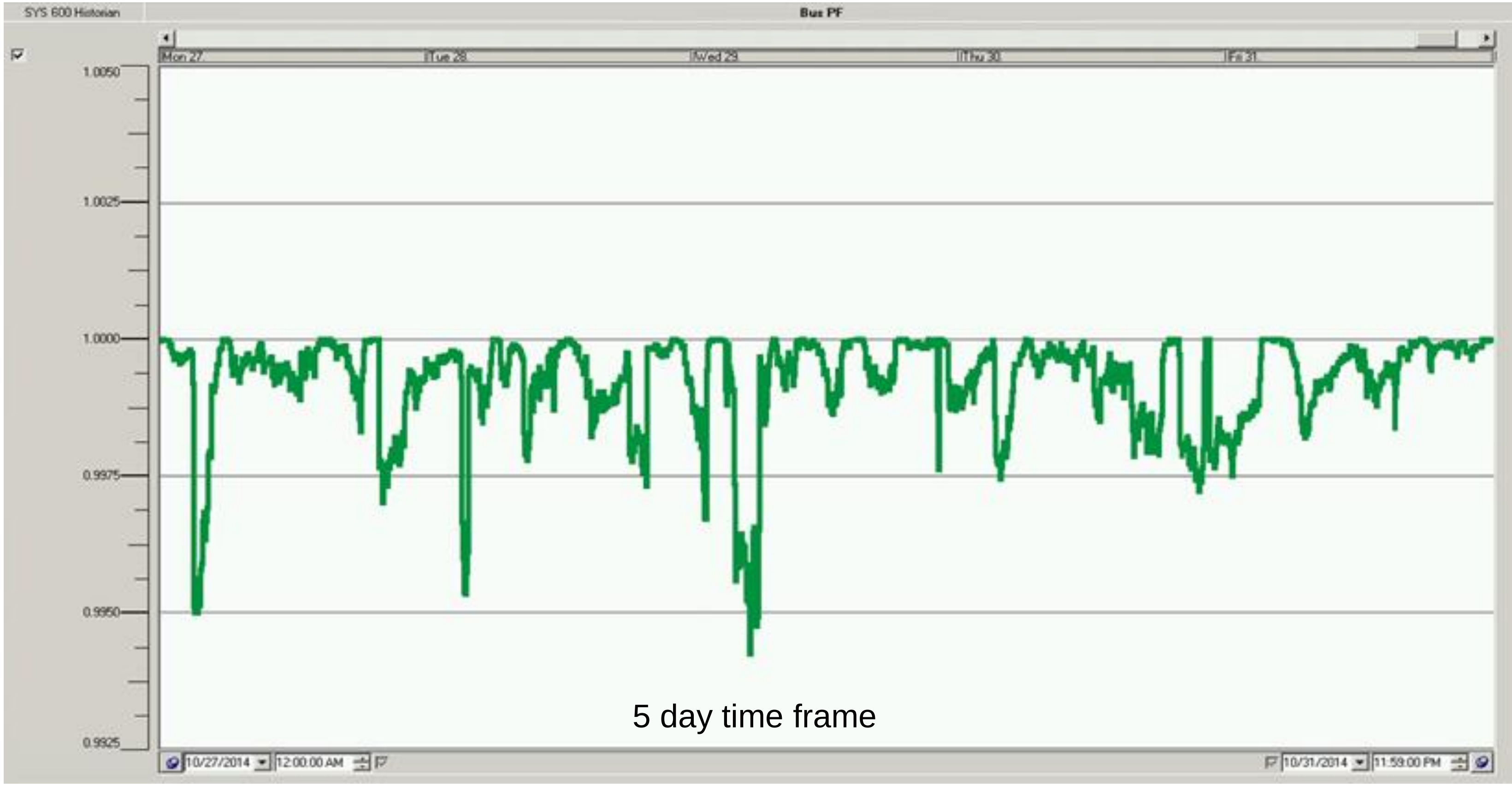


Power Factor Correction
Station Power Factor

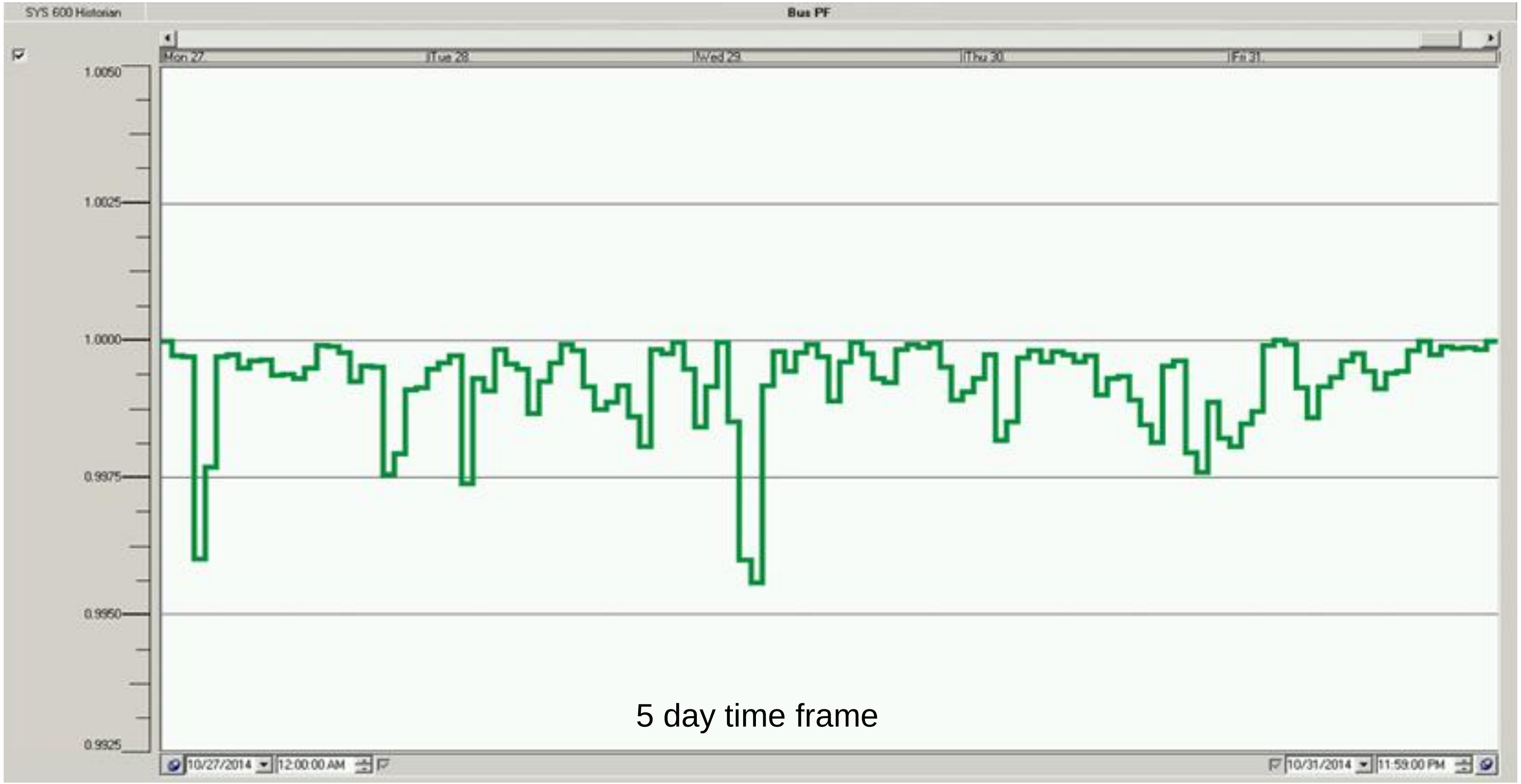


Power Factor Correction

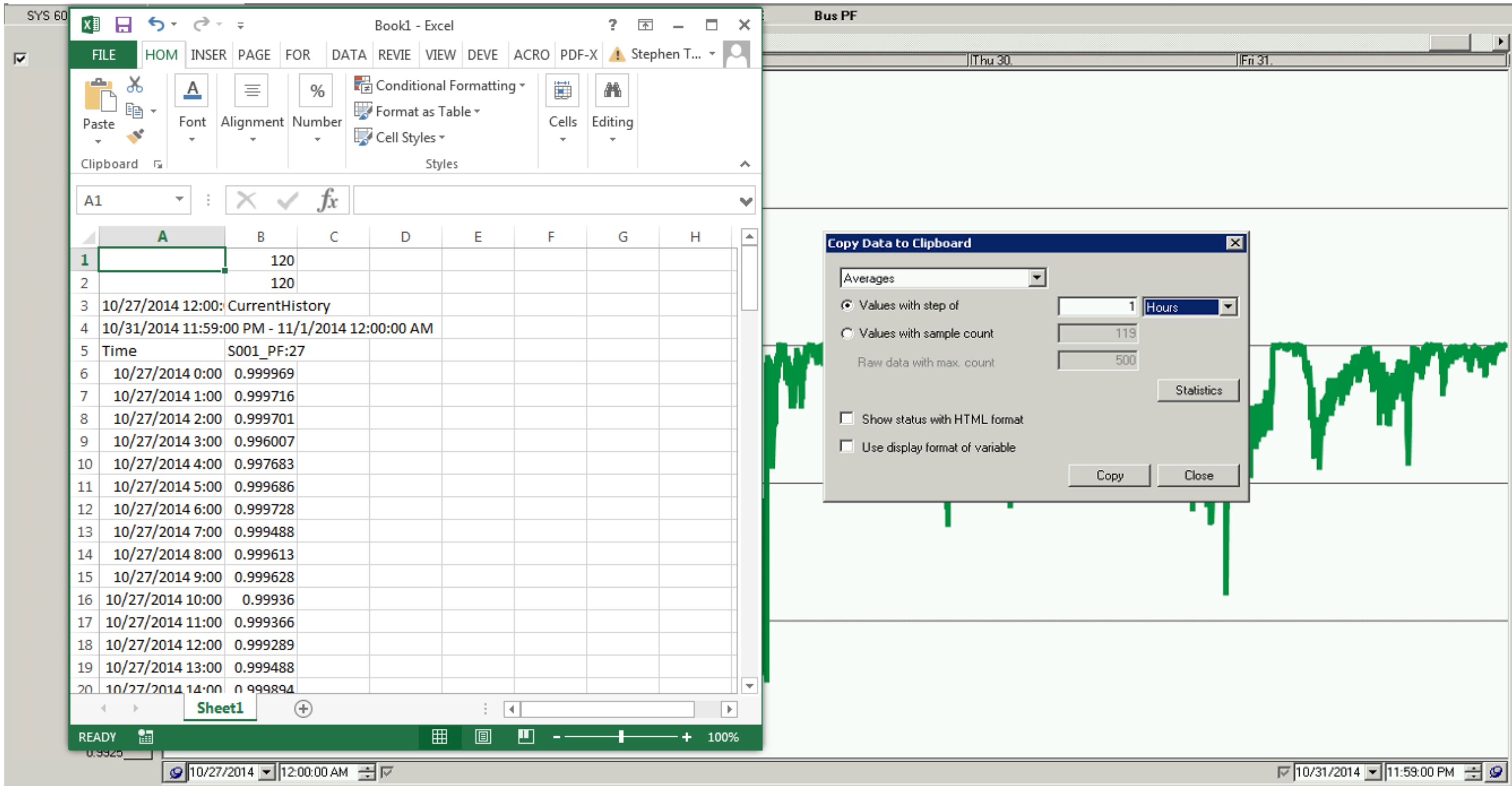
Station Power Factor – 5 Minute Average



Power Factor Correction
Station Power Factor – 1 Hour Average



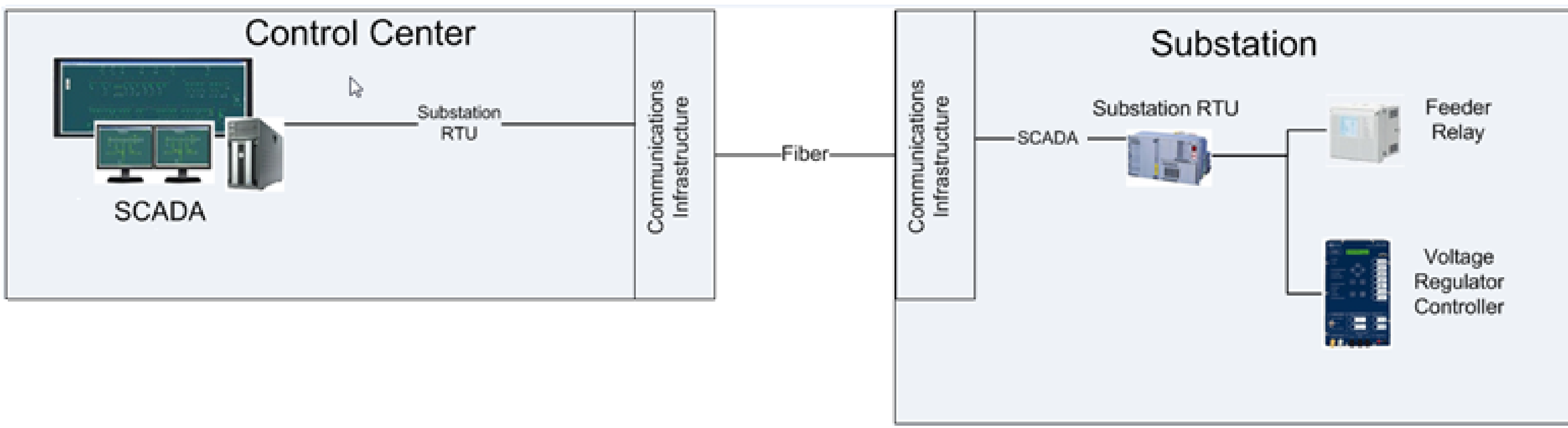
Power Factor Correction
Station Power Factor – Export Data



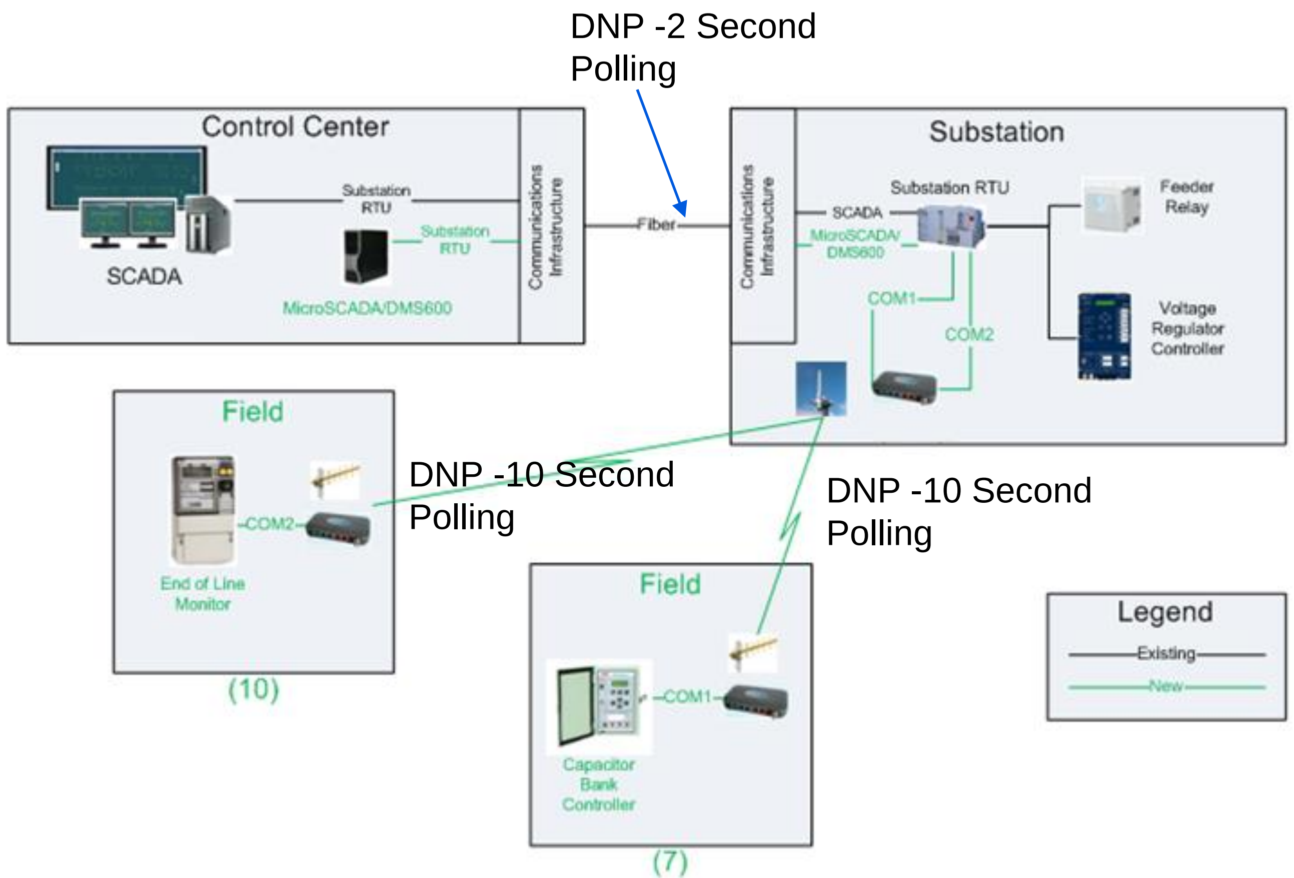
Volt-VAR Optimization
System Objectives

- Real-time monitoring of feeder voltages through strategically positioned end of line sensors
- Real-time monitoring and control of distribution capacitors and voltage regulators through integration with their corresponding controllers.
- Real-time monitoring of substation feeder metrology through integration with SCADA system.
- Advanced analytic and control software that directs the switching of distribution line capacitors and distribution voltage regulators to achieve the desired levels of regulation.
- Real time status displays of the entire feeder network from the substation down to end of the feeder lines.

Volt-VAR Optimization
System Architecture - Existing

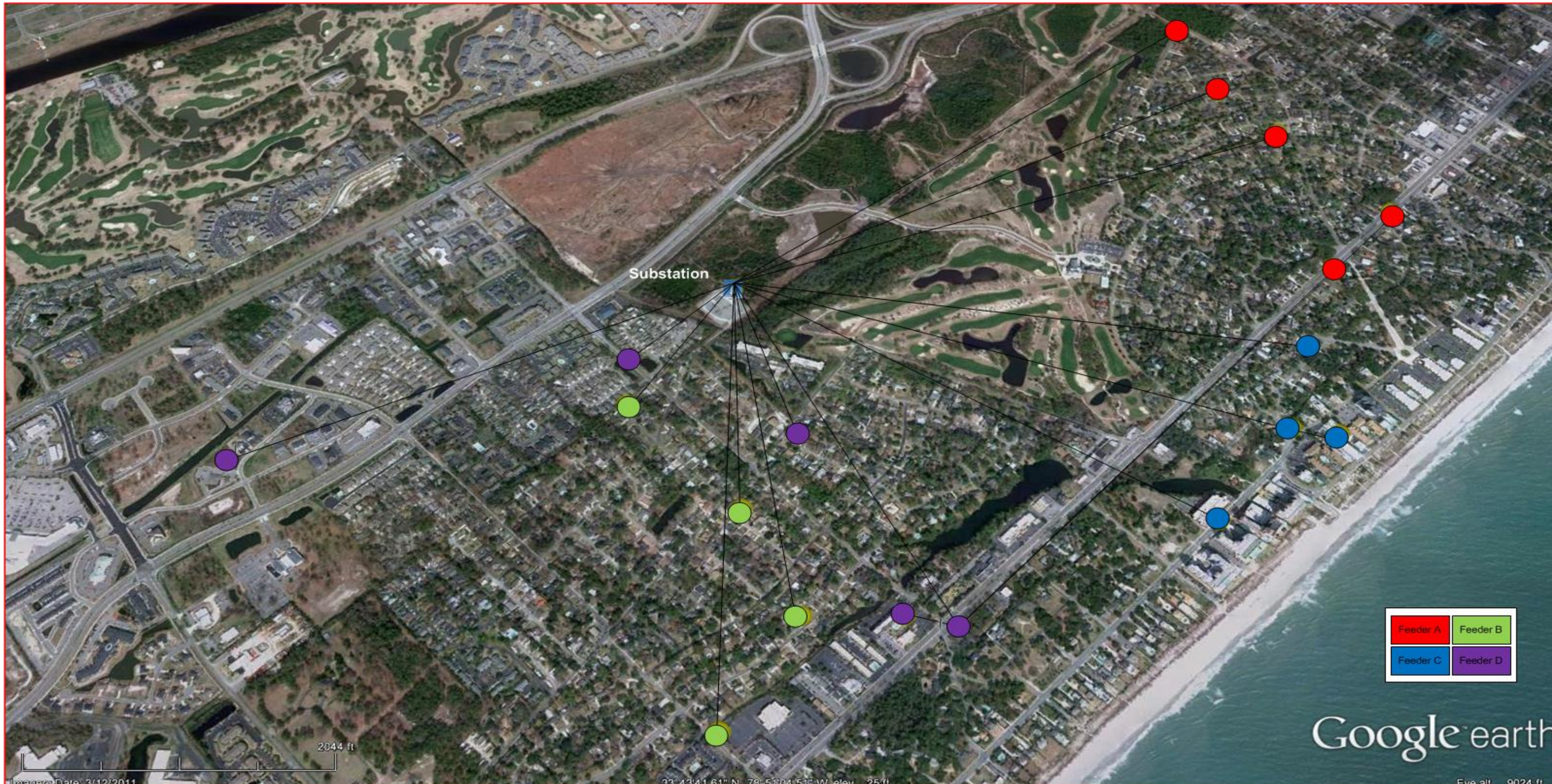


Volt-VAR Optimization
System Architecture - Expanded

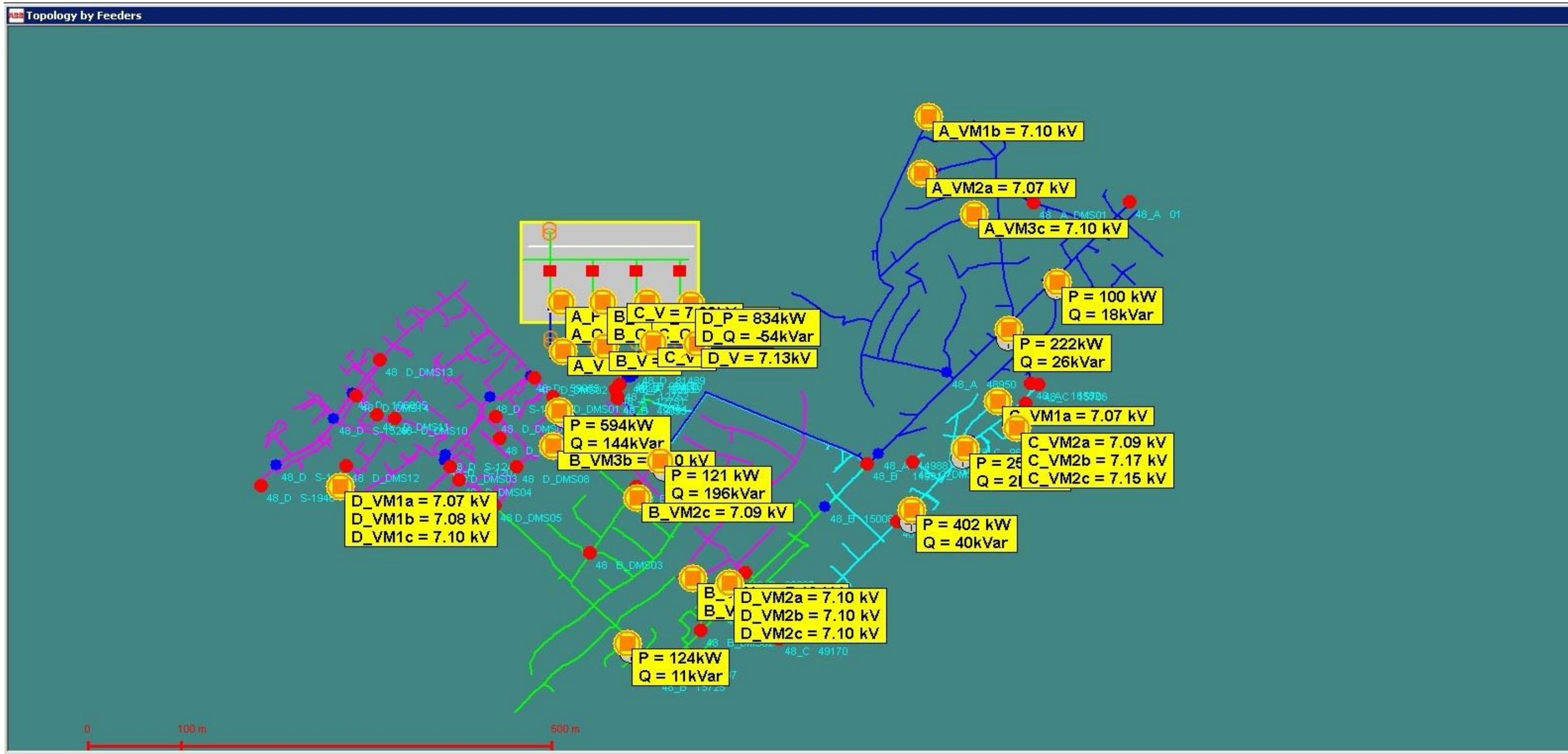


ABB

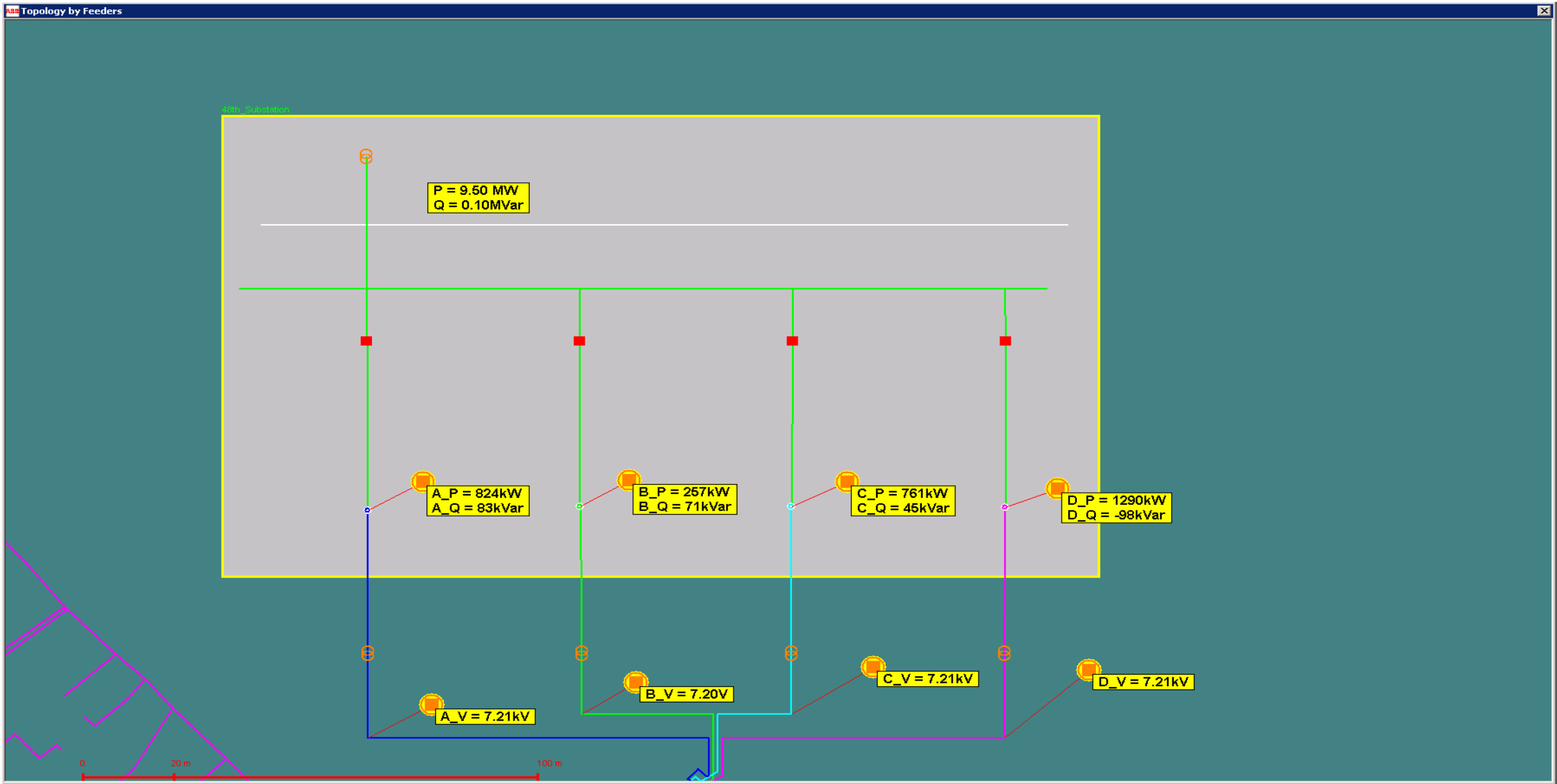
Volt-VAR Optimization
Field Device Locations



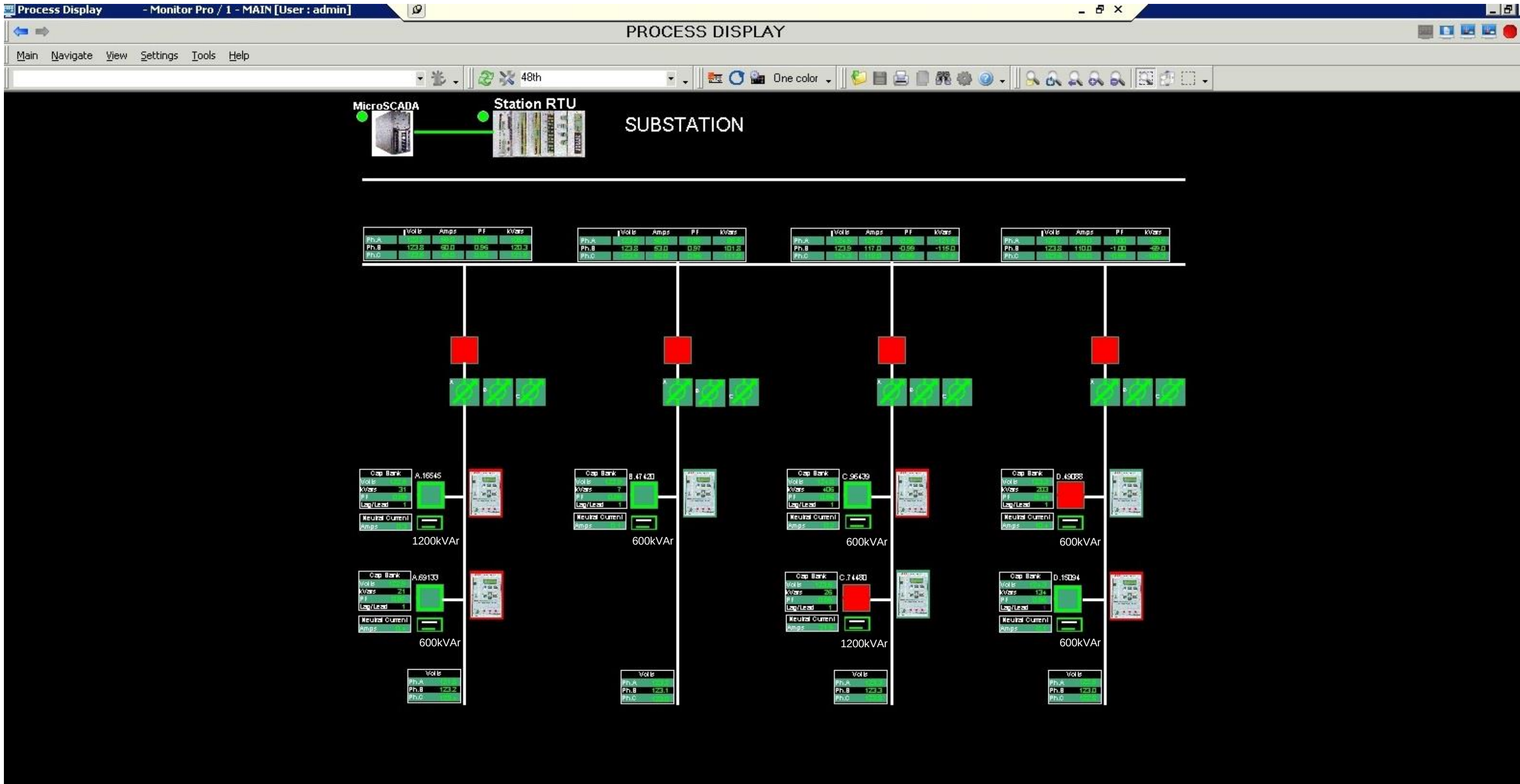
Volt-VAR Optimization
Geographic Representation



Volt-VAR Optimization
Station Layout



Volt-VAR Optimization
One Line Representation



Volt-VAR Optimization
System Hardware – Capacitor Banks

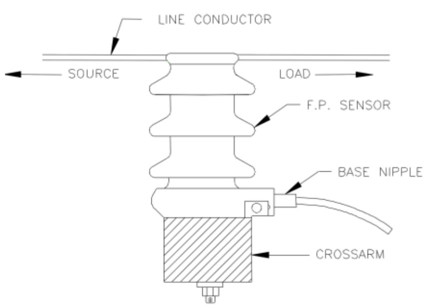
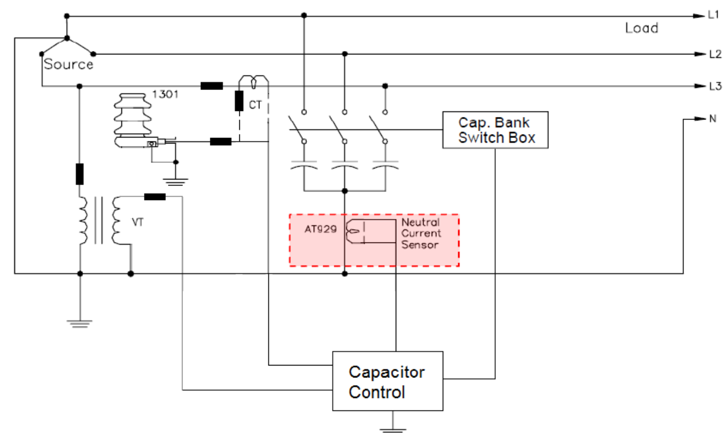


FIG. 1.

Installation and Sensor Location



Volt-VAR Optimization
DNP Data – Capacitor Banks

BINARY/CONTROL OUTPUTS POINT DESCRIPTION
CapBank close
SCADA override activate

BINARY INPUTS POINT DESCRIPTION
Capacitor bank closed
Capacitor bank open
Auto/Manual control mode
Remote control mode enabled
SCADA override active (unit is in remote mode)
Any Alarm status set
Switch fuse blown
Reclose block in effect
Switch 1 feedback error
Switch 2 feedback error
Switch 3 feedback error

ANALOG INPUT POINT DESCRIPTION
V Secondary
I Primary
kvar
kW
Power factor

Volt-VAR Optimization
System Hardware - Metering

Volt-VAR Optimization
DNP Data - Metering

BINARY INPUTS POINT DESCRIPTION
Self Check Error
Measurement Error
Low Battery
Loss of Potential

ANALOG INPUT POINT DESCRIPTION
Line 1-N Volts
Line 2-N Volts
Line 3-N Volts

Volt-VAR Optimization
System Hardware - Regulators

Volt-VAR Optimization
DNP Data - Regulators

BINARY/CONTROL OUTPUTS POINT DESCRIPTION

	Description
RB1 - RAISESV/LOWERSV	Raise command (SELOGIC equation) [VLT_D]
RB2 - INHIBSV	Inhibit conditions (SELOGIC equation)
RB3 - AUTOSV/MANUALSV	Place control in AUTO or MANUAL mode (SELOGIC equation) [AM_D]

BINARY INPUTS POINT DESCRIPTION

	Description
ENABLED	Indicate supply voltage absent, reset dead-man timeout, control disabled, firmware download, and self-test failure
ALARM	ON indicates a user-programmable alarm is asserted
INHIBSV	Inhibit conditions (SELOGIC equation)
REMOTE	Control configuration—Remote position [LR]
AUTO	Control Configuration—Auto Position [AM]
TAP_OFF	Tap is off count (count is even when it should be odd; count is odd when it should be even) [TAPK]
BLOCKSV	Block tap operations (SELOGIC equation)

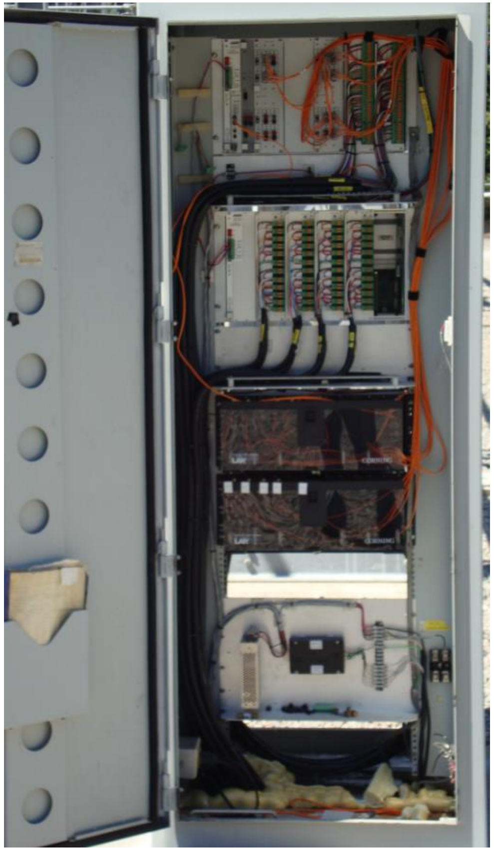
ANALOG OUTPUTS POINT DESCRIPTION

	Description
F_CNBND	Forward center band

ANALOG INPUT POINT DESCRIPTION

	Description
IL	Line Current, Magnitude, Primary [AMP]
VSSEC	S terminal Voltage, Magnitude, Secondary
VLSEC	L terminal Voltage, Magnitude, Secondary [VLT]
PL	Real Power
QL	Reactive Power
PF	Power Factor
PFLD	Power Factor: Leading = 1, Lagging = 0
TAP_POS	Tap position [TAP]

Volt-VAR Optimization
System Hardware - RTU



Volt-VAR Optimization
DNP Data - RTU

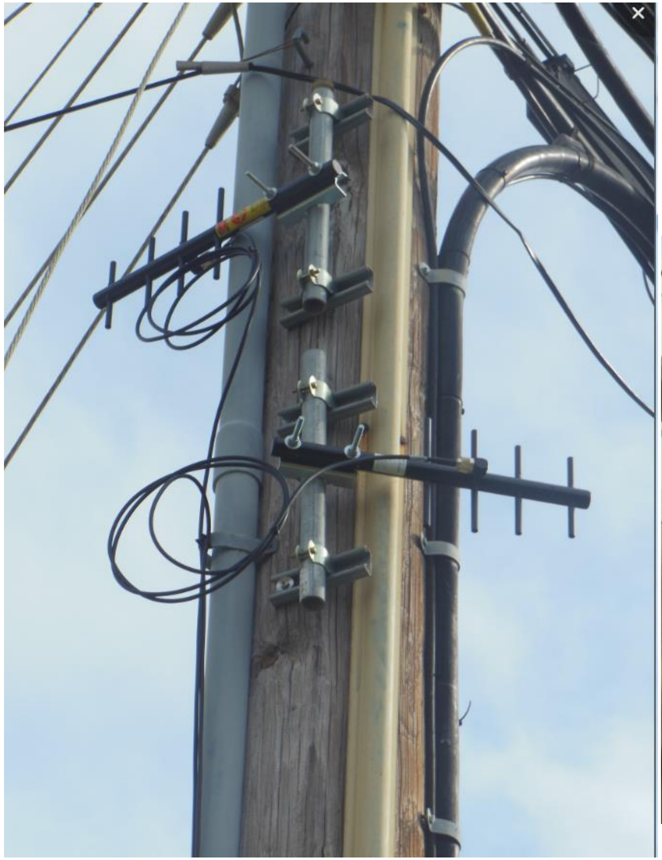
Misc. Analogs
Bus 1 MW
Bus1 Mvars

Misc. Indications
Feeder-A Breaker Position
Feeder-B Breaker Position
Feeder-C Breaker Position
Feeder-D Breaker Position

Volt-VAR Optimization
Field Device Locations – Pad Mount 3-Phase Meter

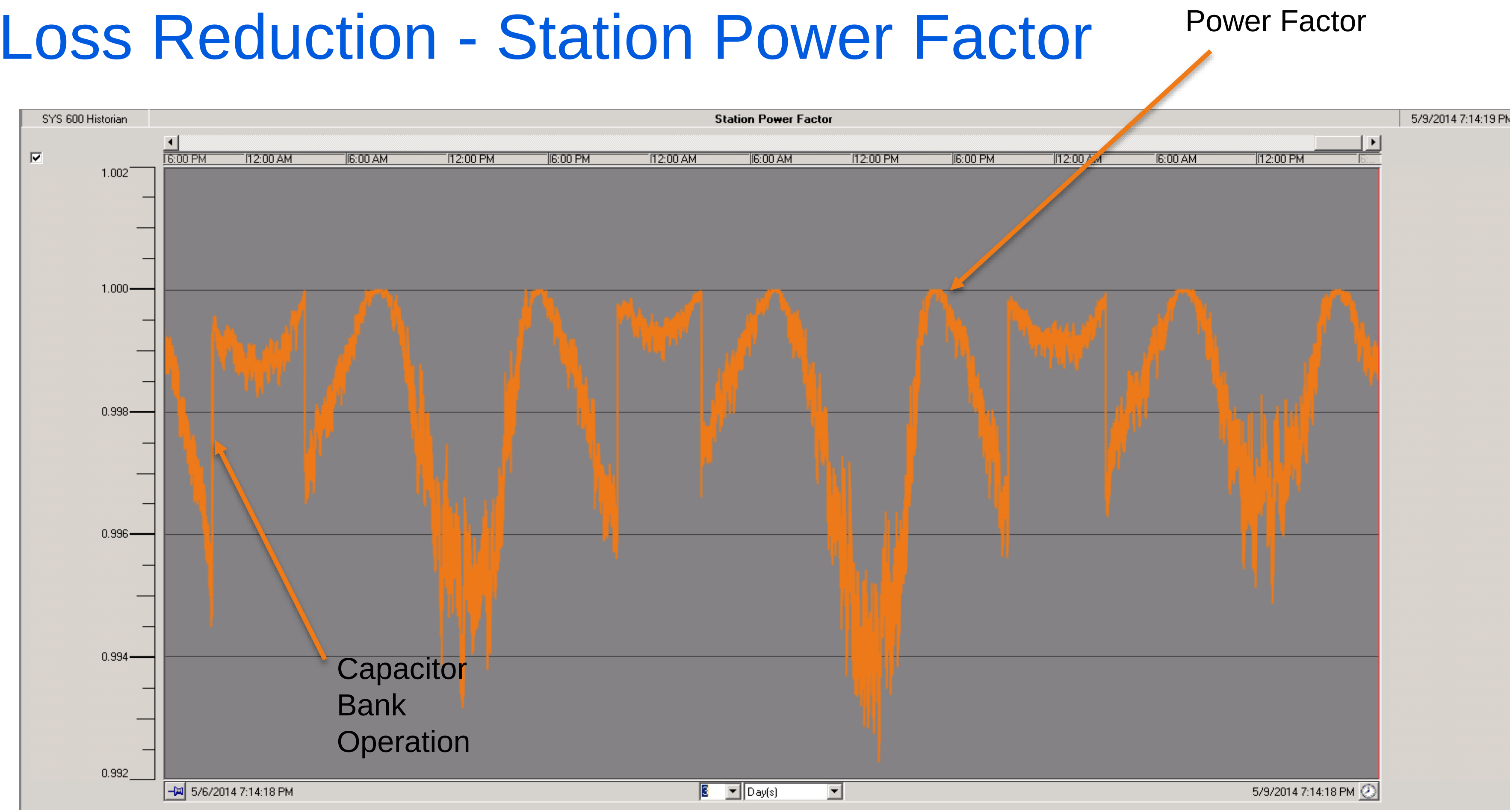
Volt-VAR Optimization
Field Device Locations – Pole Mount 1-Phase Meter

Volt-VAR Optimization
Field Device Locations – Capacitor Bank & Radio Repeater



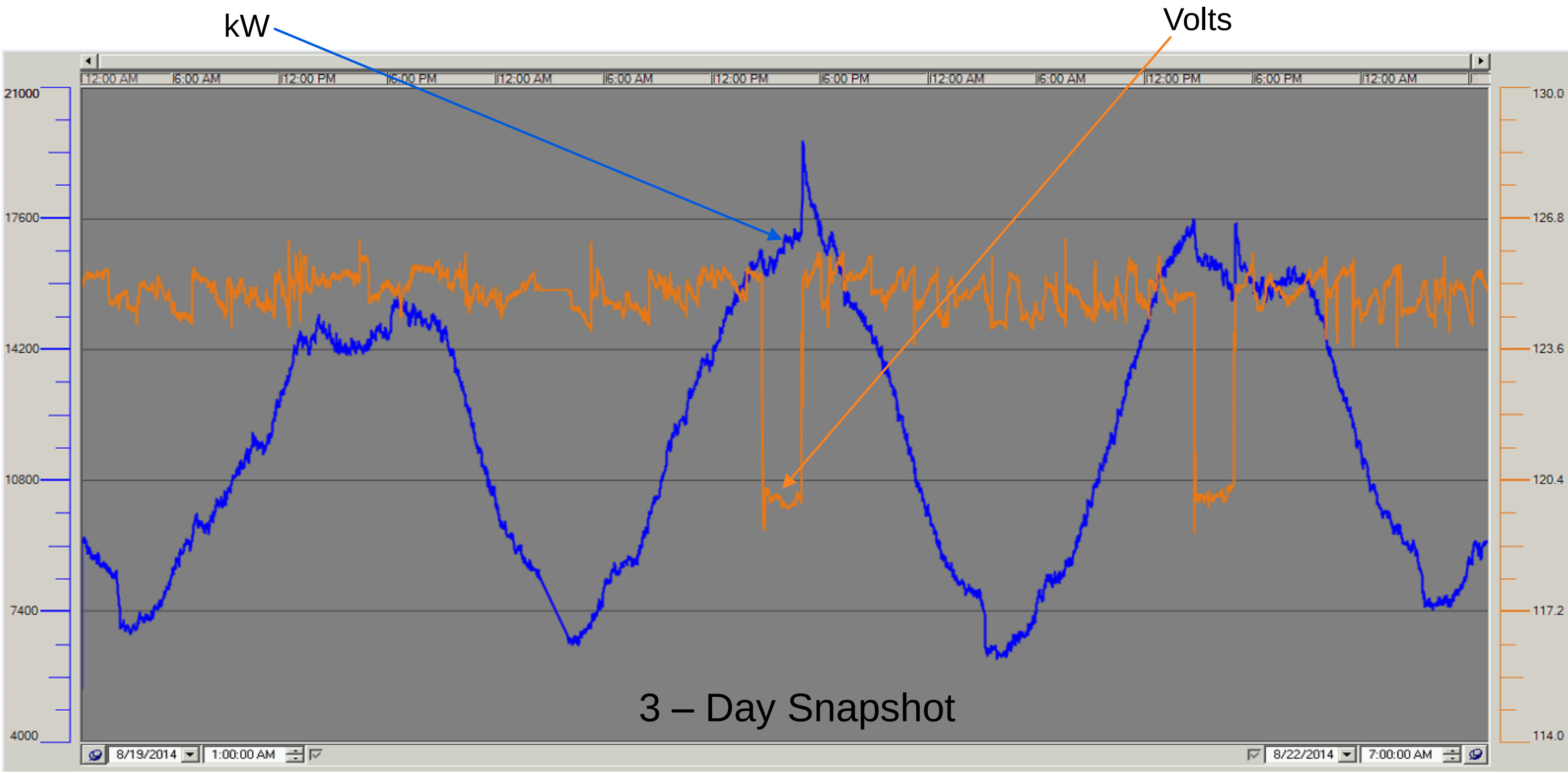
Volt-VAR Optimization

Loss Reduction - Station Power Factor

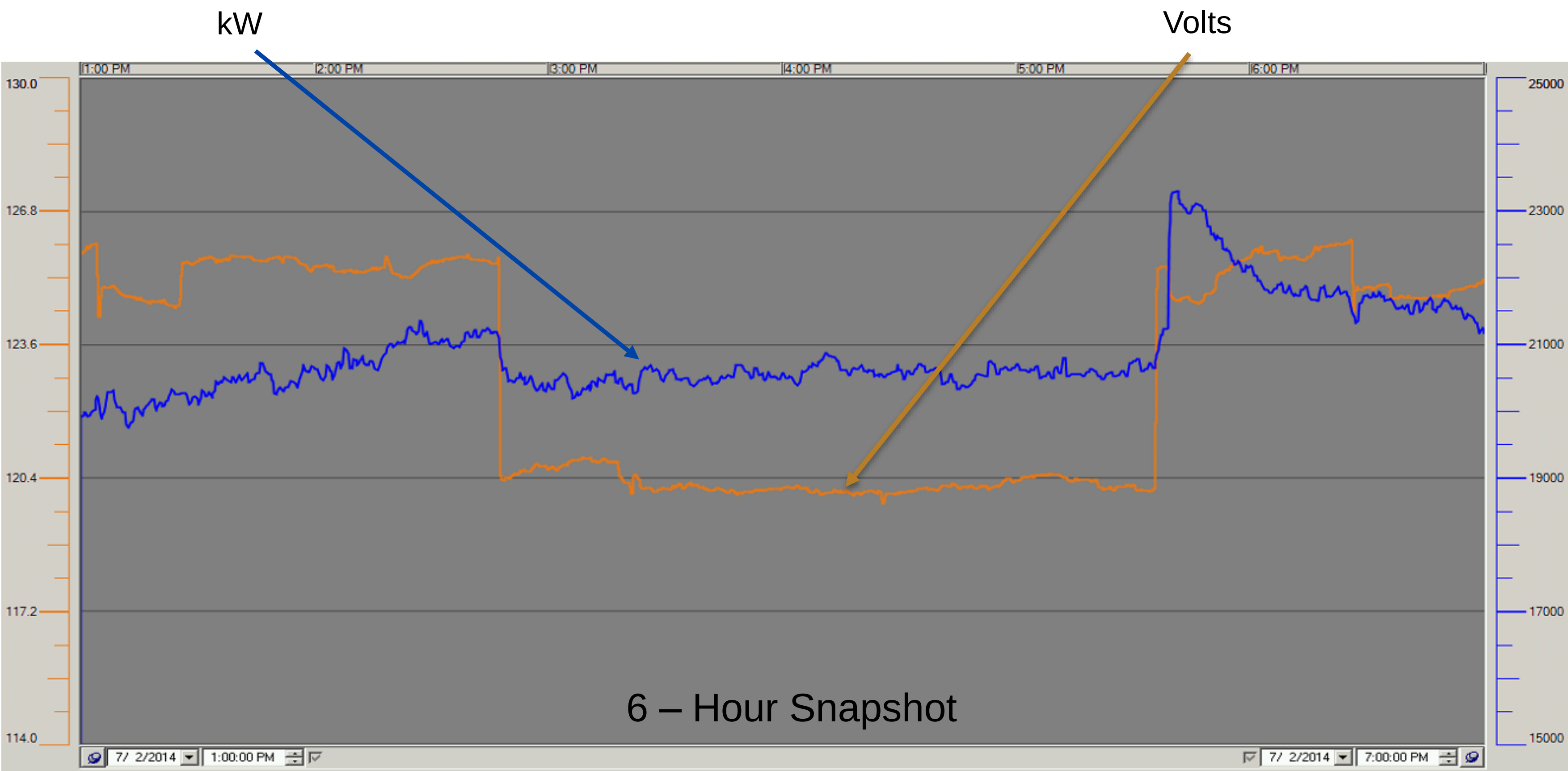


3 day time frame

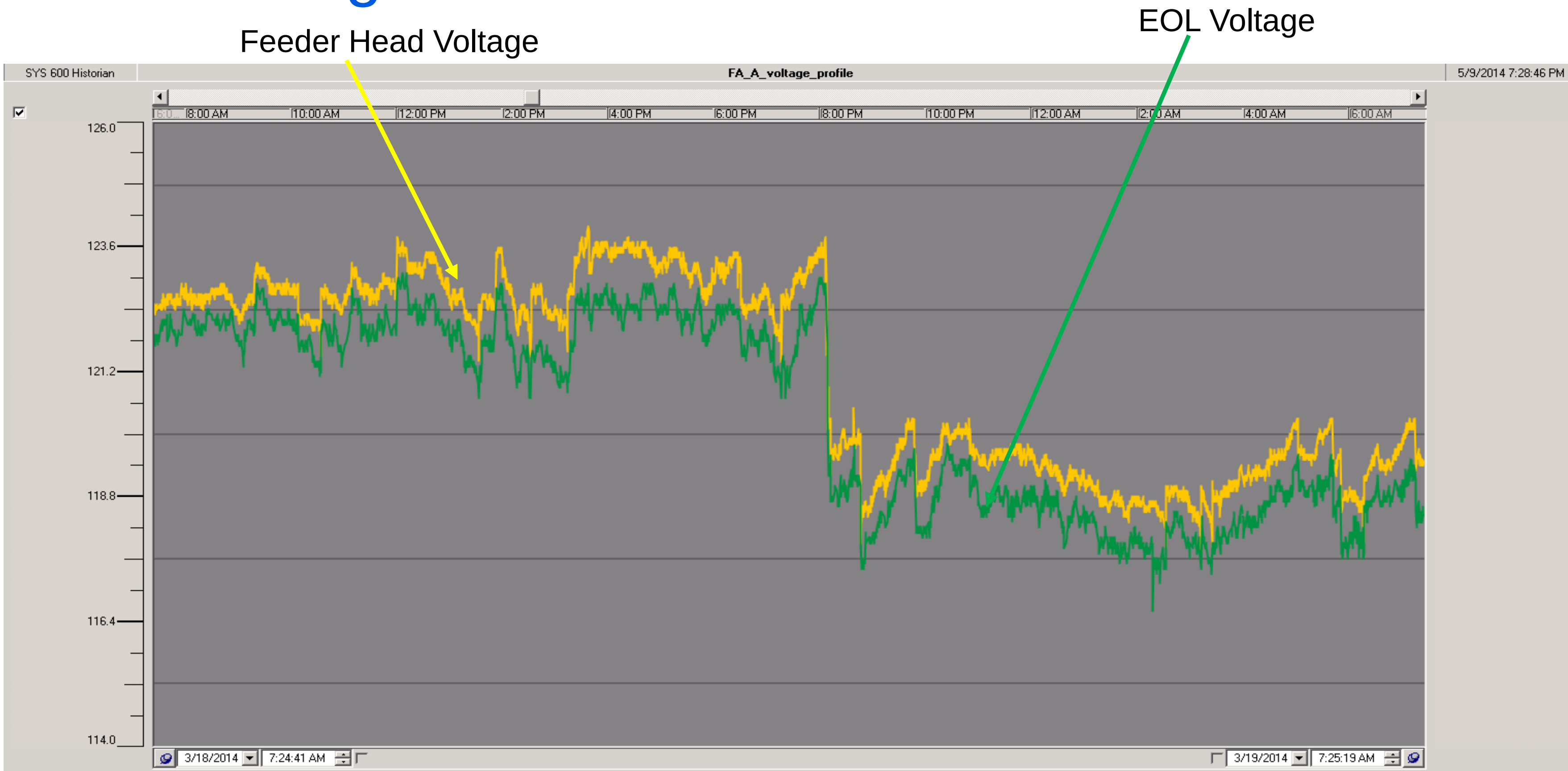
Volt-VAR Optimization
Demand Reduction - CVR



Volt-VAR Optimization
Demand Reduction - CVR

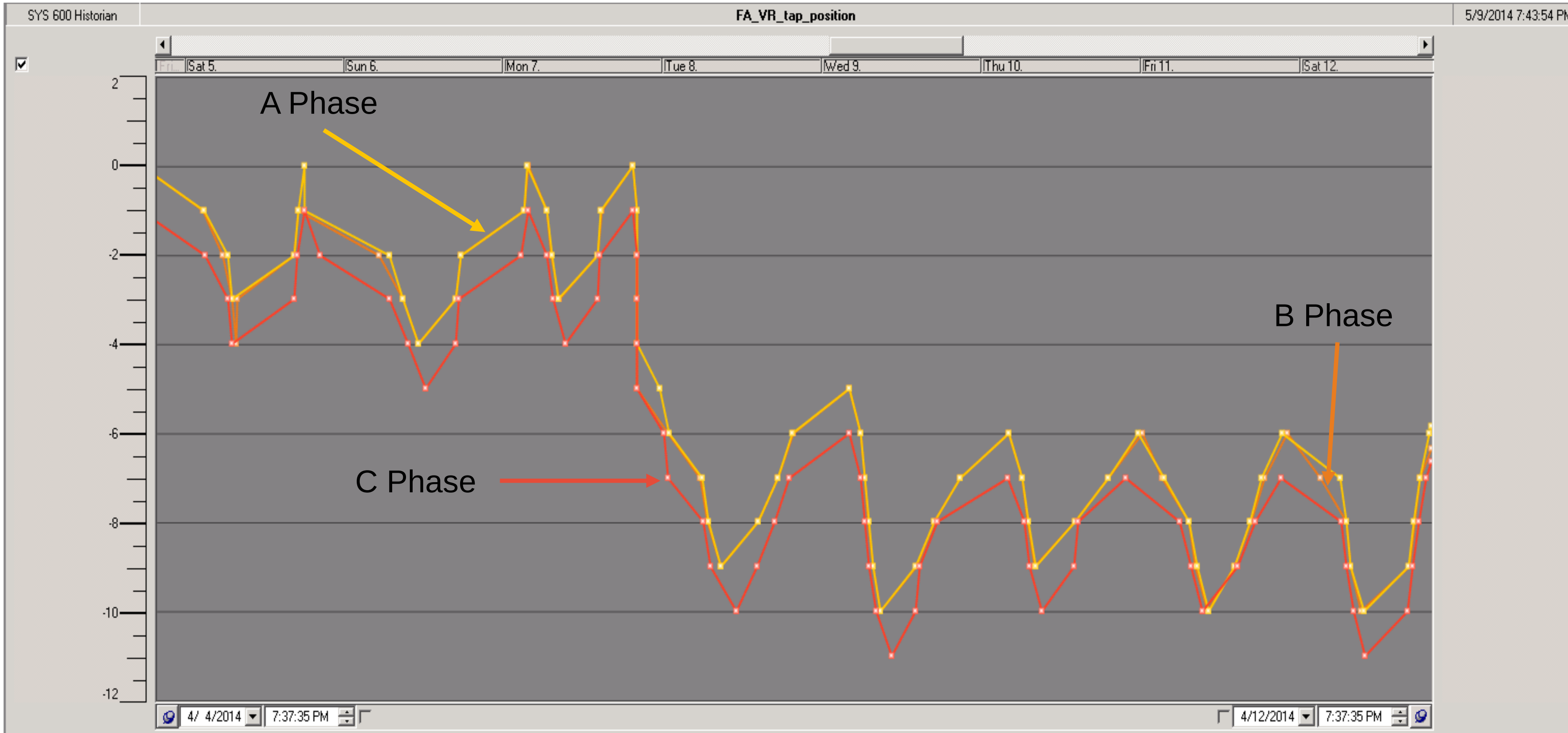


Volt-VAR Optimization
Feeder Voltage Profile

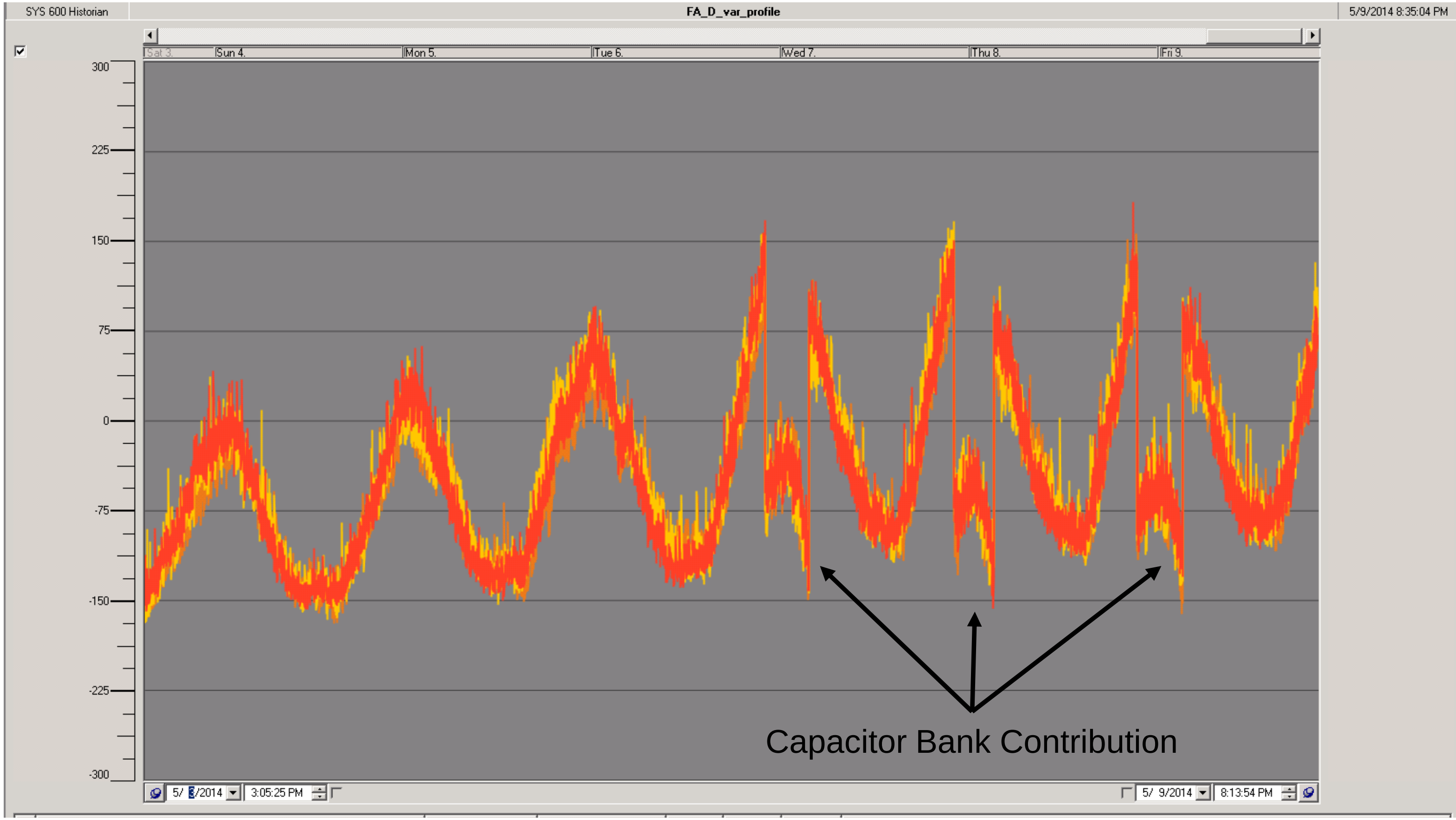


Volt-VAR Optimization

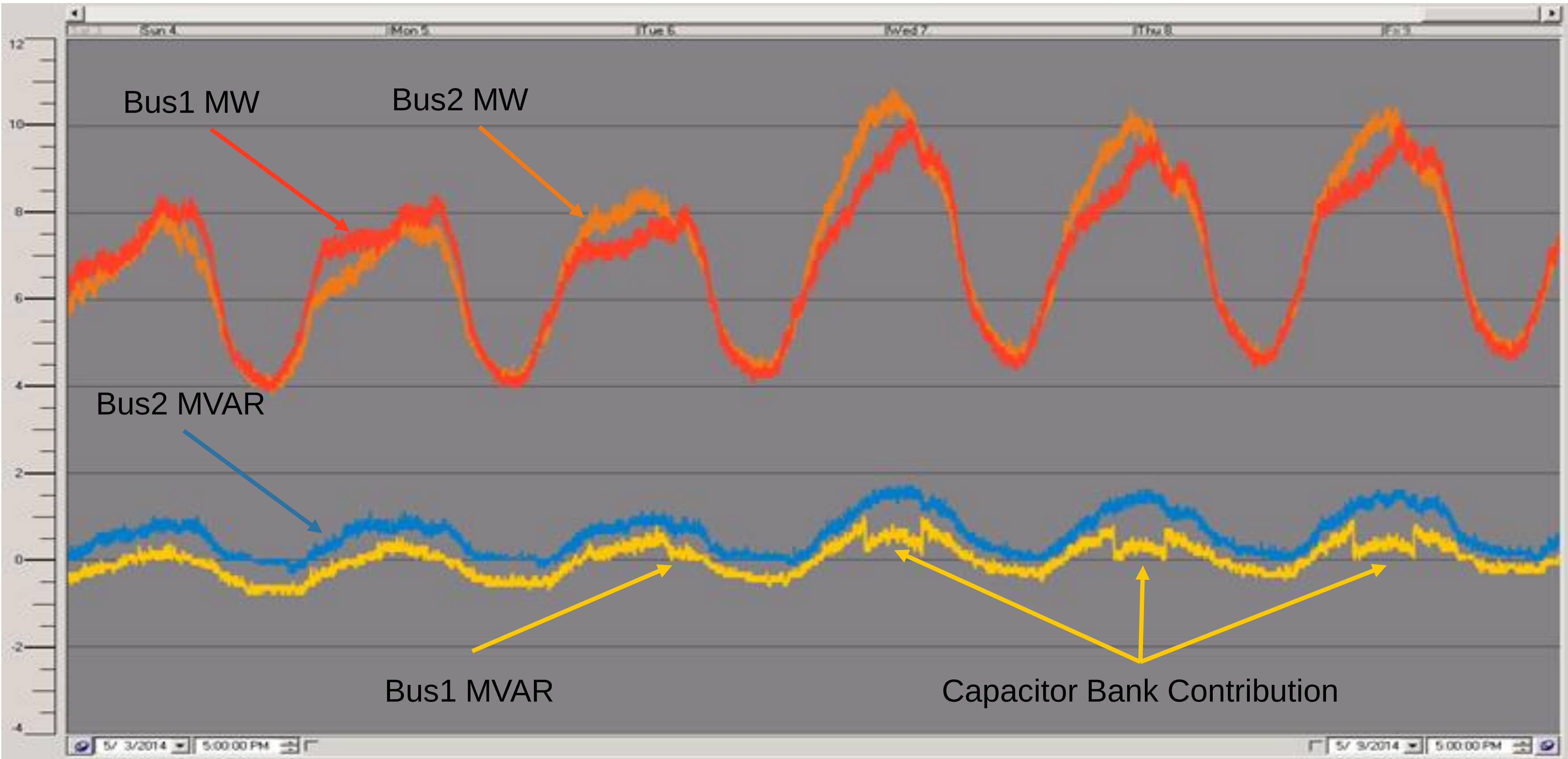
Wear and Tear Reduction - Voltage Regulator Tap Changes



Volt-VAR Optimization
Feeder kVAR

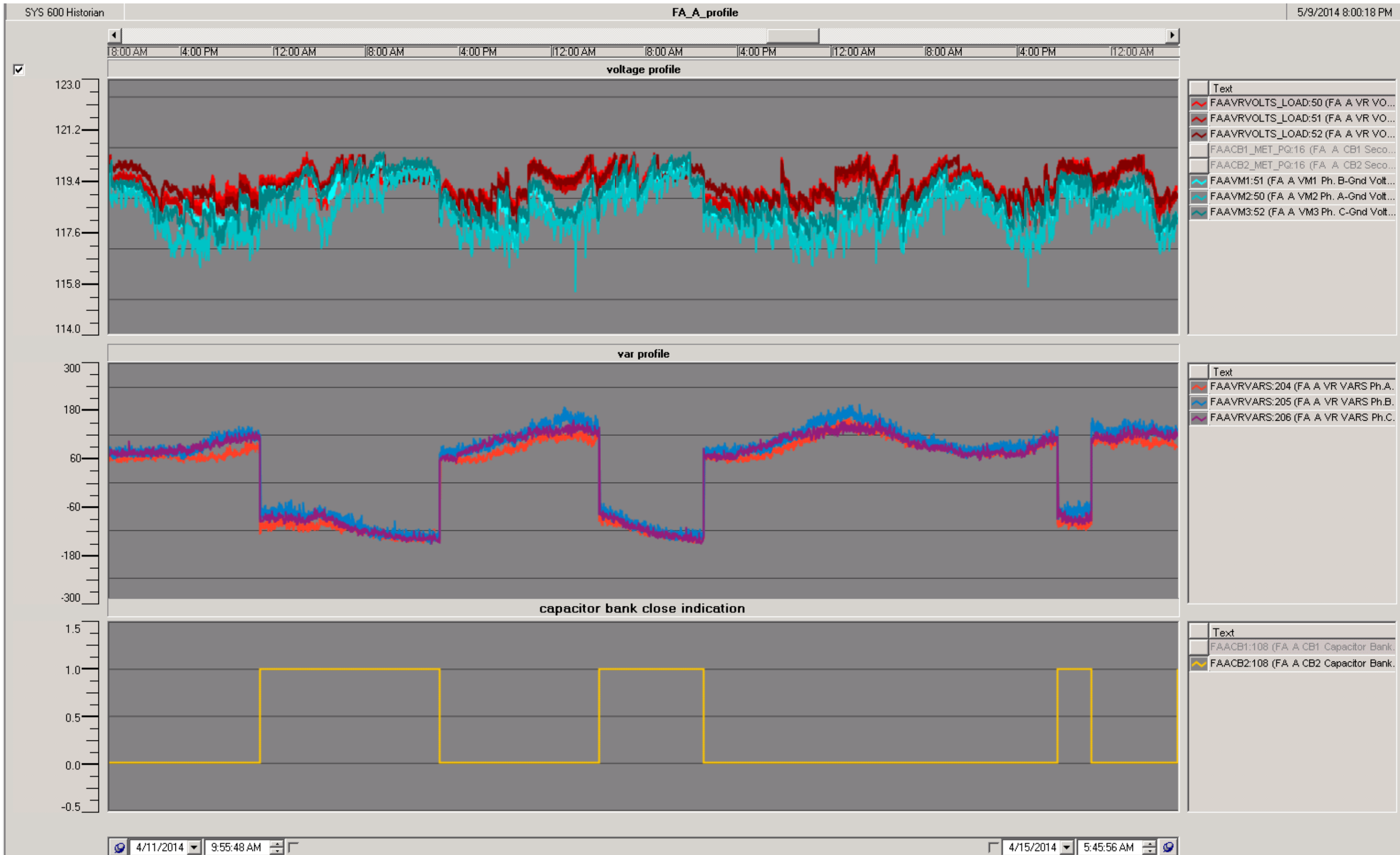


Volt-VAR Optimization
Bus MW and MVAR



Volt-VAR Optimization

Bus Voltage, Feeder kVAR, and Capacitor Bank Status



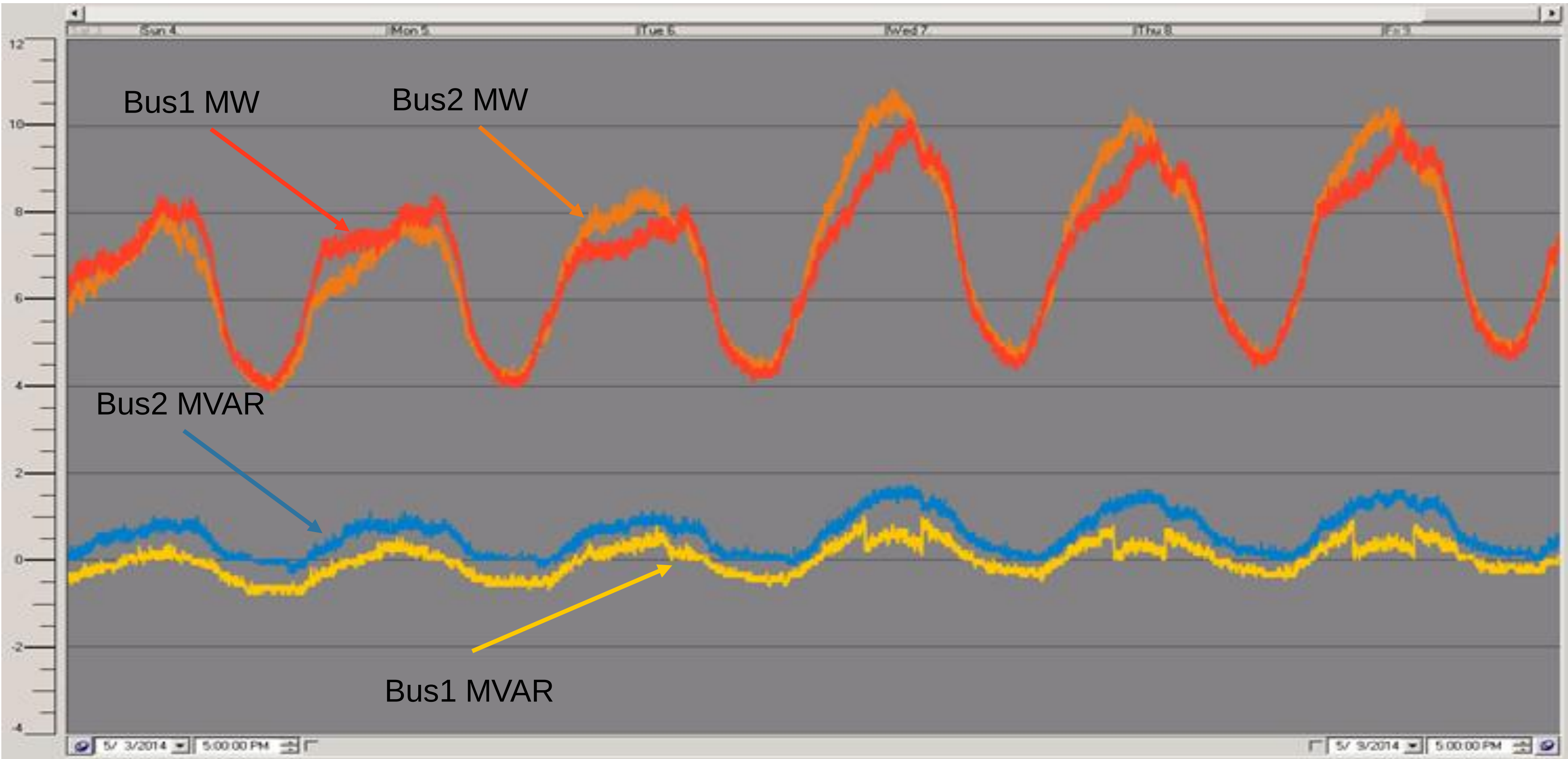
Volt-VAR Optimization
Measurement and Verification

Most used methods for measurement and verification:

- Day on Day Off
- Bus to Bus Comparison
  - One Bus always on PF correction
  - Alternate Buses from PF to CVR and compare
  - Compare for 9, 15 and 24 hours

Measurement & Verification

Bus MW and MVAR



Measurement & Verification
Results for 24hr comparison

			24Hr Run Average (9am to 9am)						
Run	Time/Date	BUS1 (MW)	BUS2 (MW)	Diff	Bus-1 Volt	Temp	PF 1	PF.2	CVR Factor
CVR-ON	Average	9.52	10.21	0.69	118.84	83.26	0.998	0.998	
CVR-OFF	Average	9.86	10.23	0.37	123.00	83.81	0.998	0.998	
Difference	Average	0.34	0.02	**0.32**	**4.16**	0.55	0.001	0.000	0.93

CVR Factor (*CVRf*)

$$CVRf = \frac{\Delta P}{\Delta V} \, watts/volt$$

An Average reduction of 300kwH per 10MVA Load

Measurement & Verification
Results for 9 and 15hr comparison

			15Hr Run Average (9am to Midnite)						
Run	Time/Date	BUS1 (MW)	BUS2 (MW)	Diff	Bus-1 Volt	Temp	PF 1	PF.2	CVR Factor
CVR-ON	Average	11.03	11.87	0.84	118.95	86.12	0.999	0.999	
CVR-OFF	Average	11.46	11.92	0.46	122.99	86.96	0.999	0.999	
Difference	Average	0.43	0.05	**0.39**	**4.04**	0.84	0.000	0.000	0.98

			9Hr Run Average (Midnite to 9am)						
Run	Time/Date	BUS1 (MW)	BUS2 (MW)	Diff	Bus-1 Volt	Temp	PF 1	PF.2	CVR Factor
CVR-ON	Average	7.01	7.42	0.41	118.66	78.67	0.991	0.994	
CVR-OFF	Average	7.62	7.87	0.25	123.00	79.87	0.994	0.996	
Difference	Average	0.61	0.46	**0.16**	**4.34**	1.21	0.002	0.003	0.56

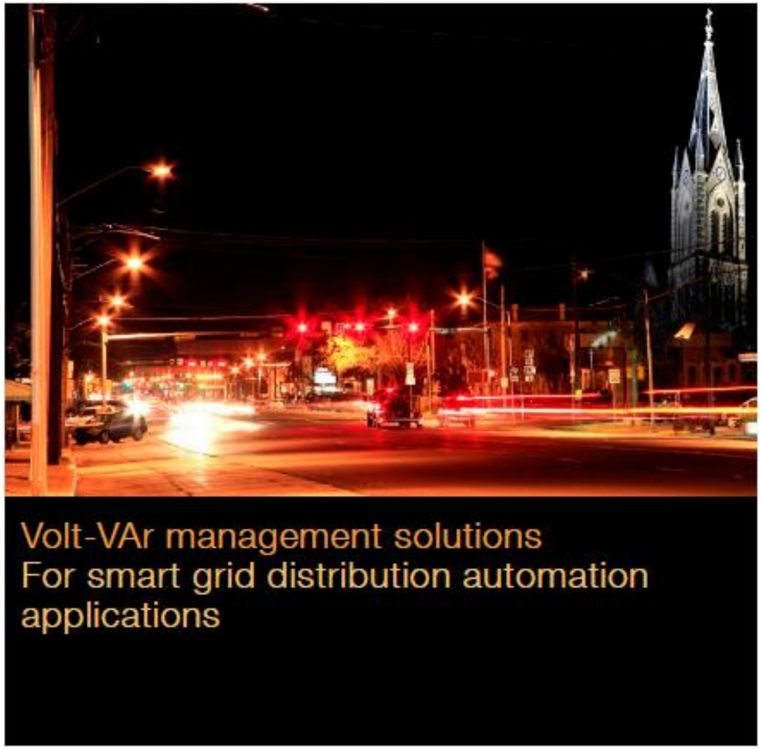
Measurement & Verification
Cumulative Results

Date	MWh(Actual)	MWh Saved(EST)	CVR Days	Feeder head Voltage	Daily MW Avg	Max MW Demand
June 2013***	7065	90	30	119.00	9.79	14.4
July 2013	7660	260	31	118.72	10.30	15.2
August 2013	7112	242	31	118.86	9.49	14.2
September 2013	5863	129	30	119.17	8.14	13
October 2013	4733	104	31	119.36	6.36	10.9
November 2013	4994	110	30	118.77	6.94	13.6
December 2013	5379	118	31	119.92	7.23	14
January 2014	7441	147	31	121.34	10.00	19.1
February 2014	5774	127	28	121.39	8.59	21.1
March 2014	4787	105	31	120.64	7.98	13.40
April 2014	2639	58	18	120.52	6.11	8.90
Total	**63446**	**1490**	**322**			

Volt-VAR Optimization
Final Takeways

- VVO systems have been proven to provide positive NPV investments
- Traditional demand response programs can take advantage of VVO to reduce peak demands on the system.
- Centralized automation systems provide system synergies, including:
  - Distribution (“outside the fence”) SCADA
  - Distribution Management Systems (DMS)
  - Outage Management Systems (OMS)
  - Automatic Reconfiguration (FDIR, FLISR, etc.)
  - Remote access to distribution devices through wireless infrastructure
- VVO is one of the only (if not the only) way to improve energy efficiency without direct customer interface.

Distribution Automation in Action
VVO brochure available on the ABB website



Distribution Automation in Action

ABB Smart Grid Center of Excellence (CoE)

ABB
Smart Grid Center of Excellence

Demonstration

- **Volt/VAr efficiency**
- **Self-Healing grid**
- **Asset Health Monitoring**
- **Distribution SCADA**

Design & Verification

- **Plan, test, implement pilot projects**
- **Verify functionality, interoperability, and operational expectations**

Deployment

- **Leverage engineering and project management expertise**
- **Seamless integration**

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