Distribution System Improvement & Voltage Optimization

A New Energy Efficiency Measure

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V2c

The Distribution System is an Industrial Plant

Distribution
Substation

Overhead
Feeder

Overhead
Feeder

Customer
Meter

- Provide Safe Electric System
- Provide Optimal Service Reliability (SAIDI , SAIFI, and CAIDI)
- Maintain Customer Voltage within Limits (126V - 114V)
- Provide Adequate Capacity (normal and emergency conditions)
- Ensure Customer Power Quality (flicker and harmonics)
- **Optimize system efficiency (minimize system losses)**

Outline of Presentation

System Improvement and Voltage Optimization Energy Efficiency Objectives

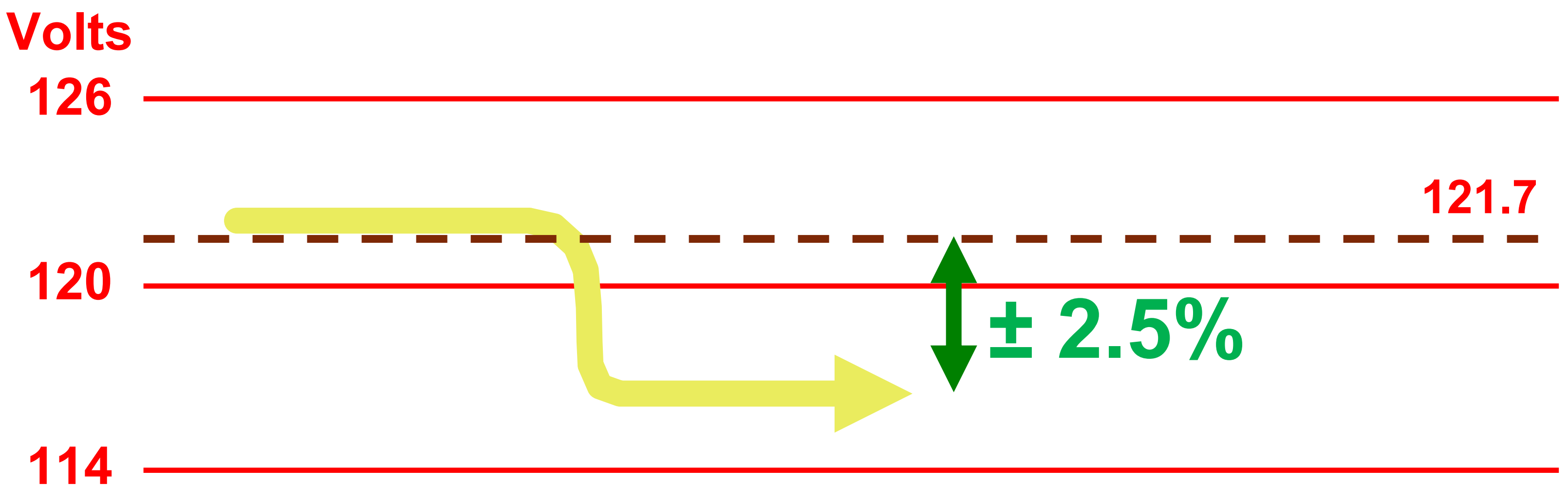
- Lower Average Service Voltage
  - ✓ Lower End-Use energy kWh consumption

- Increase Distribution System Efficiency
  - ✓ Lower transformer and line kWh losses

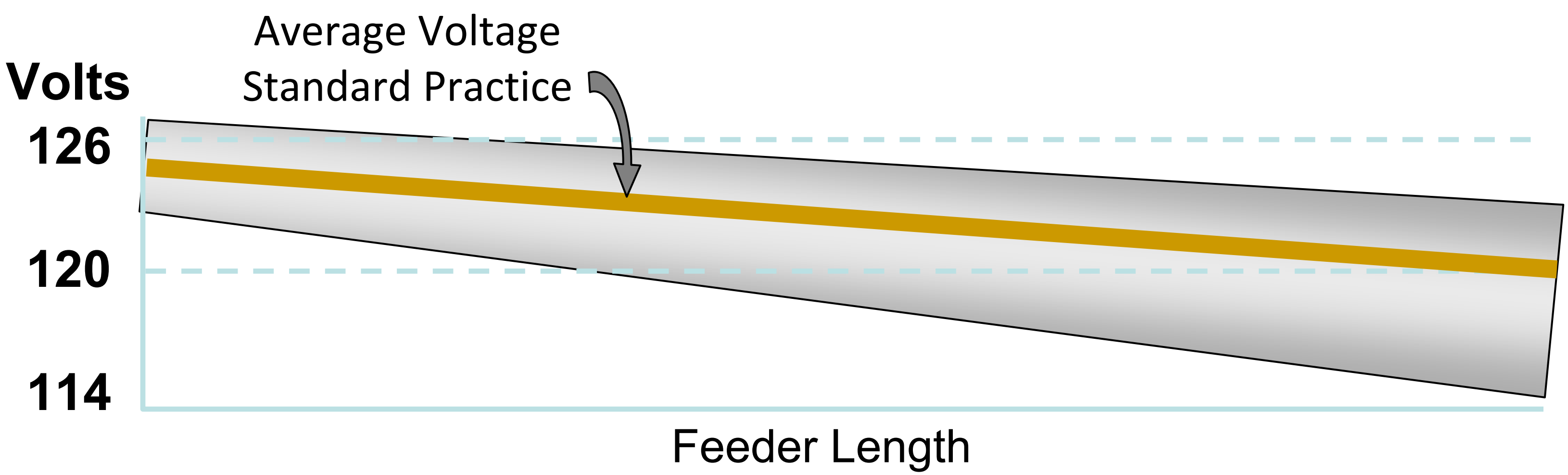
- Improve Reliability and Voltage Quality
  - ✓ Increase backup capability
  - ✓ Maintain smaller band of service voltage 114-120V

Customer Voltage within Limits

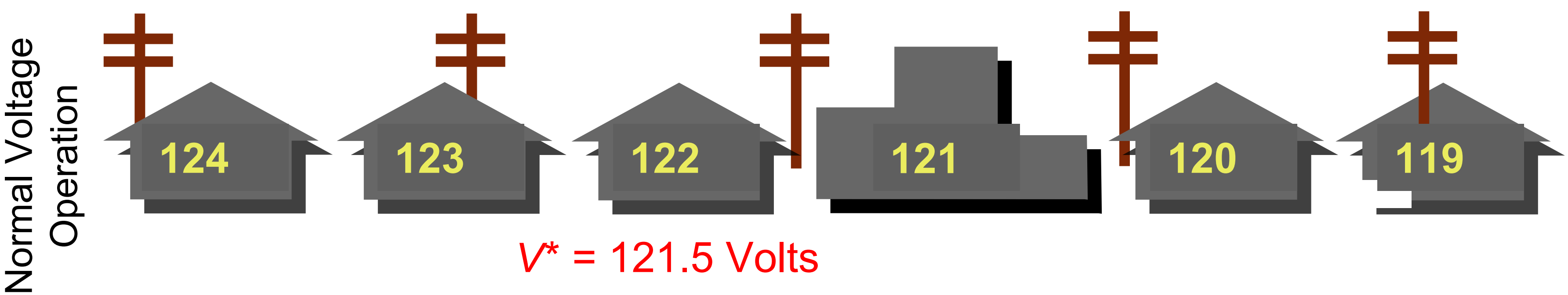
Allowed ANSI Service Voltage Range
126 – 114 V (120 V ± 5%)



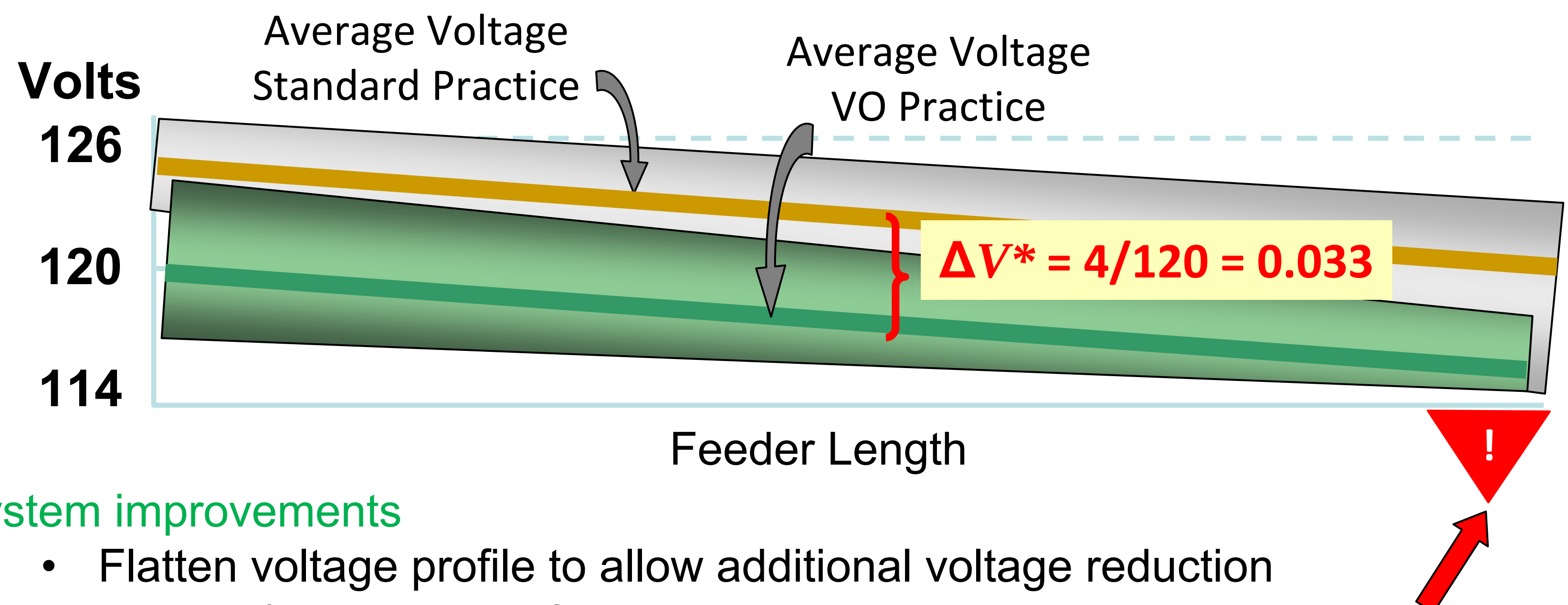
Without Voltage Optimization



Normal Voltage Operating Range in Current Practice by Utilities

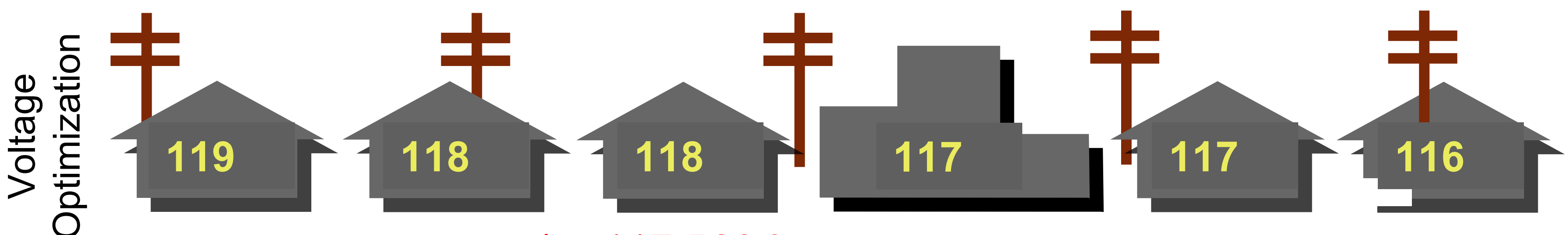


With Voltage Optimization



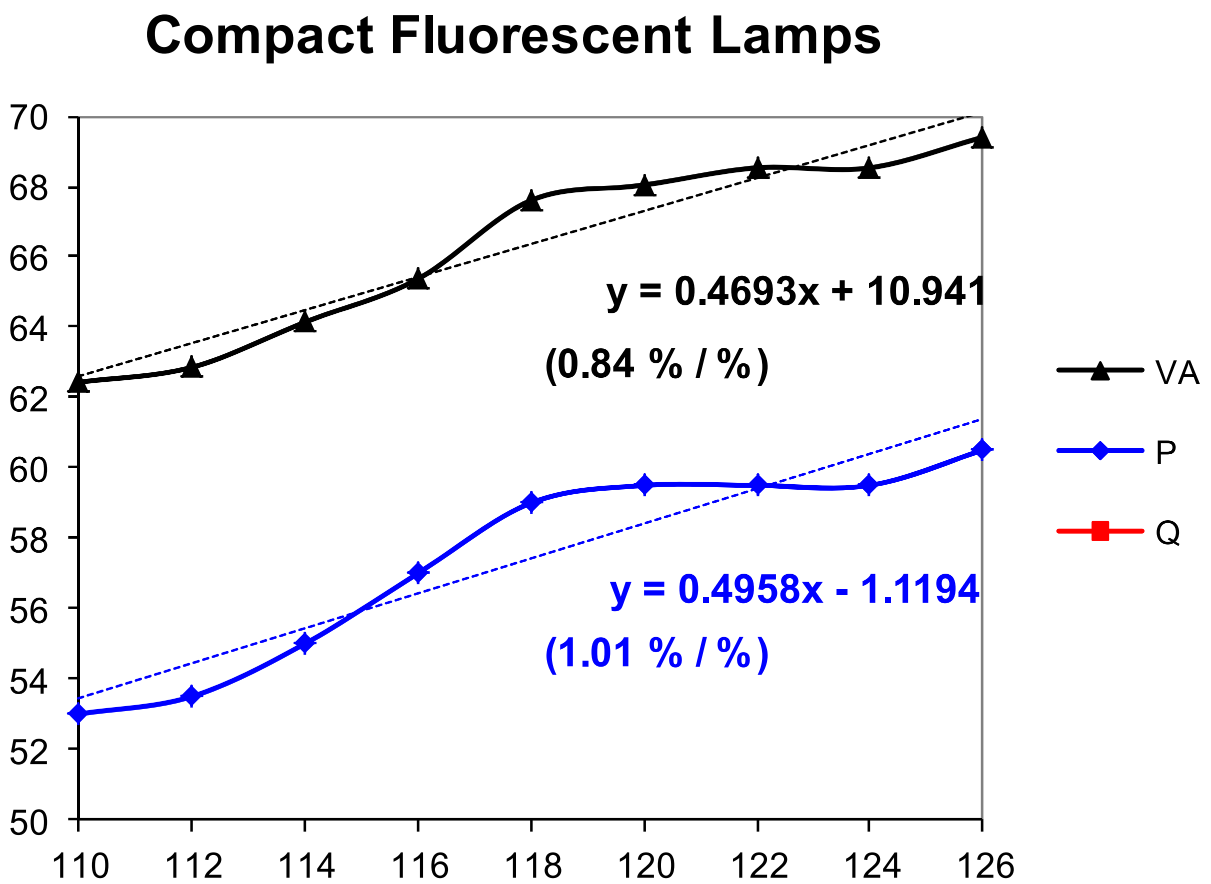
System improvements

- Flatten voltage profile to allow additional voltage reduction
- Mitigate/prevent risk of low voltage and customer power quality issues

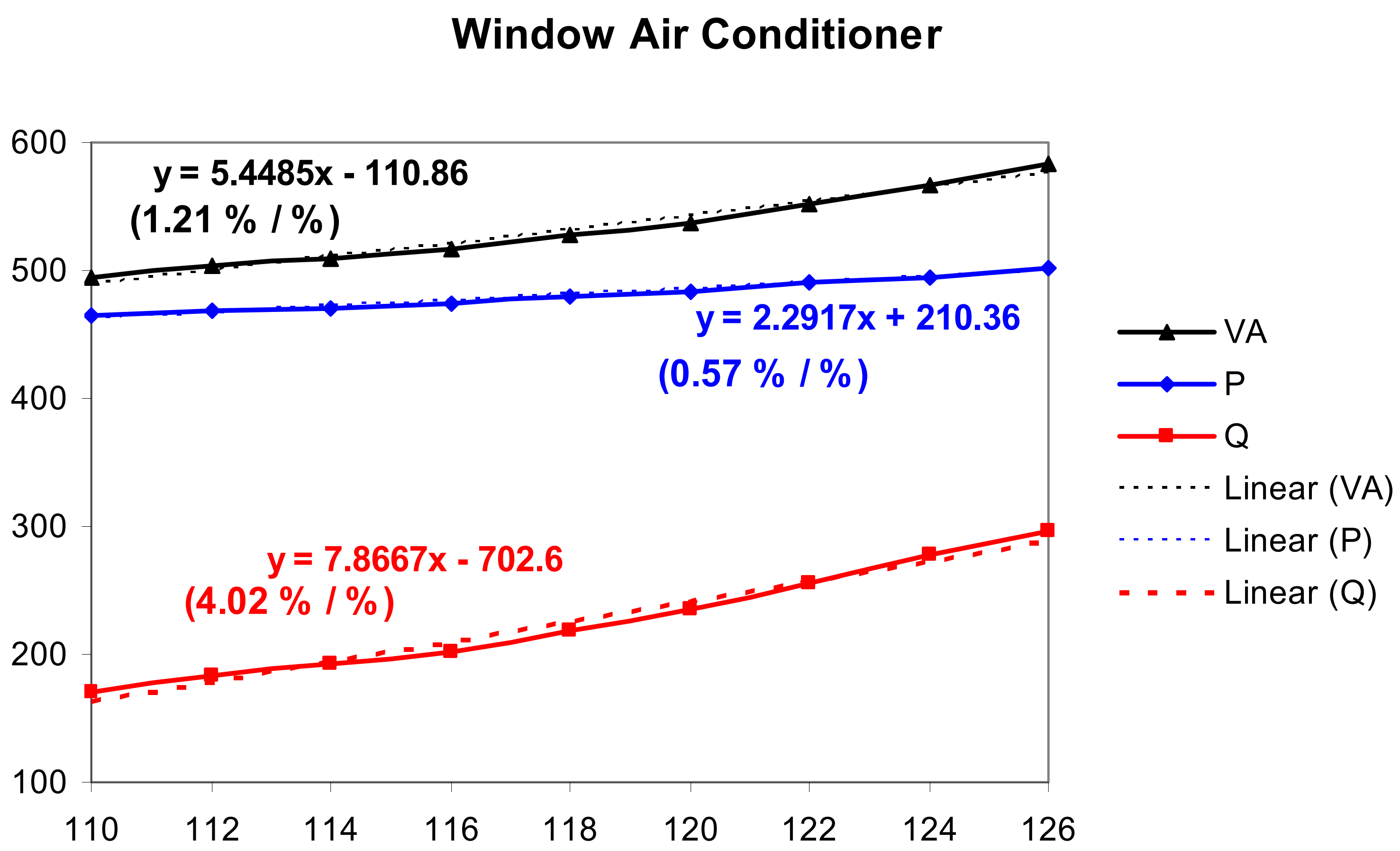


V^* = 117.5 Volts

Impact of lower voltage on end-use appliances



UT Austin Steady-State Lab Measurements, Nov. 28, 2007



UT Austin Steady-State Lab Measurements, Nov. 28, 2007

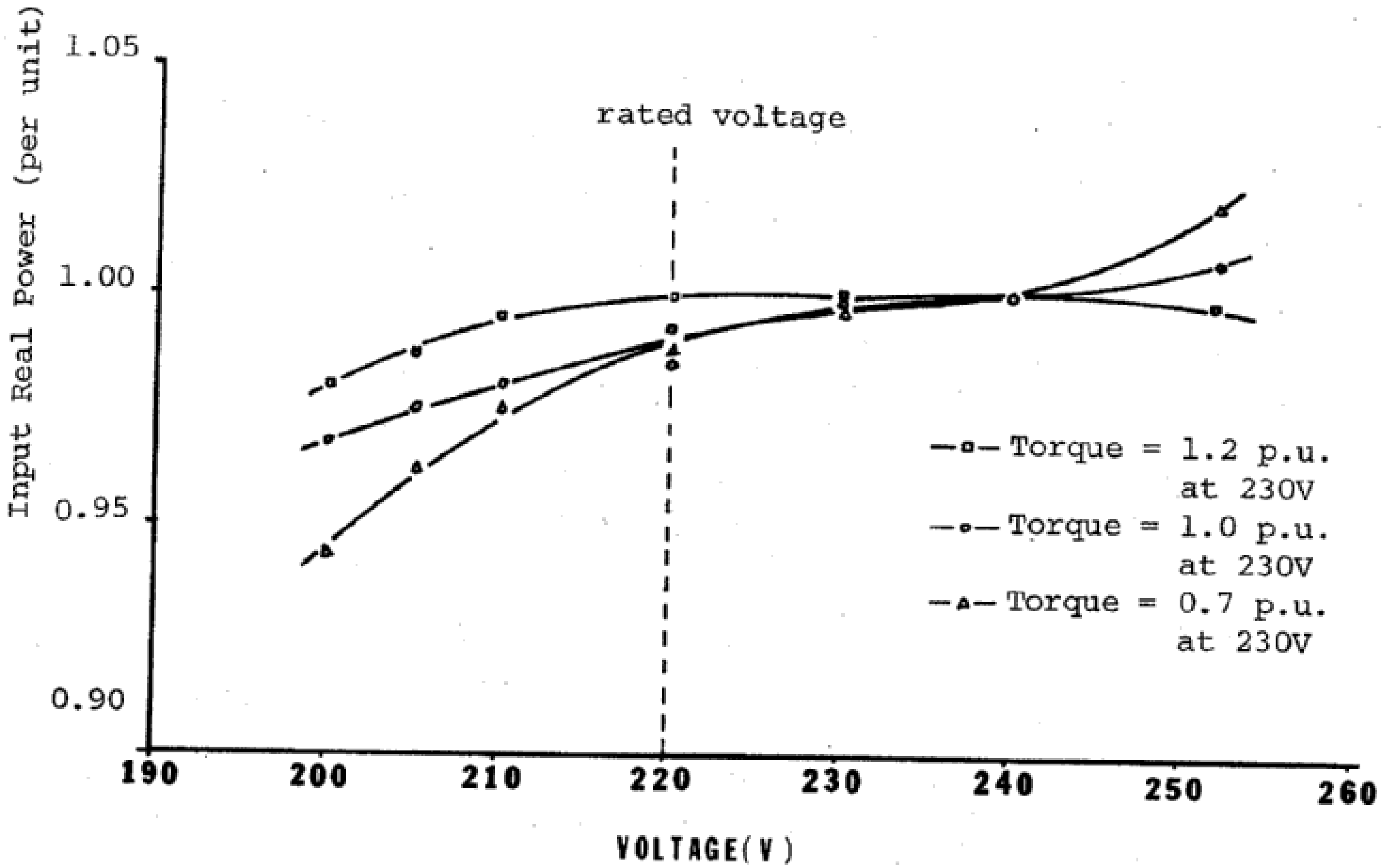


Figure C-140 Input real power as a function of applied voltage for motor No.9, mfr.G, with variable torque loads ($T \propto \omega^2$). Values normalized with respect to 240 volts.

Variable Torque Loads, Real Power Δ Wh / Δ V = 2.5

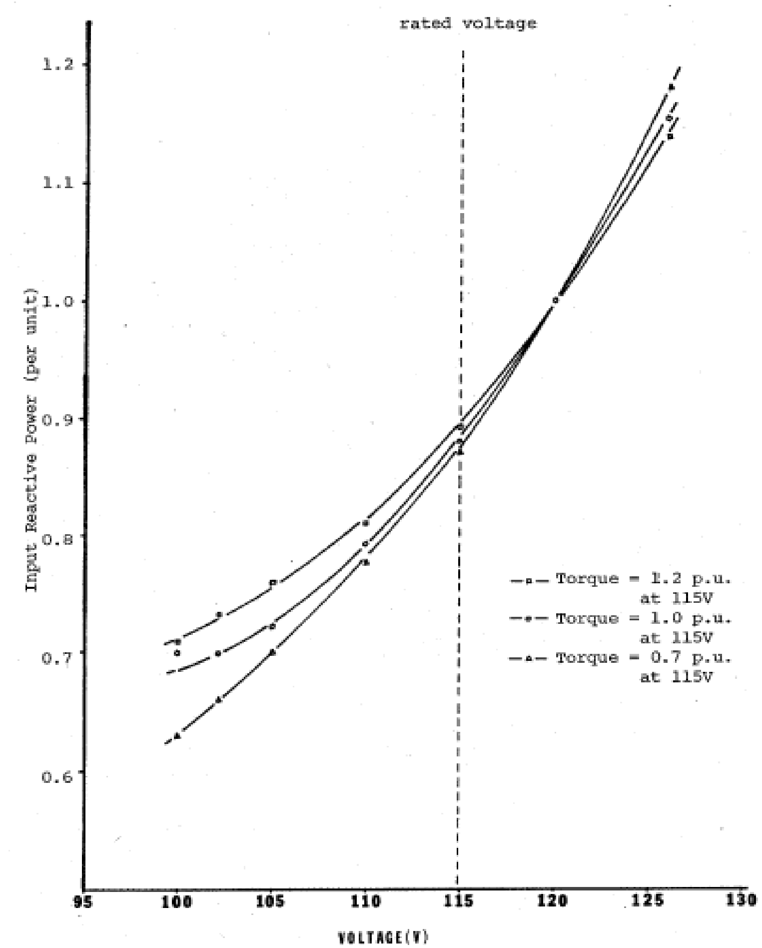


Figure C-144 Input reactive power as a function of applied voltage for motor No.1, mfr.A, with variable torque loads ($T \propto \omega^2$). Values normalized with respect to 120 volts.

¾ hp - 1ph motors

Reactive Power

Variable Torque Loads

Δ varh / Δ V = 4.6

Energy Required Ratio (ERR) - Appliances

% Reduction	16.66%	12.50%	8.33%	4.16%	0.00%	-4.16%
Volt Range	100/200	105/210	110/220	115/230	120/240	125/250
Air Cond	1.028	1.002	0.989	0.985	1.000	1.034
I - Lighting	0.764	0.815	0.876	0.937	1.000	1.074
Refrigerator	0.790	0.821	0.846	0.905	1.000	1.107
F - Lighting	0.842	0.898	0.937	0.970	1.000	1.033
Motor 3ph	1.012	1.004	1.003	0.996	1.000	1.007
Microwave	1.029	0.996	0.989	0.996	1.000	1.027
Heat Pumps	1.095	1.040	1.019	1.014	1.000	1.017
Electronics	0.717	0.783	0.861	0.924	1.000	1.080
Resistive	1.000	1.000	1.000	1.000	1.000	1.000

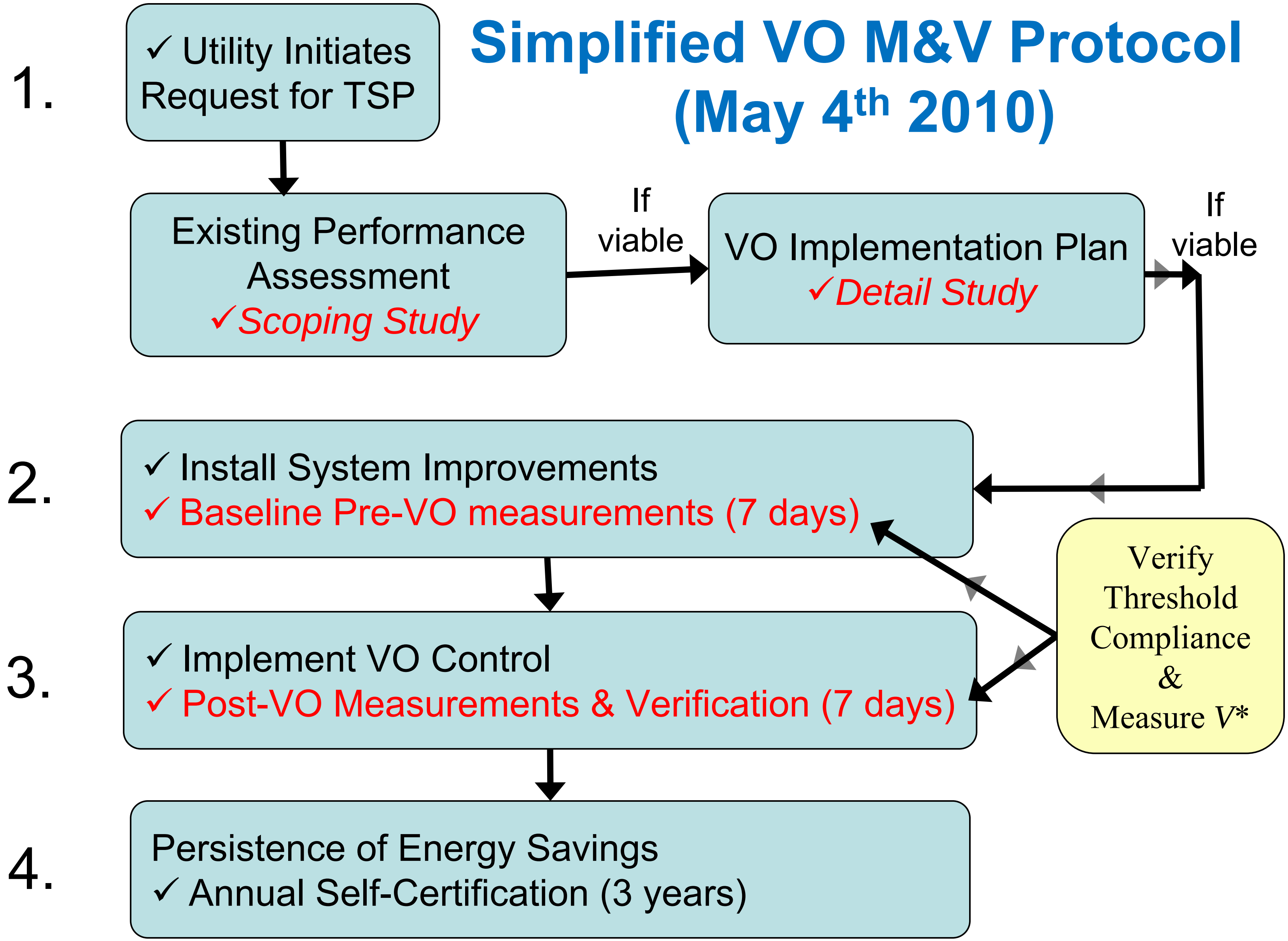
VO and CVR Misconceptions

- “Benefits are not easily measured”
- “System line losses may rise”
- “Customer may experience voltages below 114 V”
- “System power quality will be reduced”
- “Appliances will be damaged”
- “Voltage complaints will increase”

VO and CVR Misconceptions

- "There will be lost revenue"
- "System reliability will decrease"
- "Substation LTC and Regulator LDC controls are seldom used and are difficult to set and monitor"
- "It is easier to lower voltage at substation only during times of peak load to reduce demand"

Simplified VO M&V Protocol (May 4th 2010)



Simplified VO M&V Protocol

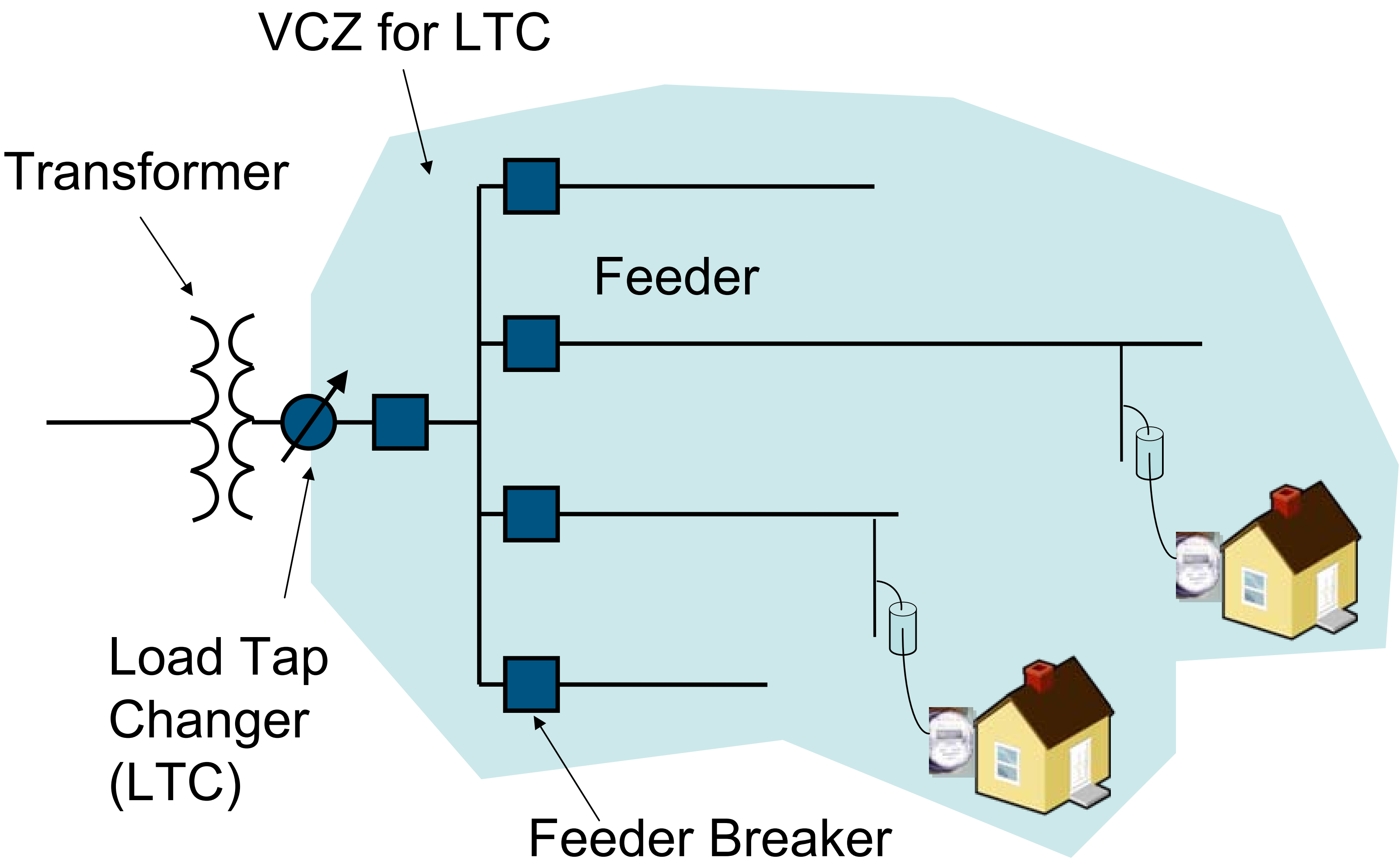
Three Voltage Regulation Techniques

VFR

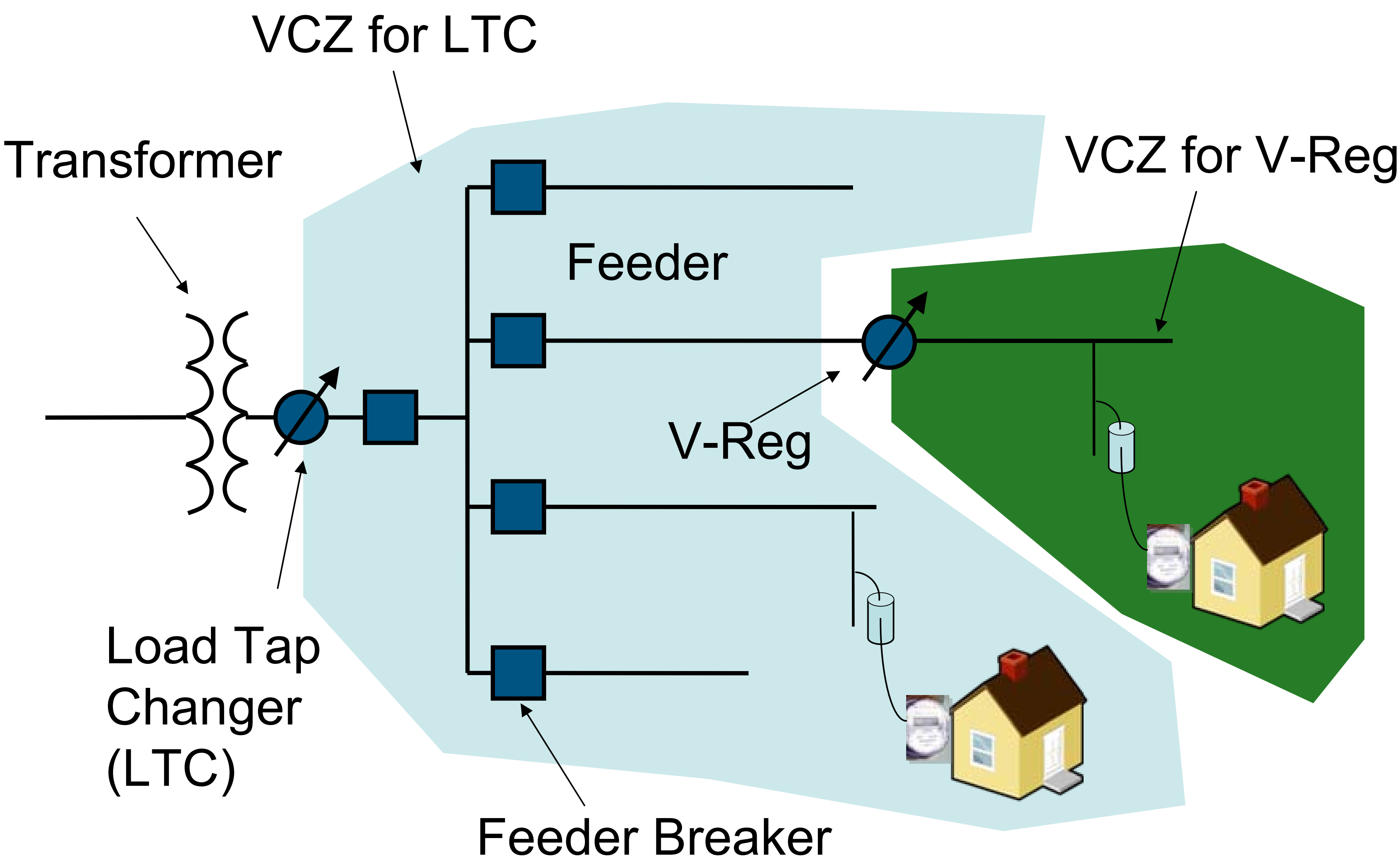
LDC

AVFC

Voltage Control Zones



Voltage Control Zones



VO Performance Stability Thresholds

- Feeder and Regulator Source Power Factor
  - Annual Average PF **> 0.98**
  - Lowest (one hour) PF **> 0.96**
- Maximum Voltage Drop for each VCZ **< 3.3%**
- Feeder and Regulator Source Ampere Imbalance at peak **< 15%**
- Maximum Secondary Voltage Drop **< 4.0%**
- Substation Feeder Maximum Voltage Drop Variance **< 2 V**

Calculating Energy Savings

SI & VO Annual Energy Saved =

Change in voltage **x** Voltage Optimization Factor
x Annual Energy **+** Energy Losses Saved

$$E \text{ Saved} = \Delta V^{*} \times VO_f \times E \text{ Annual} + \Delta E_{SI\text{-}LL} + \Delta E_{SI\text{-}NL}$$

ΔV^{*} – Change in average annual voltage (Modeling and Metering)
VO_f –End-Use VO Factor (VO M&V Protocol)
E_{Annual} –Annual Energy Delivered at Utility Substations (Metering)
ΔE_{SI} – System Line and Transformer no-load losses saved (Modeling)

End-Use VO Factor (VO_f)

Table 5 – End-Use VO Factors for Climate Zone Heating 2 and Cooling 2

% of Customers with Non Electric Heat and Heat Pumps (e.g. gas, oil, or wood heat)

%AC	0	10	20	30	40	50	60	70	80	90	100
0	27	29	32	34	38	42	46	51	58	66	75
10	27	30	32	35	38	42	47	52	58	66	75
20	28	30	33	36	39	43	47	52	58	66	74
30	29	31	34	37	40	44	48	53	59	66	74
40	29	32	32	37	41	44	49	54	59	66	73
50	30	33	35	38	42	45	49	54	59	66	73
60	31	34	36	39	42	46	50	55	60	66	73
70	32	34	37	40	43	47	51	56	60	66	72
80	33	35	38	41	44	48	52	56	61	66	72
90	34	36	39	42	45	49	52	56	61	66	71
100	35	37	40	43	46	49	53	57	61	66	71

Source: NWPCC–RTFVO M&V Protocol, Appendix A -VO Factor Tables, May 4, 2010

$VO_f = 0.37$

Average Voltage Change (ΔV^*)

- Definitions
  - *LDF* = annual system load factor $kW_{\text{Annual average}} / kW_{\text{Annual peak}}$
  - *A* = maximum annual voltage drop in Volts at peak load
  - *B* = regulator maximum annual volt rise in Volts at peak load
- ***V**** = annual average voltage for each VCZ
- Calculate ***V**** for pre-VO and post-VO conditions
- ***V**** is dependent on which voltage control method is applied
  - – VFR

    Adjusted Average Voltage for VFR

    $V^* = V_{Set} - LDF \bullet (\frac{1}{2} A)$
  - – LDC and AVFC

    Adjusted Average Voltage for LDC =

    $V^* = V_{Set} + LDF * (B - \frac{1}{2} A)$
- Annual average voltage change $\Delta V^* = V^*_{\text{pre-VO}} - V^*_{\text{post-VO}}$

VO Data Requirements

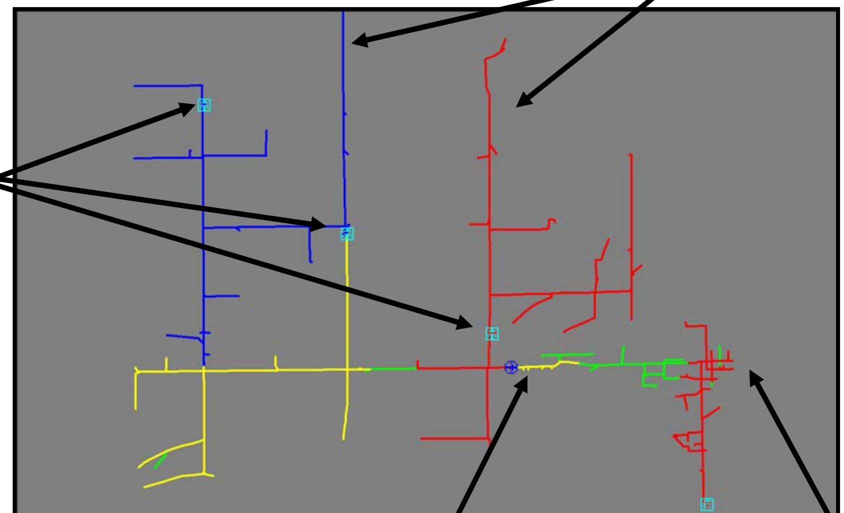
Metering data needed for Voltage Control Zones

- Metered data (avg per hour)
  - 3φ peak kW & kvar demand
  - Power factor
  - Phase Amps
  - End-of-Line Voltage
- Maximum annual 3φ peak (kW) hourly demand
- Total annual energy (kWh) delivered
- Sub LTC & Regulator Voltage Control Settings
  (V_{set}, BW, R&X, TD)

The majority of the information can be downloaded directly from the meters, SEL relays, or SCADA system.

Data Requirements (continued)

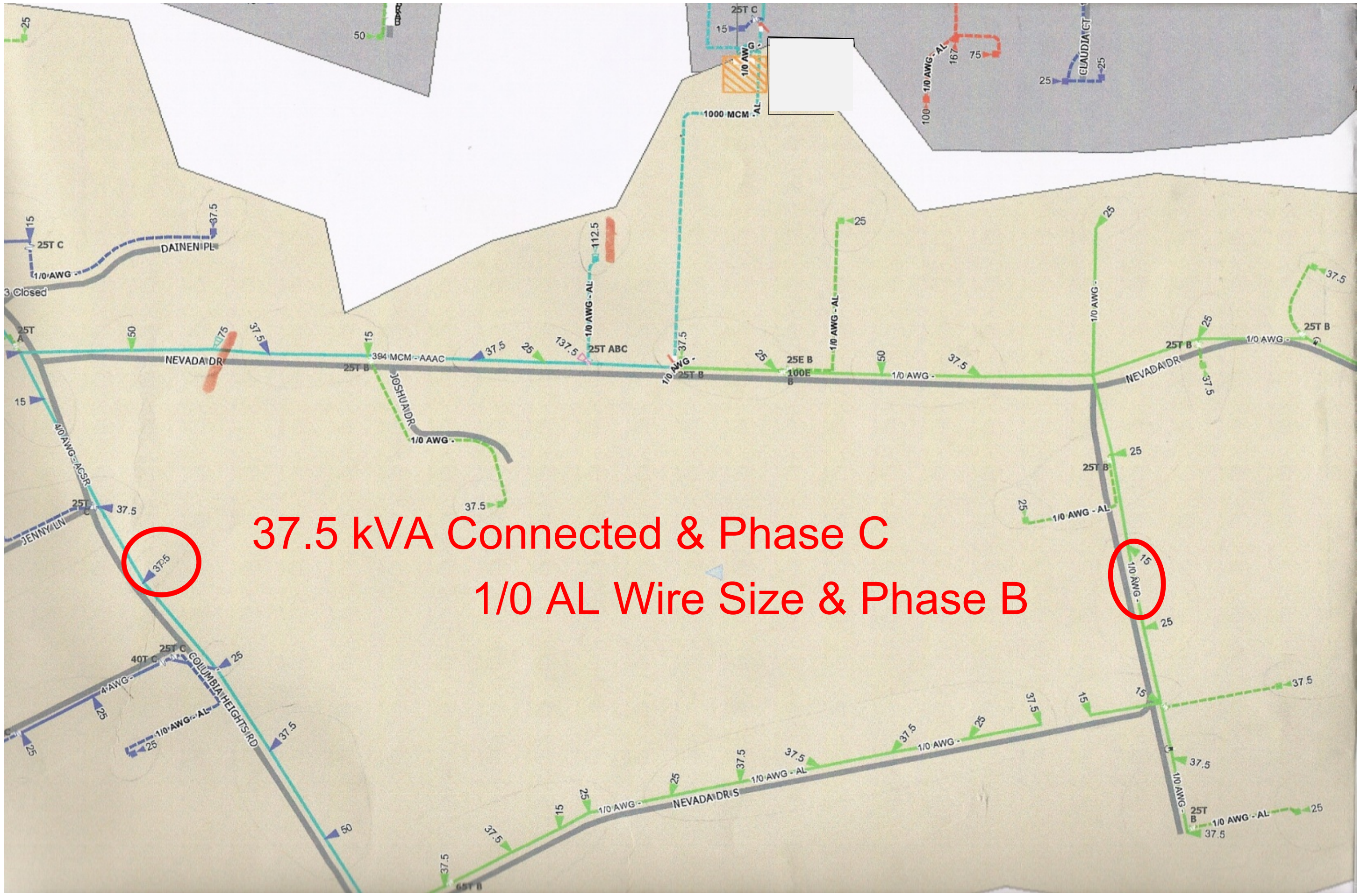
Distribution System Topology Information



- System maps
  - Conductors Types
  - Phasing
  - Location of equipment
  - kVA Connected
- Distribution equipment installation costs (lines, caps, regs. etc.)
- System Engineering Modeling (if available)
  - Conductors Types, Phasing, Location of equipment
  - kVA Connected (or allocated load)

Distribution System GIS Maps

West Substation - Feeder 1



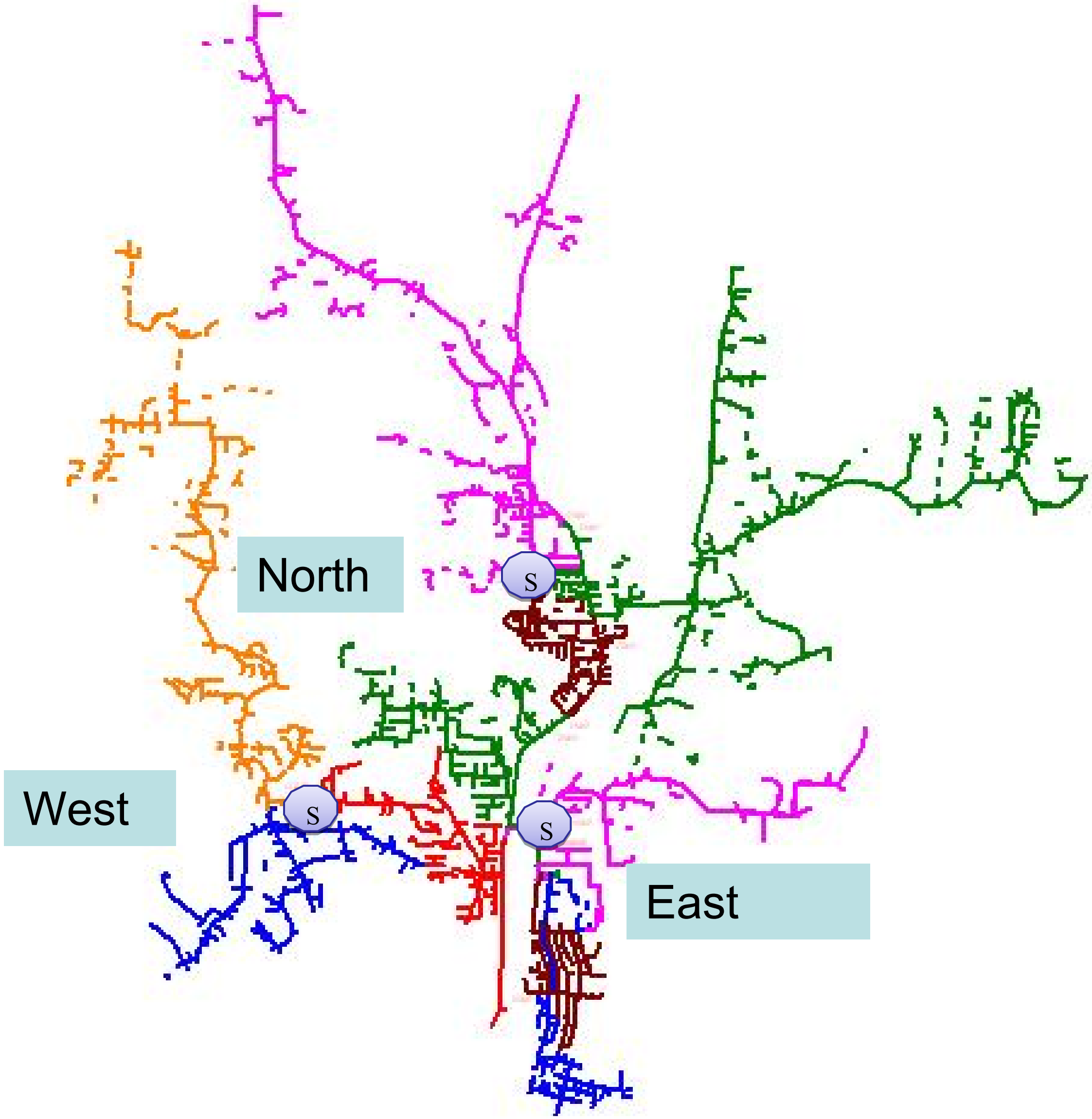
Data Requirements (continued)

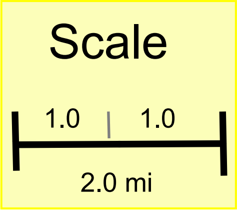
- Time requirement (typical) for Utility Data Gathering for Scoping Study – 30 to 90 mhrs
  - ✓ General Meetings with TSP (12 to 20 mhrs)
  - ✓ Meter Data (6 to 40 mhrs)
  - ✓ Maps and GIS (4 to 15 mhrs)
  - ✓ System Modeling Downloads (8 to 15 mhrs)

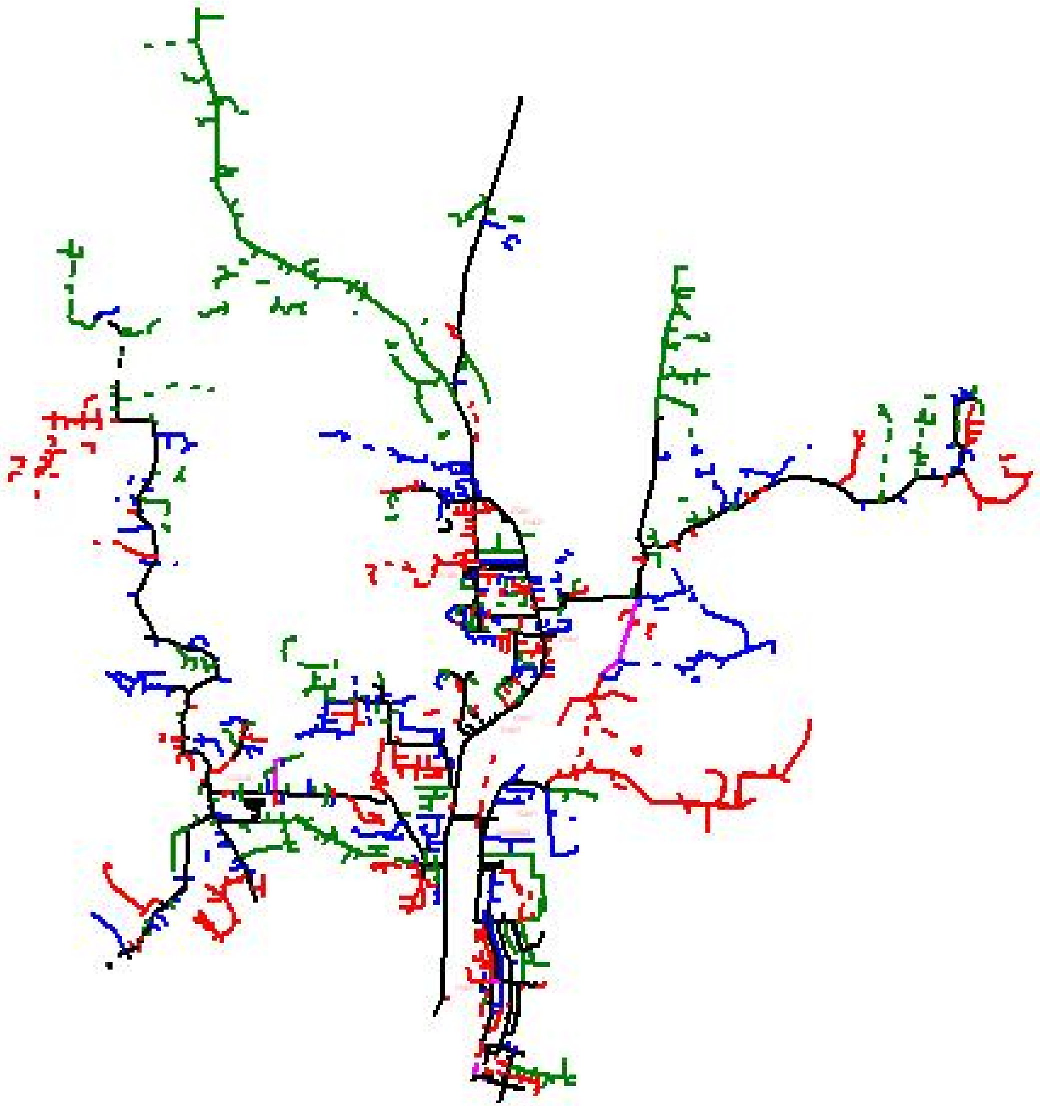
SI & VO Application to Rural / Urban Feeders Case Study

Example Distribution System (12.47 kV, 4-wire)							
Power Transf	Peak MVA	Avg PF	# of Customers	# of Feeders	Load Density	# of Line Regulators	Volt Control
Sub Name:	**North**						
12/16/20	15.1	96.29%	1706	3	Rural 1 Urban 2	0	Fixed 125 V
Sub Name:	**West**						
12/16/20	15.4	97.93%	1799	3	Rural 1 Urban 2	0	Fixed 125 V
Sub Name:	**East**						
12/16/20	15.5	96.17%	2135	4	Rural 1 Urban 3	0	Fixed 125 V
Total number of Customers =			5642	Primary Wire Size 336 AAC and 1/0 AL			
System Load Factor = 0.380				Annual Energy = 151,398 MWh			
				kVA Connected = 76110.5			

Primary Feeder Routes



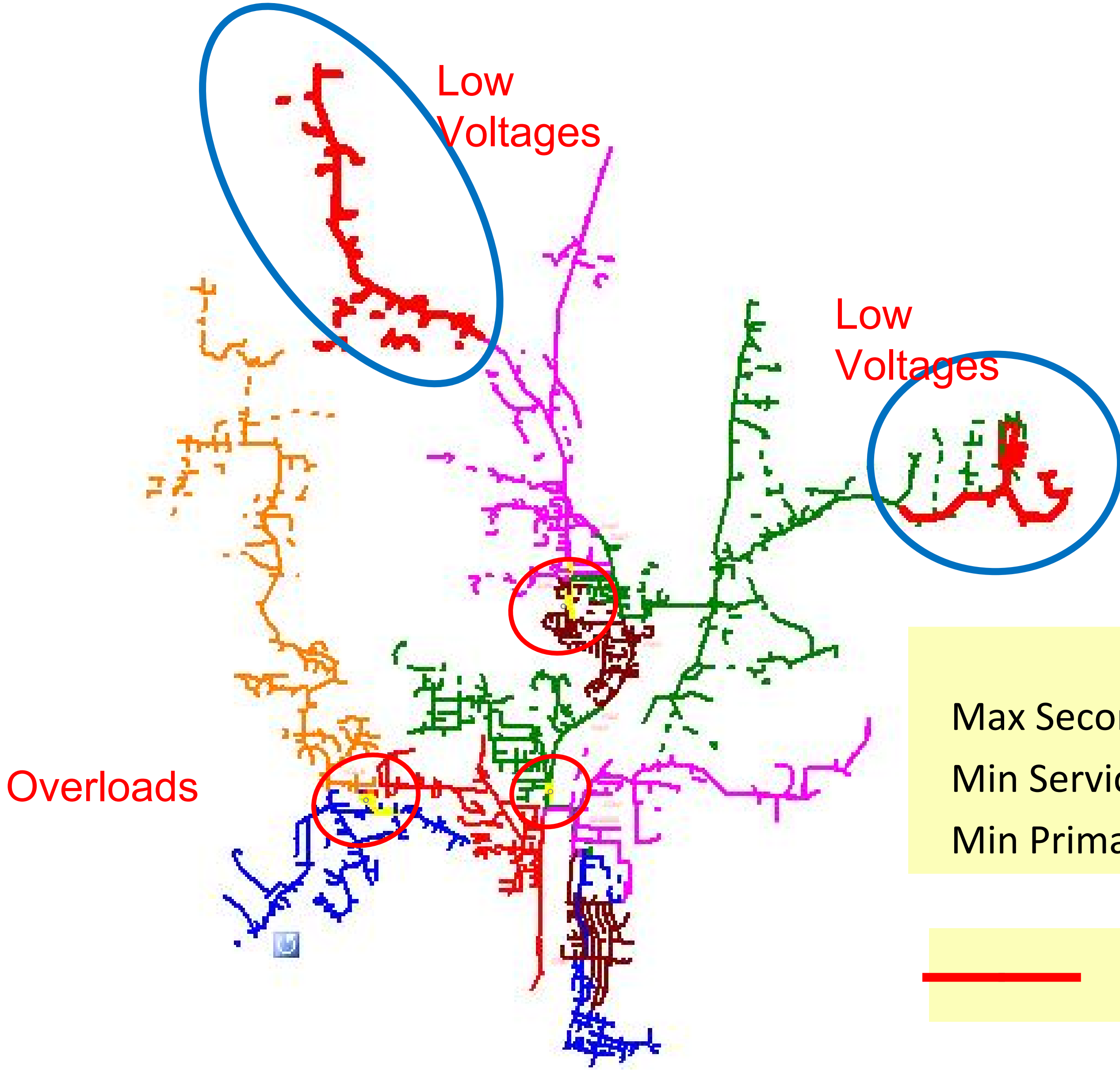




Primary Feeder Phases

3 ph	
A ph	
B ph	
C ph	

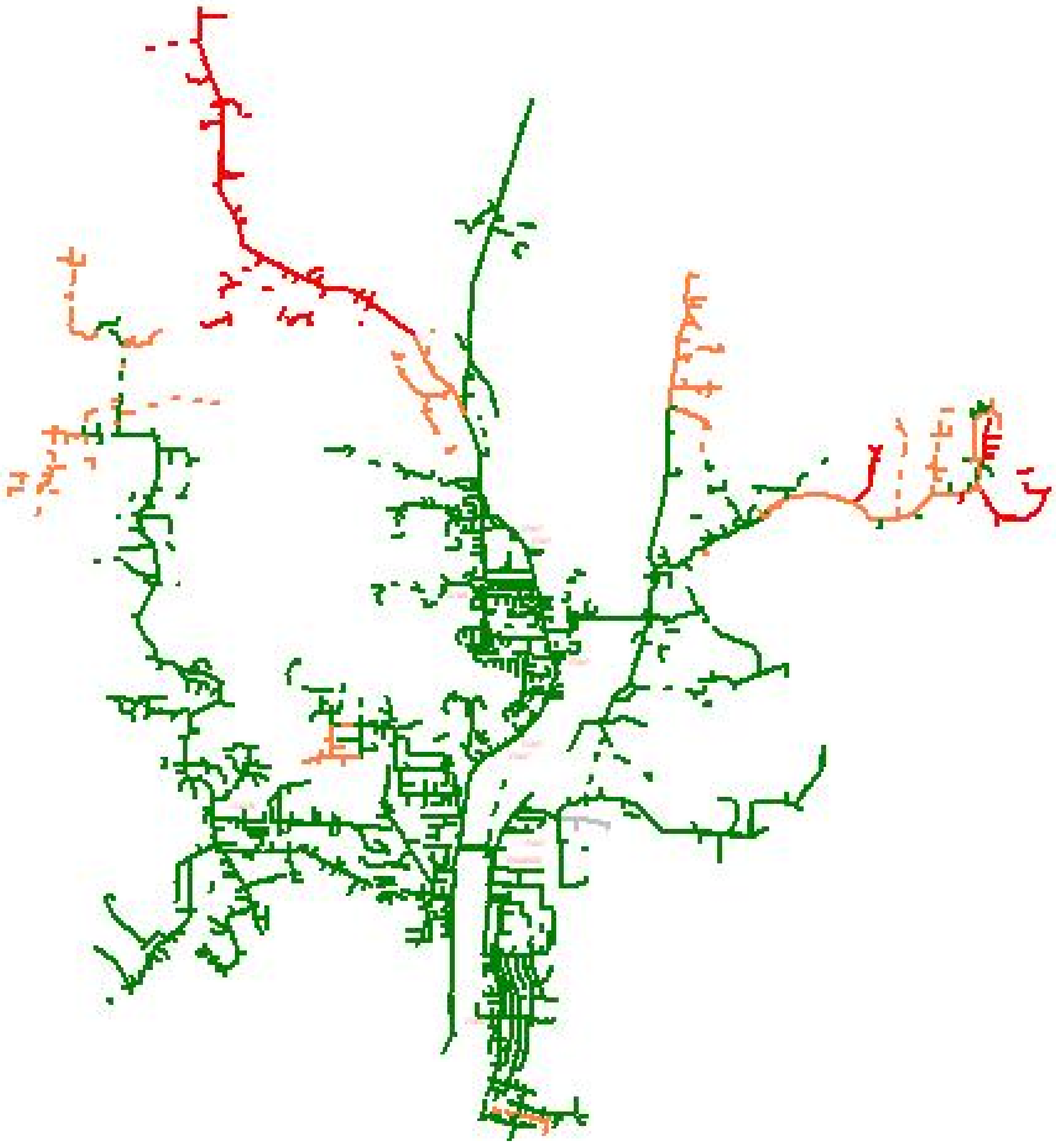
Threshold Assessments



	VD%	Volts
Max Secondary VD	3.0	3.6
Min Service Volts		115.0
Min Primary Volts		118.6

< 118.6 V

Threshold Assessments



Max Volt Drop

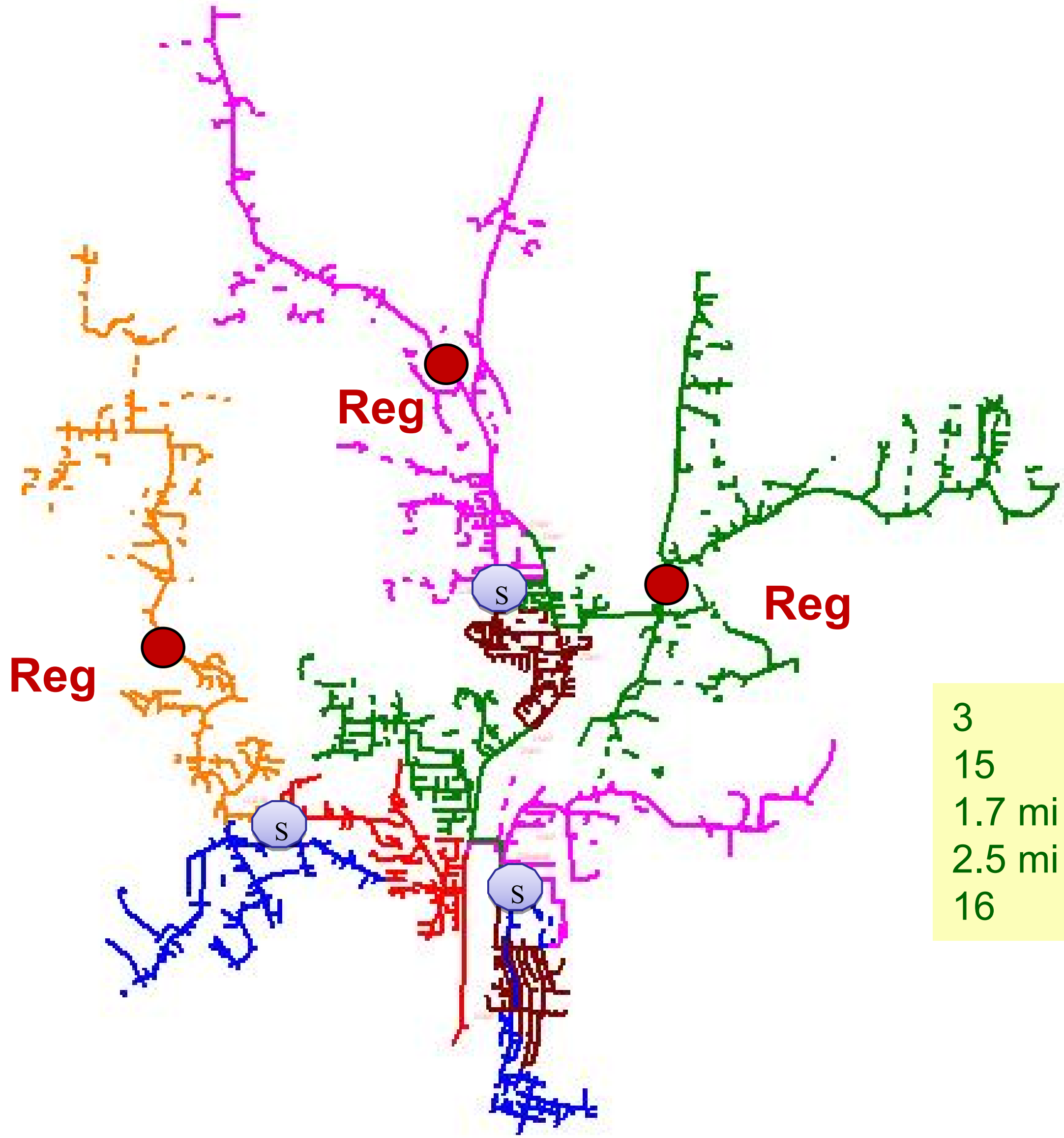
- 0 – 3.5%
- 3.5 – 5%
- > 5%

System Improvements (Typical)

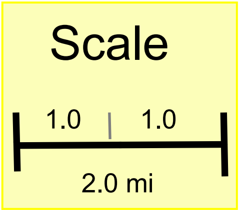
- Develop System Improvement Plans
  - Comply with Minimum System Thresholds
  - Improve System Modeling and Mapping
  - Add Voltage Control Zones
  - Revise Voltage Controls
  - Add Metering

- Typical System Improvements
  - Add Shunt Capacitors
  - Change feeder configuration (switching)
  - Change phase assignments (transformers and 1-ph taps)
  - Add phases on feeders (e.g., 1-ph to 3-ph)
  - Reconductor main feeders
  - Add Line Volt-Regulators
  - Change Voltage Control Settings (e.g. LDC)

SI & VO System Improvement Plan



3 – Line Volt Regulators
15 – 300 kVAr Caps
1.7 mi – Phase upgrades
2.5 mi – Line Reconductoring
16 – Lateral tap reconfigurations



Distribution System Improvements Installation Costs

Project Costs		Overall		North		West		East	
	Cost/unit	Units	Total Cost	Units	Total Cost	Units	Total Cost	Units	Total Cost
Capacitor Installations (300 kVAr)	$3,000	15	$45,000	4	$12,000	4	$12,000	7	$21,000
Regulator Installations	$50,000	3	$150,000	2	$100,000	1	$50,000	0	$0
Phase Upgrades 1ph to 3ph/mi	$100,000	1.66	$166,000	0.54	$54,000	0.56	$56,000	0.56	$56,000
Line Reconductor 1/0 A to 336 A	$100,000	2.50	$250,000	0.25	$25,000	1.25	$125,000	1.00	$100,000
Lateral Tap Relocations	$2,000	16	$32,000	5	$10,000	4	$8,000	7	$14,000
Substation Metering	$5,000	13	$65,000	4	$20,000	4	$20,000	5	$25,000
Regulator Metering	$3,000	3	$9,000	2	$6,000	1	$3,000	0	$0
EOL Volt Metering	$3,000	13	$39,000	5	$15,000	4	$12,000	4	$12,000
Total VO Project Installed Cost			$756,000		$242,000		$286,000		$228,000

Total End-Use Energy Saved

Heating Climate Zone	2
Cooling Climate Zone	2
Customers with Electric Heat or Heat pump (%)	70
Customer with AC (any kind) %	30
VO Factor (End-Use) from VO M&V Protocol Table 5	0.37

$$E_{Saved} = \Delta V \quad x \quad VO_f \quad x\ E_{annual} \quad + \Delta E_{SI\text{-}LL} \quad + \Delta E_{SI\text{-}NL}$$

$$E_{Saved} = \quad 0.0288 \times 0.37 \times 151{,}398 \quad + \Delta E_{SI\text{-}LL} \quad + \Delta E_{SI\text{-}NL}$$

$$E_{Saved} = 1613.3 \quad + 74.6 \quad + 110.4$$

89.7% 4.1% 6.2%

E_{Saved} = $\underline{1798.3}$ MWh/yr

Total Resource Cost (TRC) Analysis

Regional TRC Benefit Cost Analysis *(using ProCost assumptions)*	
Wholesale Electric Energy Saved (kWh/yr)	1,960,958
PV Total Regional Benefit	$2,800,113
PV Total Regional Cost	$1,114,927
TRC B/C Ratio	2.5
Total Levelized Cost ($/kWh saved)	$0.0456

If > 1.0

BPA Energy Efficiency Incentive Payment (ESUE program)	
SI & VO Energy Saved (kWh)	**1,798,300**
BPA Energy Efficiency Incentive ($/kWh)	$0.25
A - BPA willing to pay First Year	$449,575
Utility Project Cost of Improvements	$756,000
BPA Energy Efficiency Incentive Rate (pu)	70%
B - BPA willing to pay First Year	$529,200
Total BPA Incentive Payment (lower of **A** or **B**)	$449,575

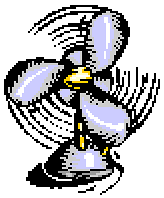
Assumed Retail Utility Financial Factors

Retail Utility Financial Factors - Typical	
Average Marginal Purchase Power Rate ($/kWh)	$0.050
Annual Cost increase for Construction (%/yr)	3.0%
Annual Cost increase for kWh Energy (%/yr)	4.0%
Operations, Maintenance, and Insurance (%/yr)	5.0%
Present Worth Rate for Cost of Investment (%/yr)	7.0%
Present Worth Rate for Cost of Energy Losses (%/yr)	6.0%
Planned life of energy savings (yr)	15

Utility Benefit Cost Analysis

Utility Benefit Cost Analysis / Project	
SI & VO Energy Saved (kWh)	**1,798,300**
Utility Project Cost of DSE & VO Improvements	$756,000
Less BPA Efficiency Incentive Payment	($449,575)
First Year Utility Investment Costs – Subtotal	**$306,425**
Plus NPV Operations, Maintenance, and Insurance	$420,275
Total NPV Utility SI & VO Costs	$726,700
EEM Levelized Cost per kWh Saved (Cost)	**$0.031**
Utility Revenue Requirements / Project	
Total NPV Utility SI & VO Costs	$726,700
Less NPV Purchase Power Costs	($1,155,342)
Net NPV Utility SI & VO Costs / Project	($408,641)
Benefit / Cost Ratio	**1.59**
Project Costs per year	$65,360
Less Purchase Power Savings per year	($89,915)
Net EEM Project Savings per year	($24,555)

Comments and Questions



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Appendix – VO M&V Protocol 7-day measurement of V^*

- Annual measurements for each feeder and VCZ
  - *C* = Source regulated voltage V_{Set} (e.g. 119 V to 125 V)
  - *D* = Maximum annual 3φ peak (kW) hourly demand
  - *E* = Total annual energy (kWh) delivered
  - *F* = Annual Load Factor (*LDF*) = [*E* / 8760h] / *D*

- 7 day M&V period (measurements shown in green)
  - *A* = Maximum annual voltage drop in Volts at peak load =
    [Average of hourly (V_{Source} - V_{EOL})] • [*D* / Average hourly kW demand]
  - *B* = Regulator maximum annual volt rise in Volts at peak load =
    [Average hourly (V_{Source} – *C*)] • [*D* / Average hourly kW demand]
  - V^* = Annual average voltage = C + F • (B - 1/2 • A)
  - Annual average voltage chan $\Delta V^* = V^*_{pre\text{-}VO} - V^*_{post\text{-}VO}$