

# **Volt VAR Optimization (VVO) Project – Rate Case Justification**

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Voltage Regulation track  
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# Agenda

- Introduction
- Volt-VAR Control/Optimization Technologies and tradeoffs
- Cost-Benefit Analysis of VVO
- Verification, Assessment and Monitoring Requirements for CVR
- Acknowledgements

# Introduction

By presenting a well-structured and thoroughly supported justification, utilities can build a strong case for rate recovery of their VVO project, ensuring the continued enhancement of grid operations and the delivery of value to customers and stakeholders.

- When electric power companies planning to implement Volt/VAR optimization (VVO) projects and recover the associated costs through a rate case, they typically need to provide justification materials to demonstrate the benefits and cost-effectiveness of the project
- These materials would include several aspects of the VVO implementation, including its impact on grid operations, reliability, energy efficiency, and cost savings.

## **Typical justification materials for a VVO project rate case:**

### 1. Project description and scope

- Define the distribution system VVO project's objectives along with implementation details.
- Provide specifics on the technologies to be used including apparatus (LTC transformers, voltage regulators, capacitor banks, DERs (solar PV, wind, battery storage), and their controls), communications architecture, VVO software, if appropriate.
- Outline the projected timeline for project deployment.

## 2. Technical rationale and benefits

- **Voltage regulation and reliability improvement**

- Voltage profile
- Explain how VVO helps maintain voltage levels within acceptable limits, even with increasing penetration of distributed energy resources (DERs) like solar PV.
- Demonstrate the positive impact of VVO on power quality and grid reliability by mitigating voltage fluctuations.

- **Energy efficiency, loss reduction, and demand reduction**

- Show how optimizing reactive power flows and voltage reduction using VVO can reduce energy losses within the distribution system.
- Provide estimates of energy savings and peak shaving potential attributable to VVO

- **DER Hosting capacity enhancement**

- Illustrate how VVO can increase the distribution system's capacity to integrate additional DERs without requiring costly infrastructure upgrades.

- **Reduced operations of voltage control devices**

- Highlight how VVO can minimize the need for frequent operation of LTC transformers, capacitor banks and voltage regulators, thereby extending their lifespan and reducing maintenance costs

### 3. Cost-benefit analysis

- **Present a cost-benefit analysis comparing the VVO project with alternative approaches (e.g., traditional infrastructure upgrades).**
- **Quantify the economic benefits, including:**
  - Energy and demand savings.
  - Reduced operations and maintenance costs.
  - Deferred or avoided capital expenditures for infrastructure upgrades.
  - Other benefits associated with reduced energy consumption such as lower emissions.
- Include any potential costs, such as capital investment in apparatus & associated controls, communications equipment, VVO software, and ongoing maintenance.

### 4. Evaluation, measurement, and verification (EM&V) plan

- Detail the methodology for evaluating, measuring, and verifying the VVO project's benefits
- Specify the data collection and analysis procedures to track key performance indicators (KPIs) like energy savings, voltage improvements, and DER integration levels.

### 5. Regulatory & standards compliance

- Demonstrate how the VVO project aligns with relevant regulatory requirements, standards (e.g., IEEE 1547), and utility objectives.
- Show how VVO contributes to achieving grid modernization goals and enhances the overall resilience of the distribution system.

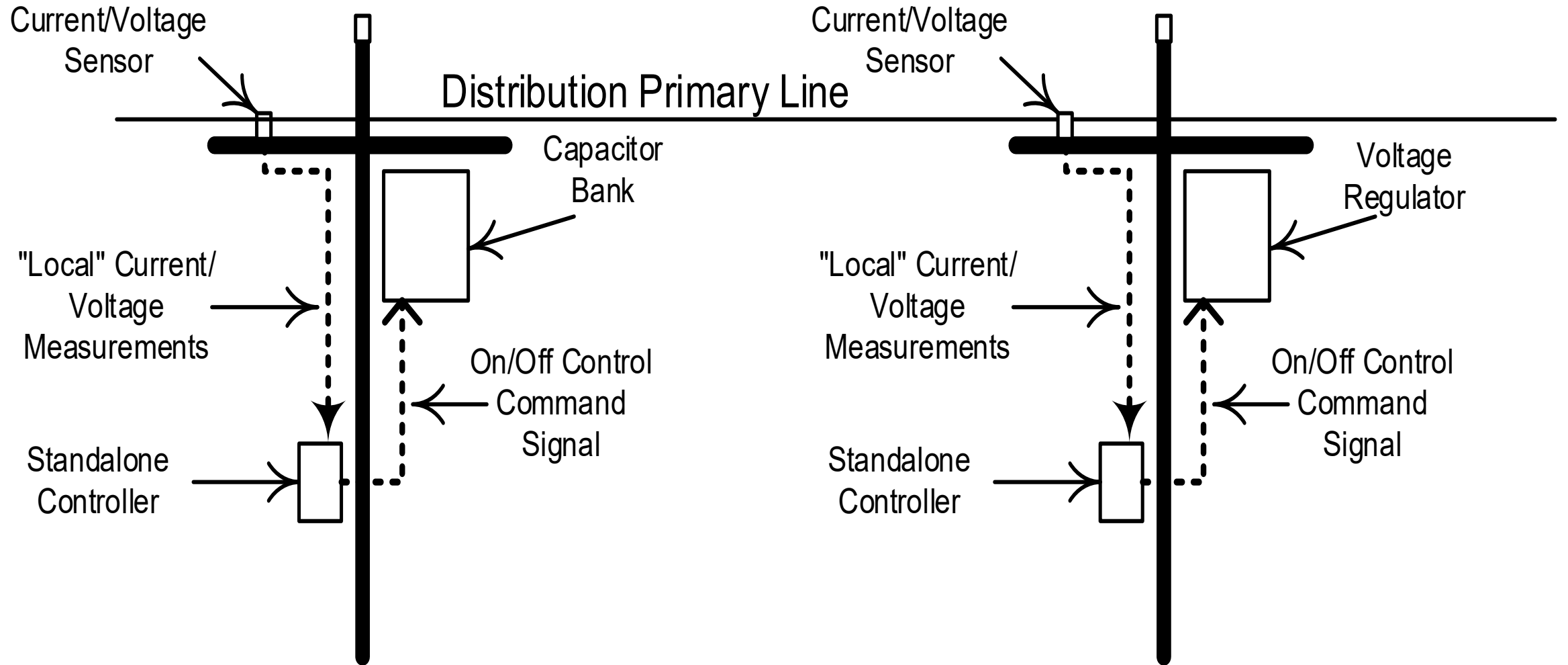
# **Volt-VAR Optimization Technologies and Tradeoffs**

# Approaches to Volt-VAR Optimization

- **Standalone** - Field devices perform independent VV Control actions based on “local” measurements
- **SCADA “Rule-based” control** - Field devices based on distribution system measurements and fixed rules
- **Heuristics approach** – VV control actions based on past experience (“self learning”) and judgment rather than detailed analysis of measurements
- **Advanced Analytics** - Field devices controlled based on detailed analysis of measurement data
- **DMS Model-Driven** VV control of field devices based on analysis of “as operated” distribution system powerflow model

## Standalone Controller Approach – Covered in detail by Bob McFetridge

- VV Control managed by individual, independent, standalone volt-VAR regulating devices:



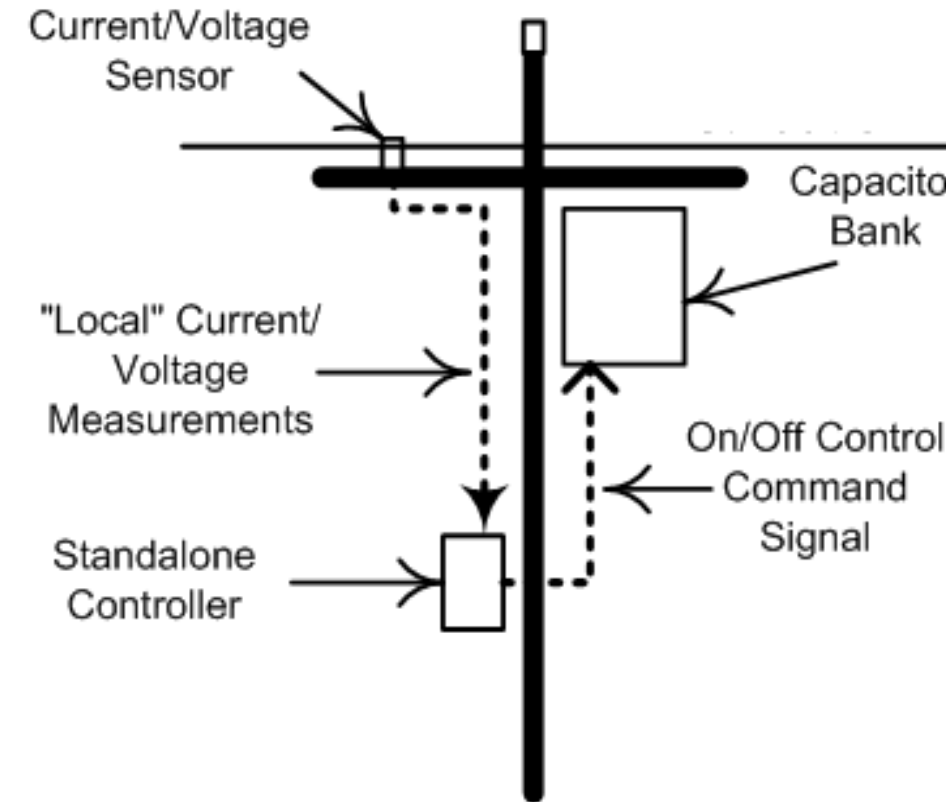
## Standalone Controller Approach – Covered in detail by Bob McFetridge

### Strengths

- Low cost – no cost
- Minimal learning curve
- Does not rely at all on field communications
- Very scalable approach – can do one feeder or many

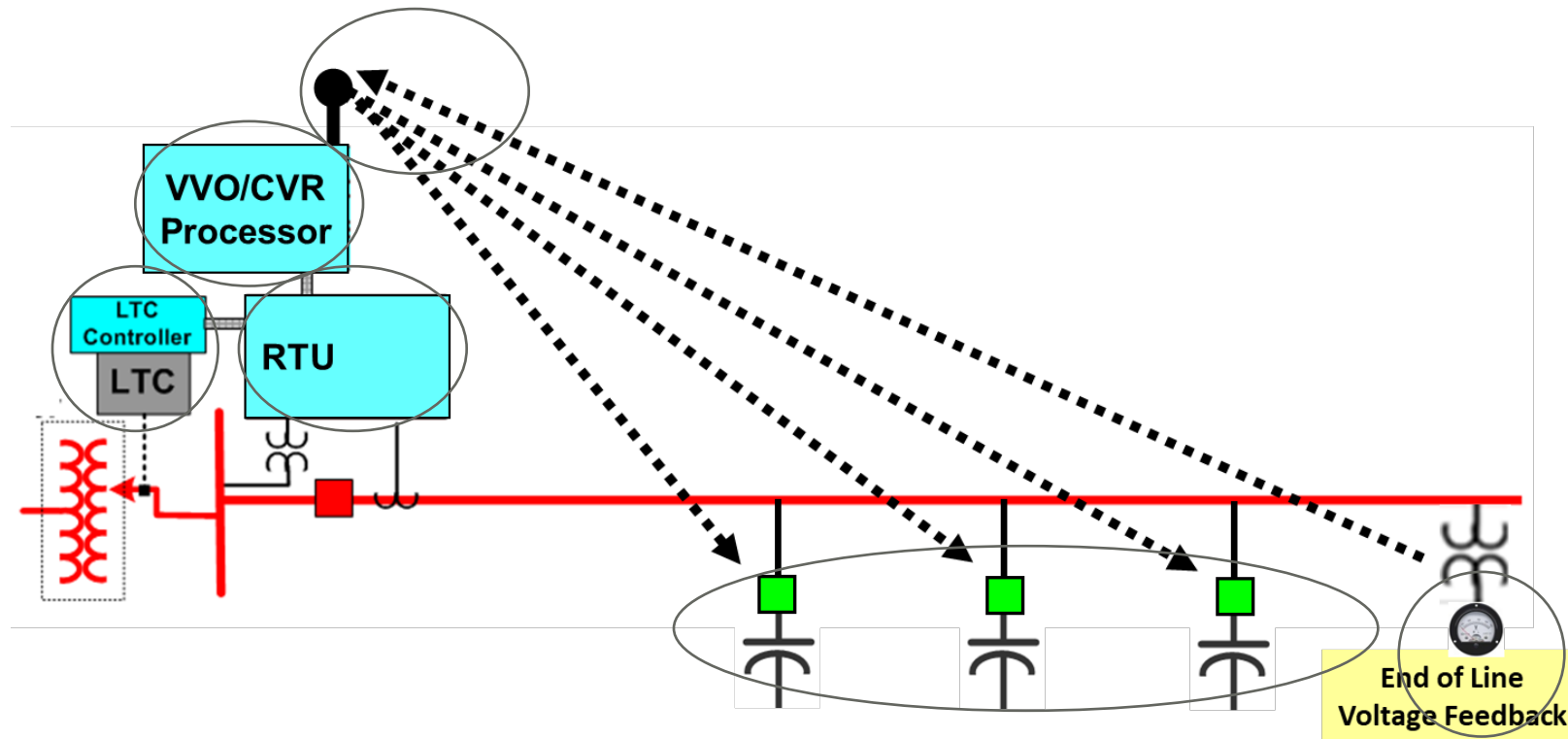
### Weaknesses

- No self monitoring features
- System operation may not be “optimal” under all conditions – need to build in bigger safety margin due to lack of “visibility” of remote conditions
- Lacks flexibility to respond to changing conditions out on the distribution feeders
- May not handle high penetration of DER very effectively
- Cannot override normal operation during power system emergencies



# SCADA “Rule-based” control

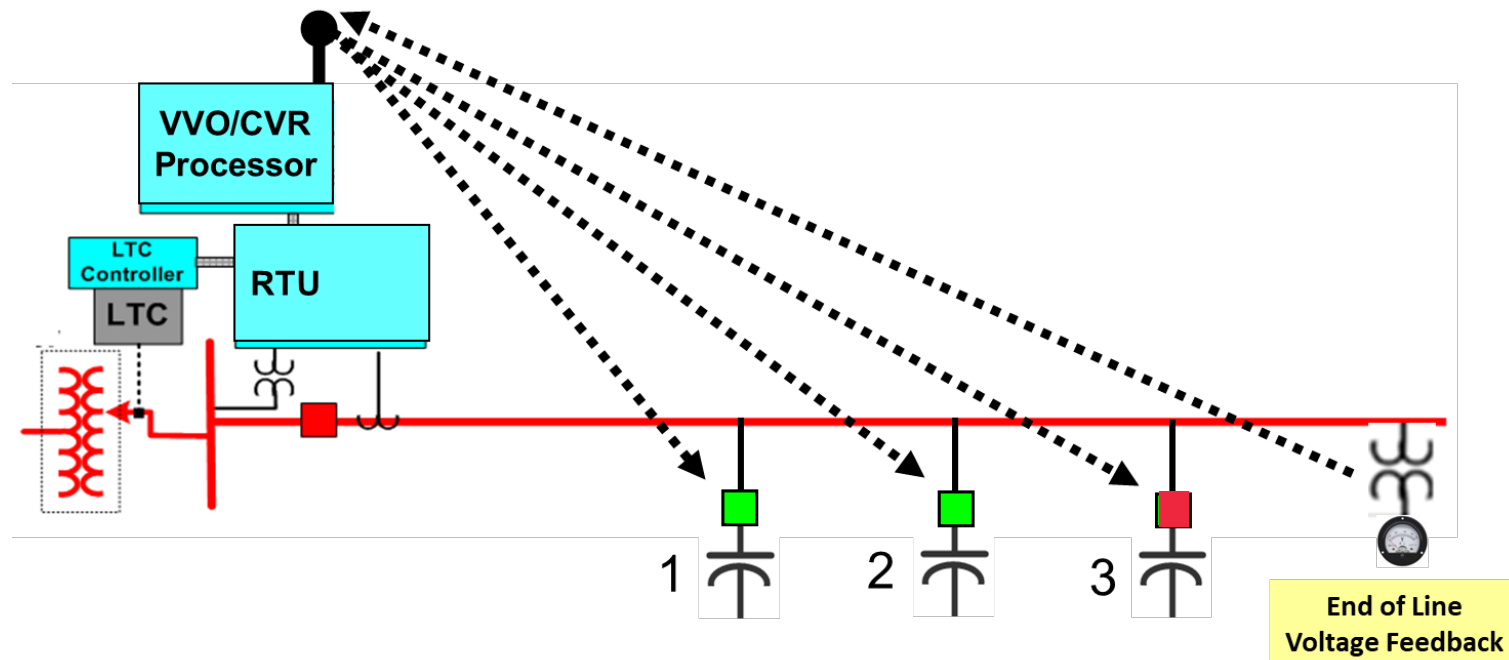
- Substation Remote Terminal Unit (RTU) – handles device monitoring and control
- VVO/CVR processor – contains “rules” for volt and VAR control
- Switched Cap banks & local measurement facilities – common practice use IEDs
- Voltage regulators (LTCs) & local measurement facilities
- Communication facilities, end of line voltage feedback (optional)



# SCADA “Rule-based” control

## Sample Rules:

- Identify “candidate” cap banks for switching
  - Cap bank “i” is currently “off” (“i” = 1,2 or 3)
  - Rating of cap bank “i” is less than measured reactive power flow at head end of the feeder
- Choose the “candidate” cap bank that has the lowest measured local voltage
- Switch the chosen cap bank to the “ON” position



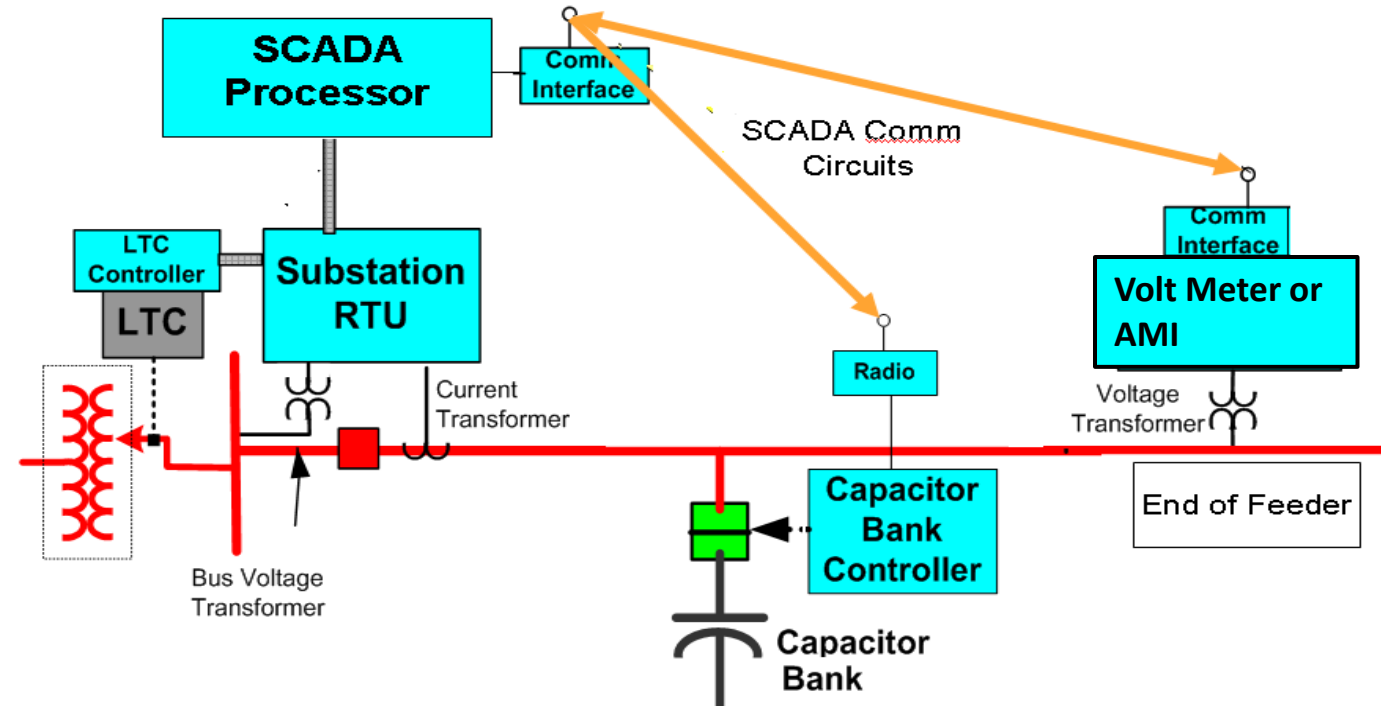
# SCADA “Rule-based” control

- **Strengths**

- Has self monitoring capabilities
- Control actions are based on feeder level and system level measurements
- Some coordination between volt and VAR controls
- Cost is moderate if DSCADA exists

- **Weaknesses**

- Difficulty handling highly meshed networks with frequent switching
- May not handle high penetration of DER very effectively



# “Heuristics” Approach

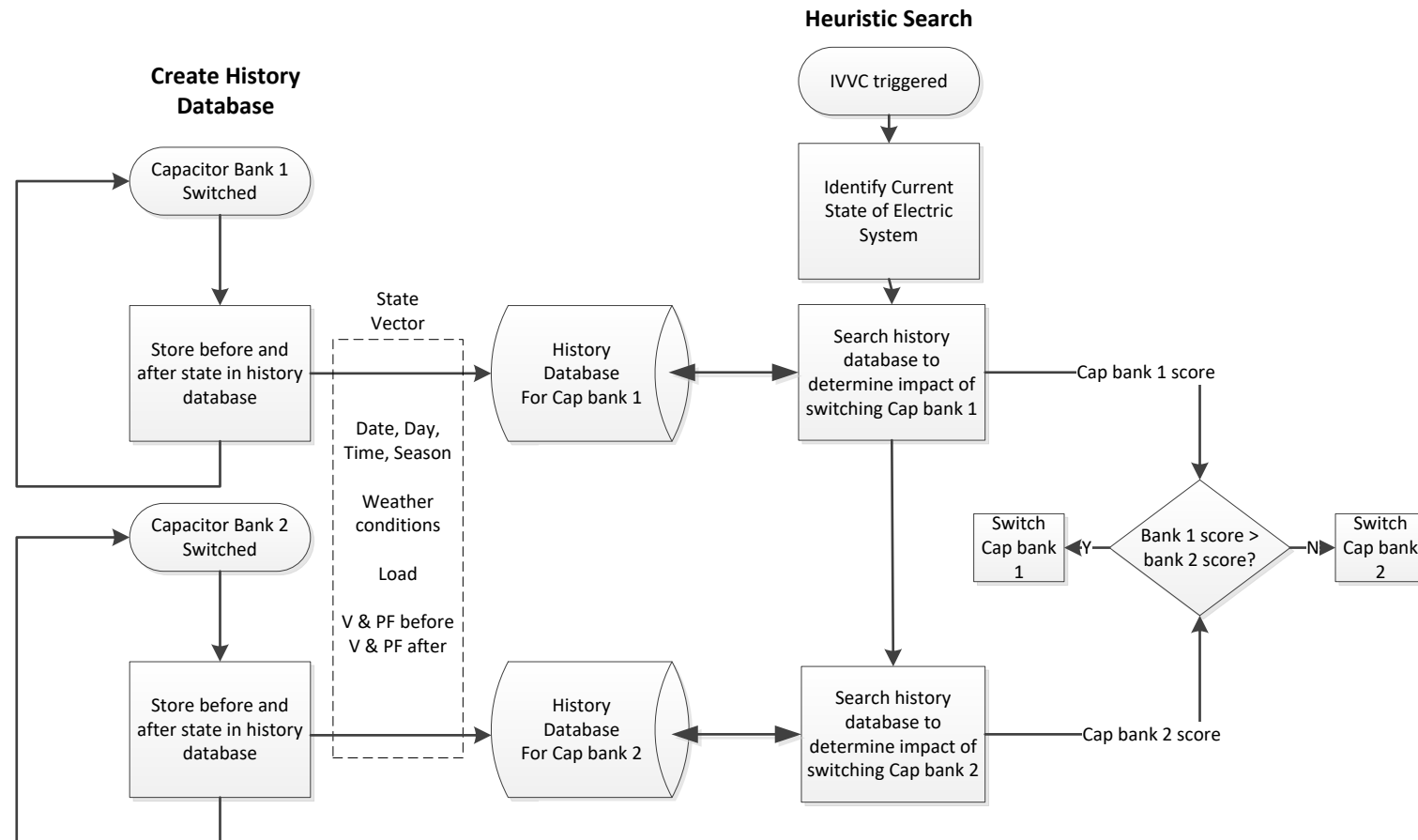
- Many VVO vendors call their solutions “heuristic”, which is a much-overused term
- Definitions of heuristic process:
  - “Experience-based techniques for problem solving”
  - "Rule of thumb" or “an educated guess”
  - “Running tests and getting results by trial and error”

***Heuristics are often used to reduce the number of possible switching actions that needed to be considered***

***Most solutions involve some degree of heuristics!***

# “Heuristics” Approach

- Control decisions based on past experience
- Electrical system state is stored before and after every switching operation
- When VVO is triggered, VVO system searches for switching action that produced the most benefits the last time



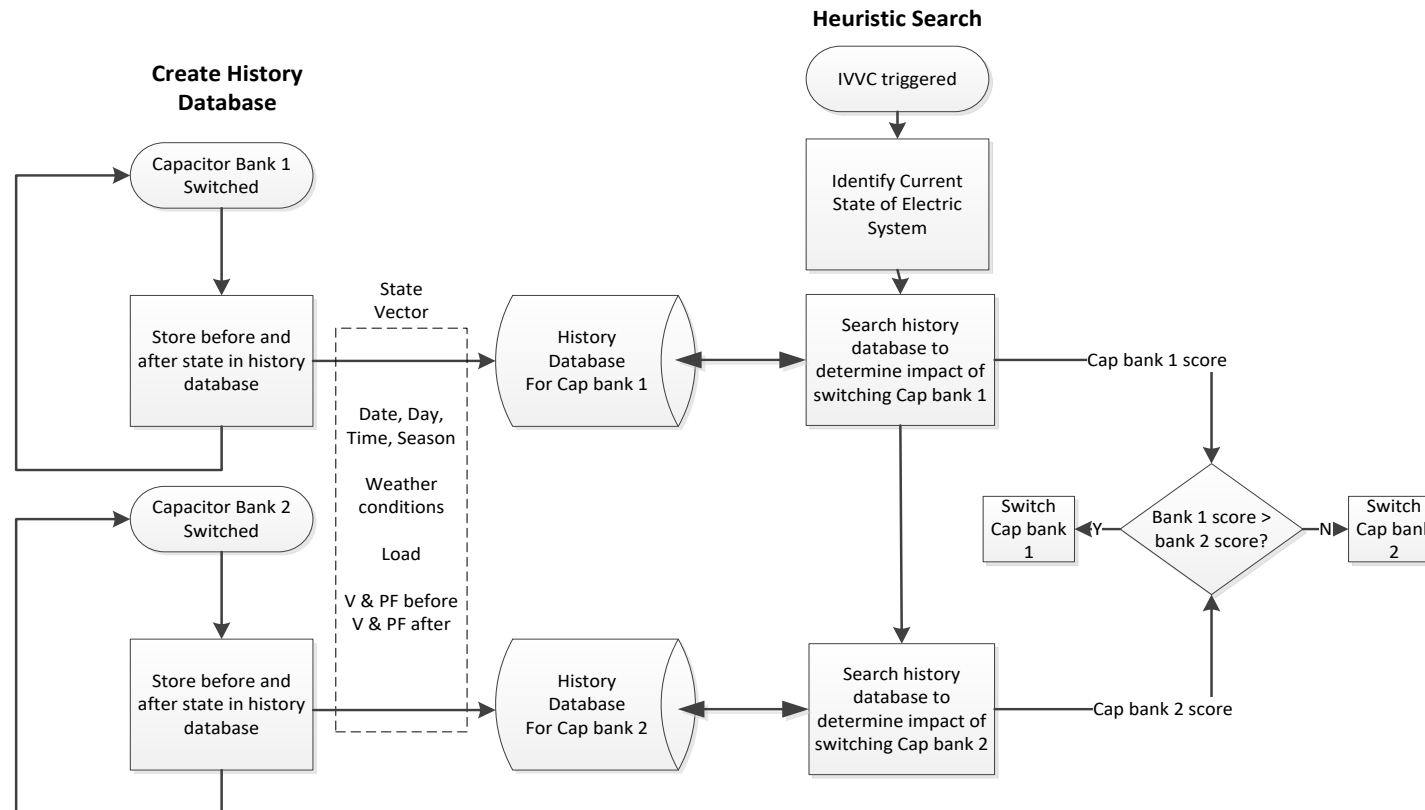
# “Heuristics” Approach

## Advantages

- No model required
- System is scalable

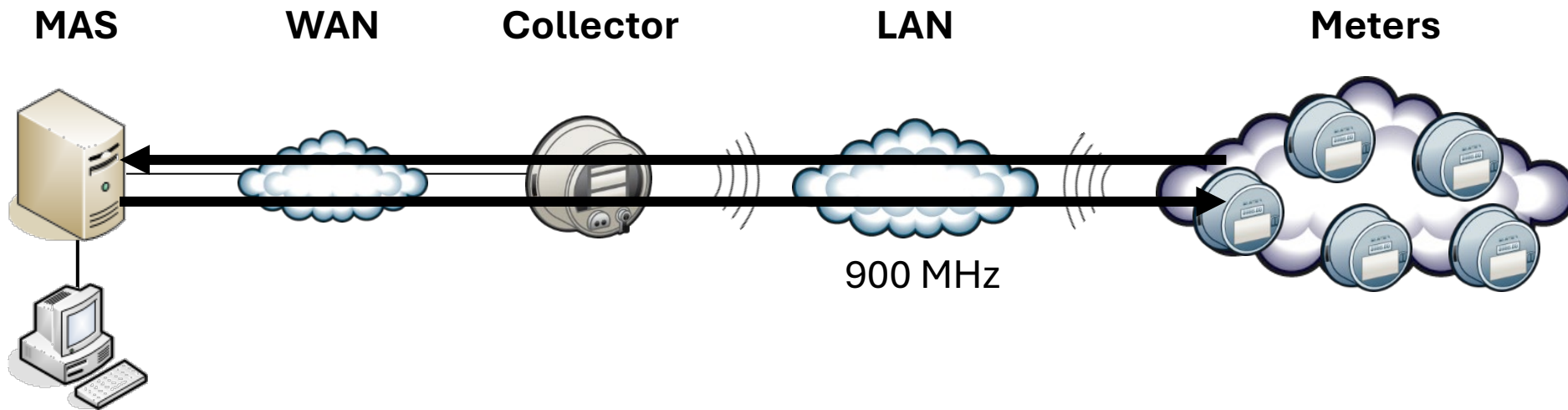
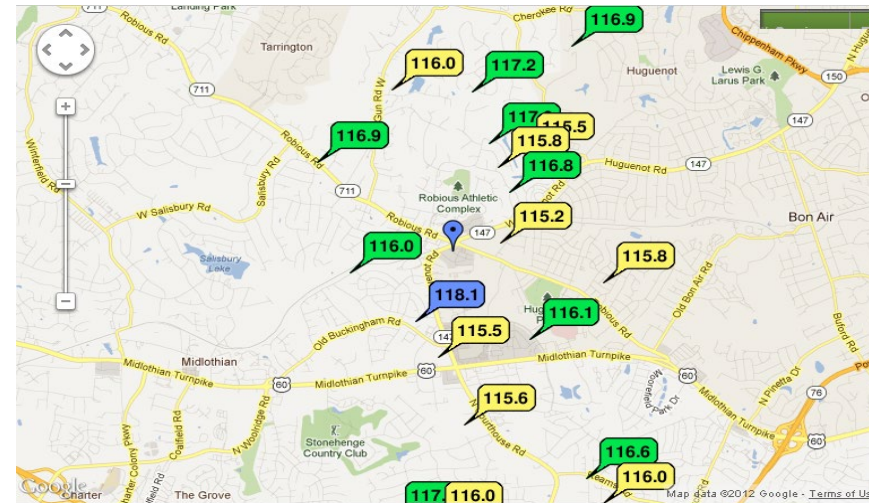
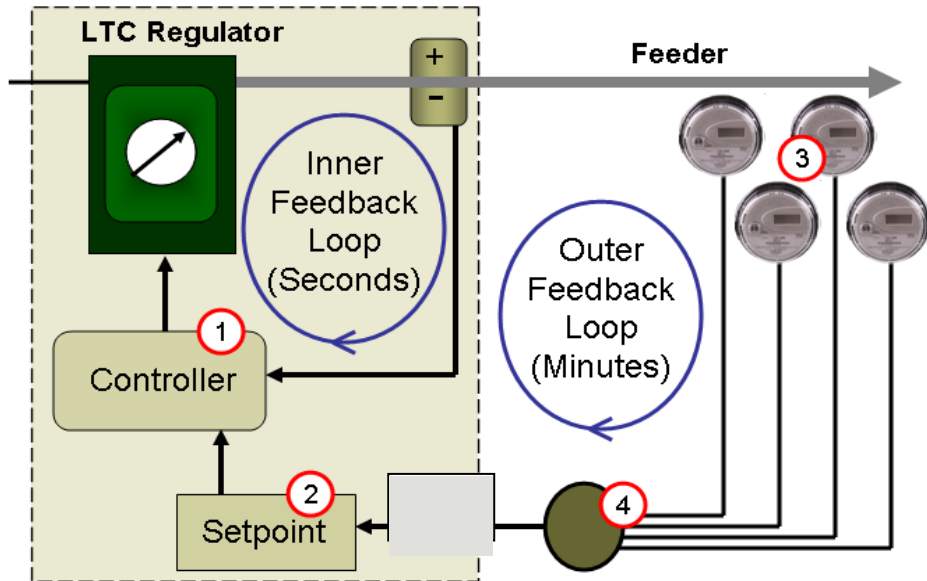
## Disadvantages

- Large amount of data storage
- Reconfiguration and DER difficult to handle
- Takes a while to “learn”



# Advanced Analytics

- Use of AMI measurements for Obtaining Voltage Feedback



# Advanced Analytics

## Strengths

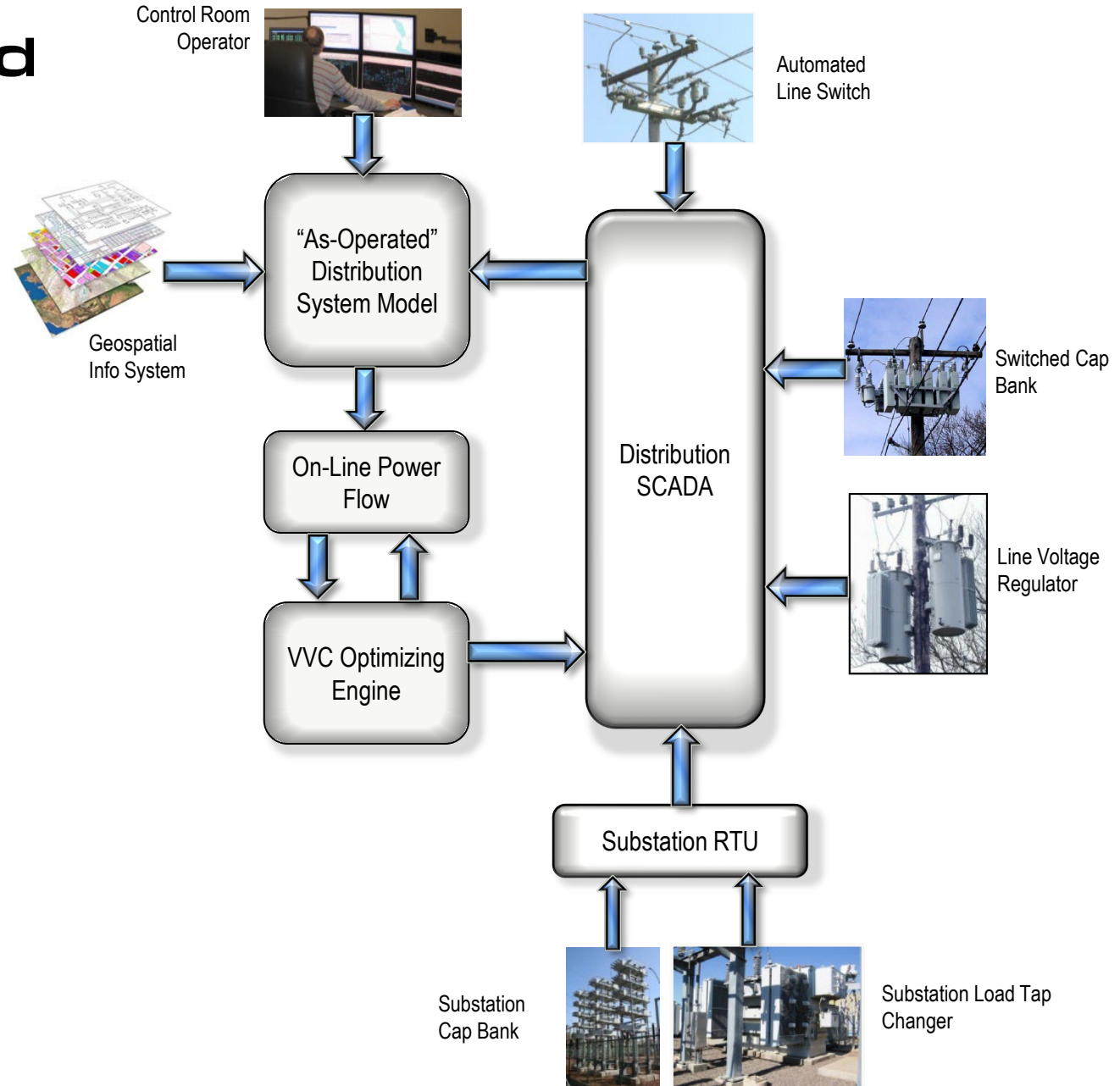
- Fully coordinated solution
- May adapt to presence of DER

## Weaknesses

- Higher cost of field equipment (substation processors, field measurements)
- Usually requires a topology/connectivity model
- Learning curve for control room personnel
- Usually turned off after feeder reconfiguration

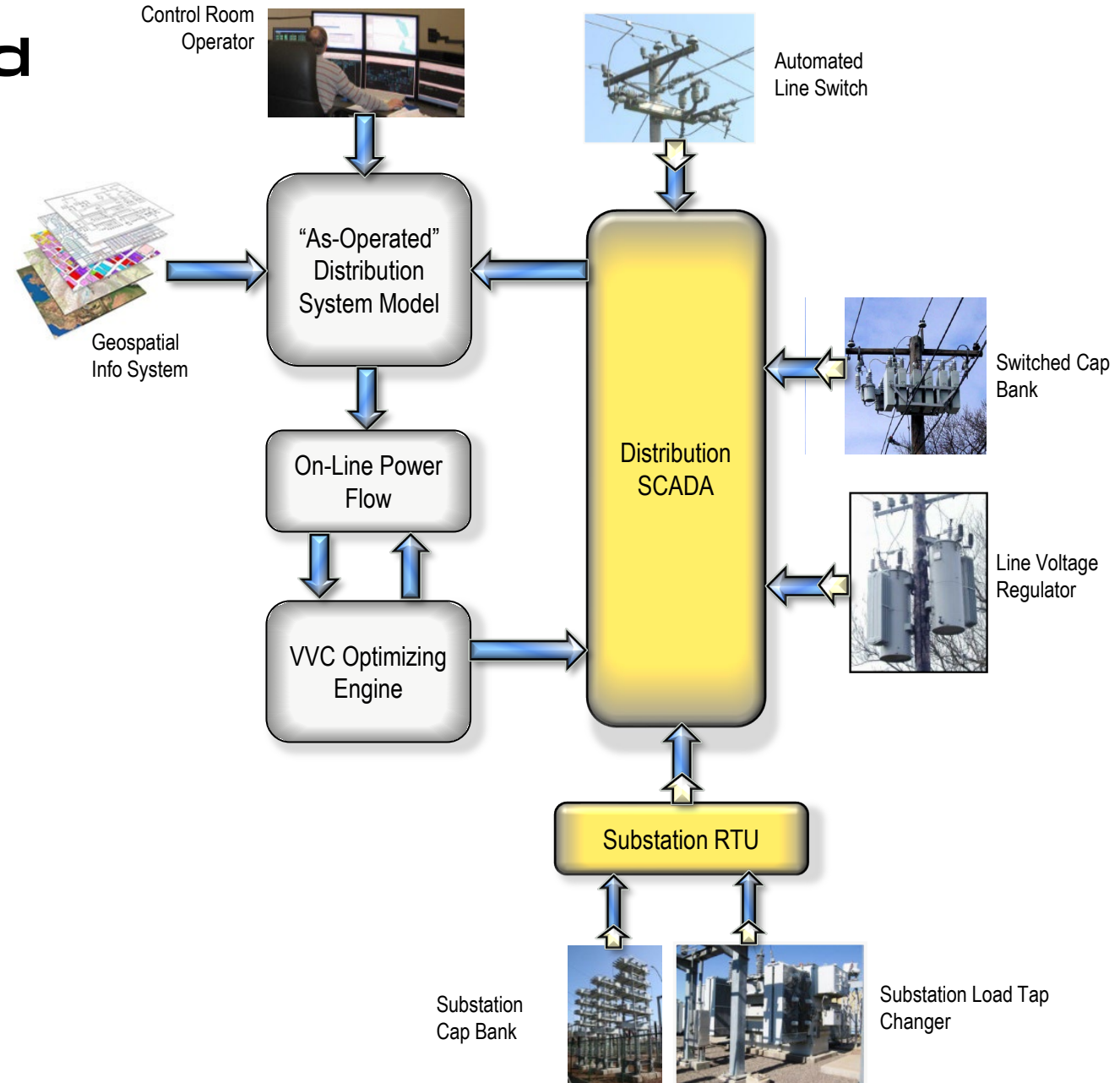
# Optimal Power Flow Based Volt-VAR Optimization - DMS model driven

- Centralized Optimal Power Flow Based Approach to Volt-VAR Control and Optimization
- Non-linear, mixed integer optimization problem
- Minimize a weighted objective function of MW demand, MW energy loss, and voltage/ current



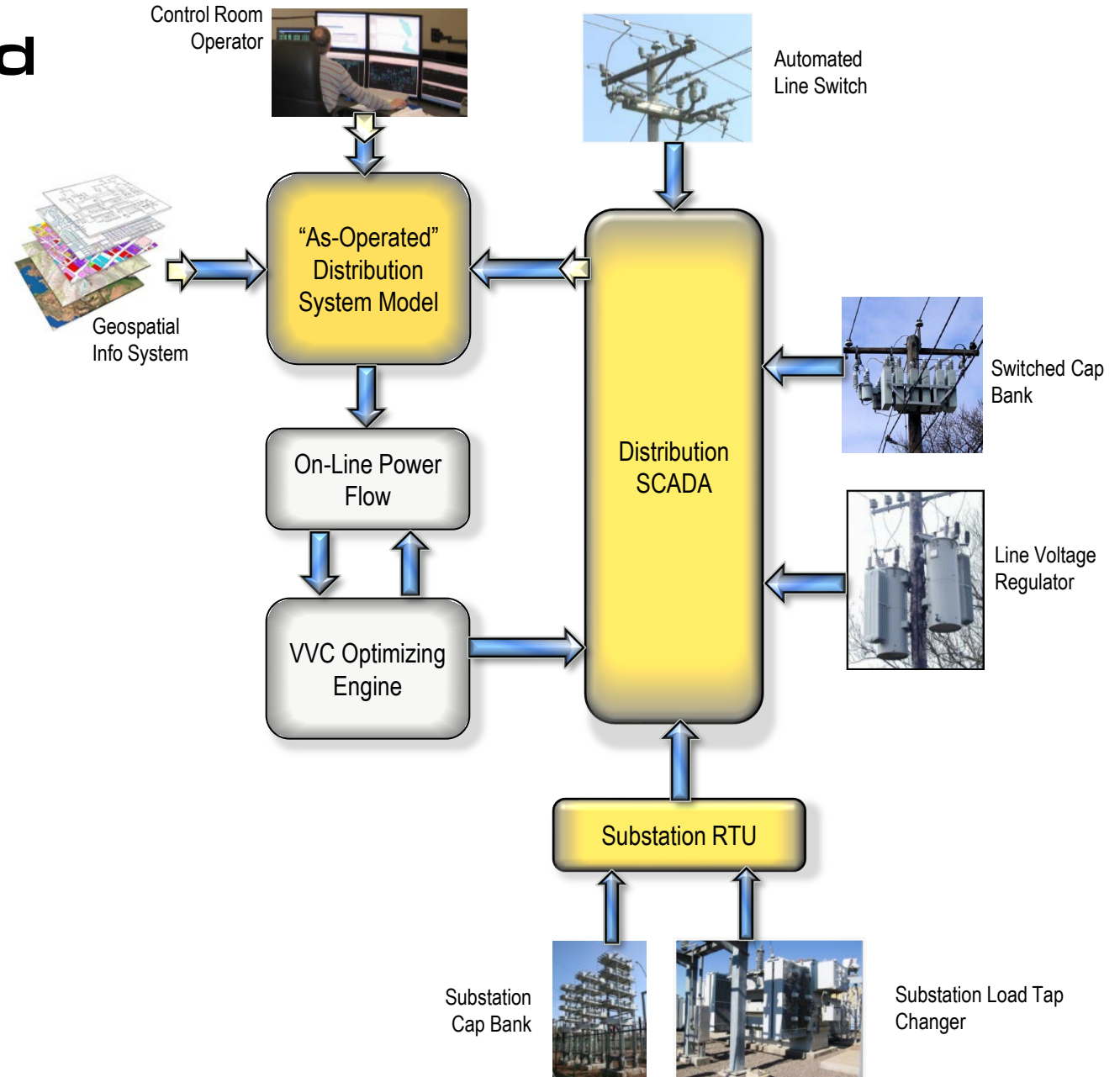
# Optimal Power Flow Based Volt-VAR Optimization - DMS model driven

- DSCADA provides real-time measurements



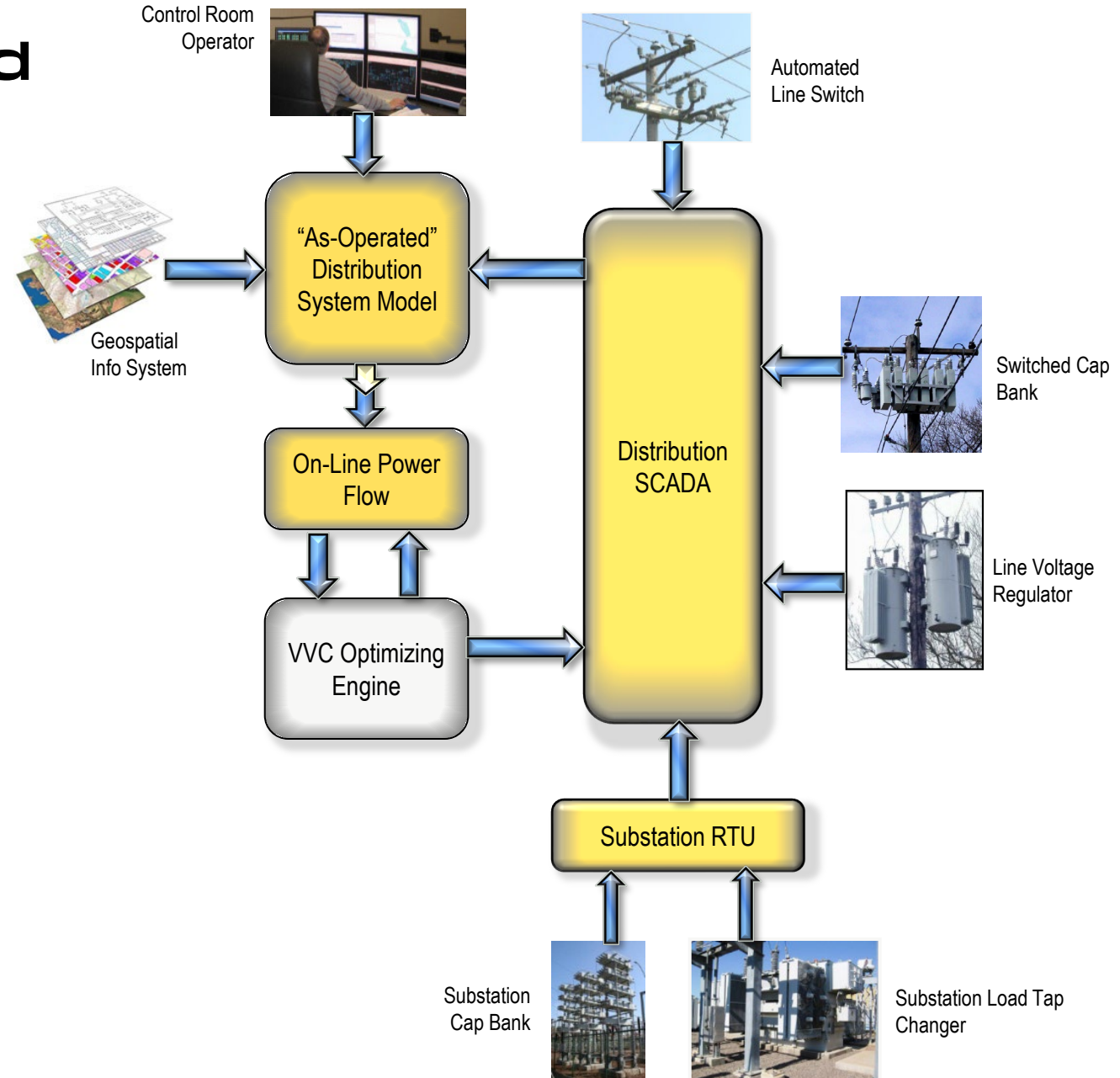
# Optimal Power Flow Based Volt-VAR Optimization - DMS model driven

- “As Operated” model maintained via DSCADA, GIS, & Operator Inputs



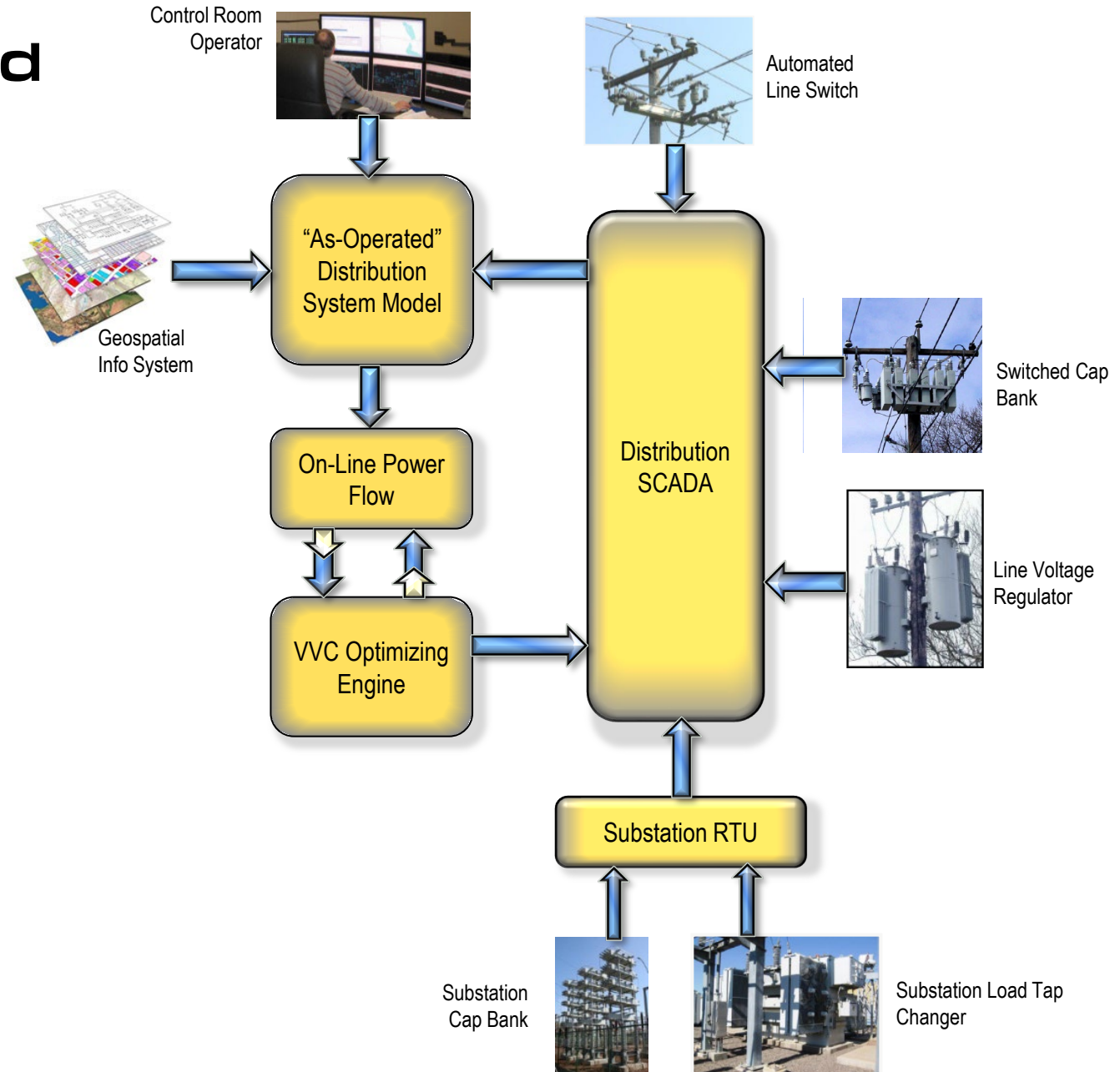
# Optimal Power Flow Based Volt-VAR Optimization - DMS model driven

- “As Operated” model Delivered to On-Line Power Flow



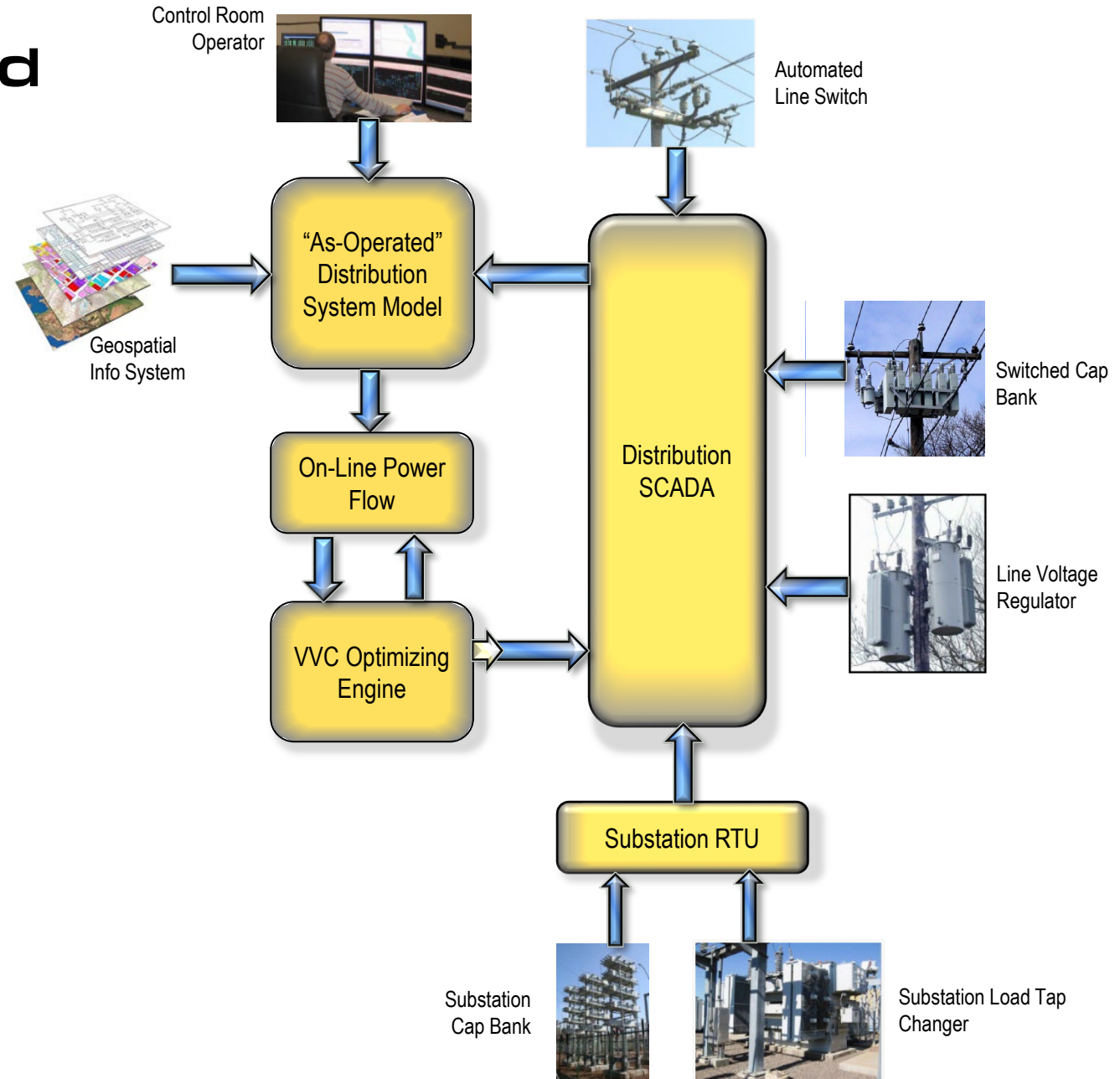
# Optimal Power Flow Based Volt-VAR Optimization - DMS model driven

- OLPF Iterates with VVC Optimizing Engine to Determine Optimal Switching Plan



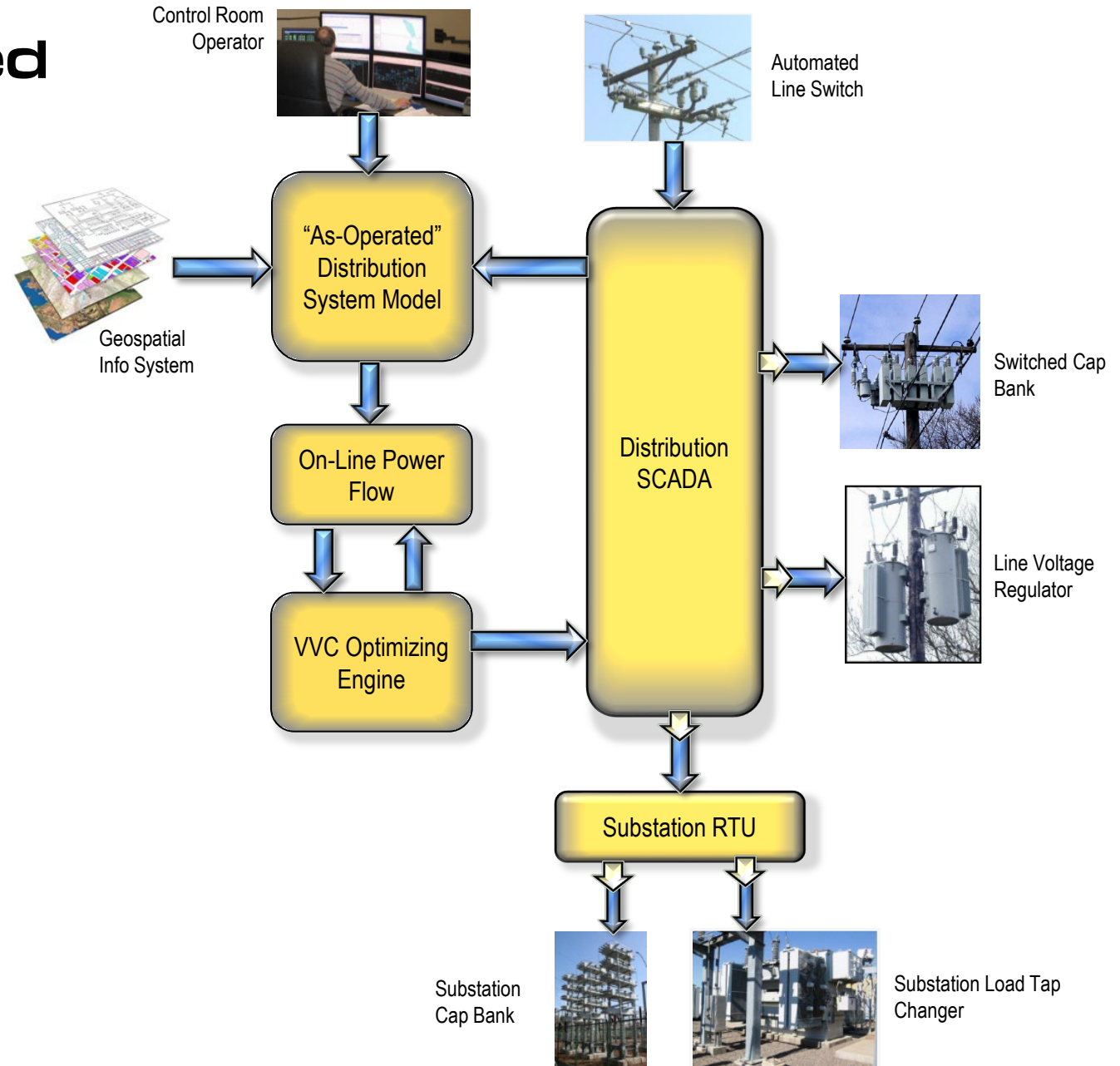
# Optimal Power Flow Based Volt-VAR Optimization - DMS model driven

- Optimal Switching Plan  
Delivered to DSCADA



# Optimal Power Flow Based Volt-VAR Optimization - DMS model driven

- Optimal Switching Plan Executed by DSCADA



# Optimal Power Flow Based Volt-VAR Optimization - DMS model driven

## Strengths

- Fully coordinated solution
- Variable operating objectives
  - Reduce demand
  - Reduce energy consumption
  - Reduce losses
  - Reactive power area support
  - Weighted combination of the above
- Adapts to feeder reconfiguration
- Handles high penetration of DER
  - Proper handling of reverse power flows
  - Utilizes DERs (smart inverters) for improved VVO performance (as allowed by IEEE 1547)

## Weaknesses

- Requires a full-blown power flow model
- Potentially high cost to implement, operate and sustain
- Learning curve for control room personnel
- Lack of field proven products

# Cost-Benefit Analysis of VVO

# Expanded objectives for Volt-VAR Optimization

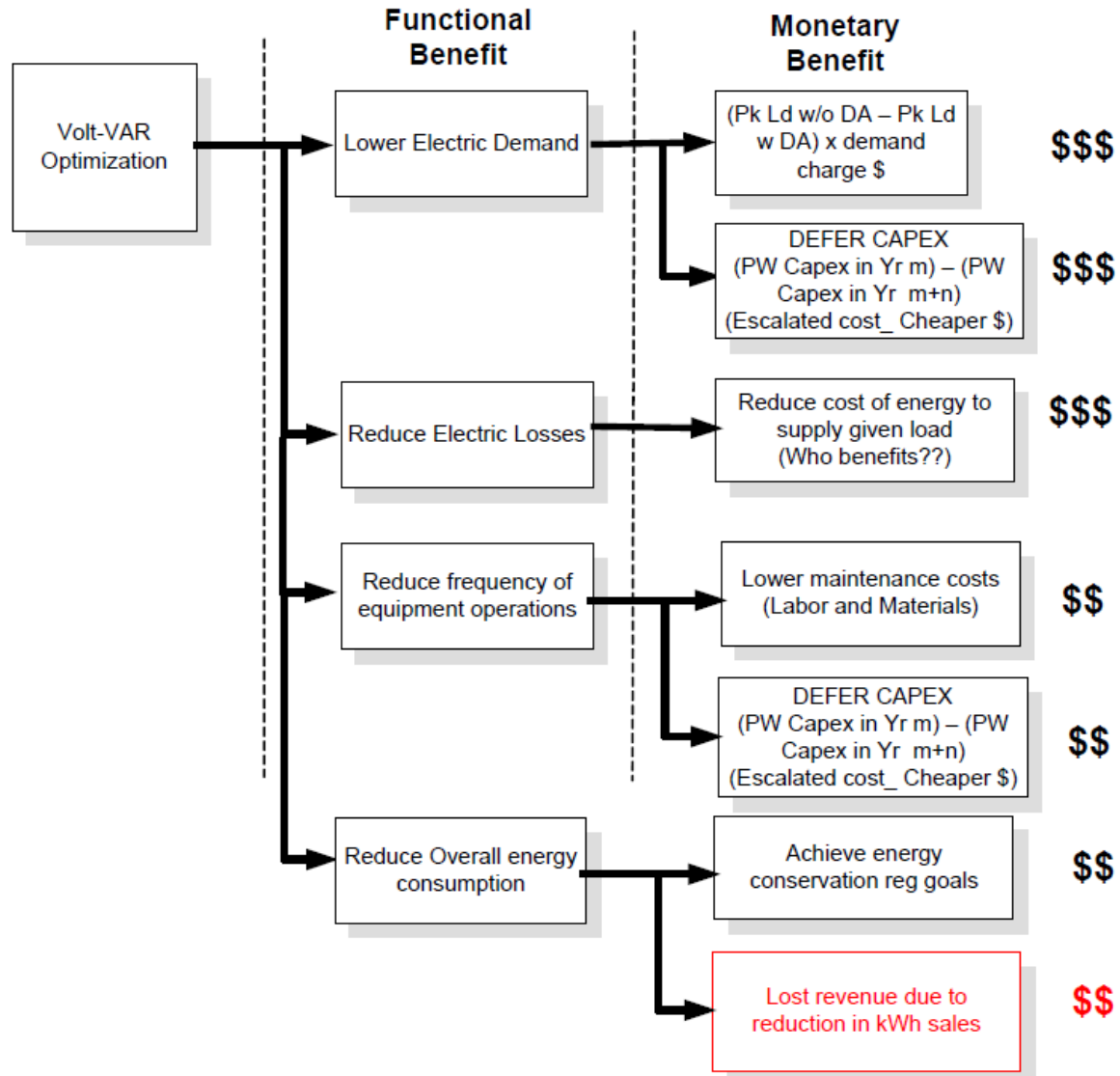


Basic requirement – maintain acceptable voltage

Support major “Smart Grid” objectives:

- **Reduce electrical demand** and/or **promote energy conservation** through voltage reduction
- **Improve efficiency** (reduce technical losses) through voltage optimization
- **Maintain voltage profile** following feeder reconfiguration (“self healing”)
- **Provide reactive power support** on feeders with high penetration of renewables

# Volt-VAR Optimization Benefit Tree



## Loss reduction due to Power Factor correction

$$\% \text{ Reduction in Electrical Losses} = 100 \times \left(1 - \frac{P f_i^2}{P f_f^2}\right)$$

Where:

$P f_i$  = initial average power factor prior to VVO deployment

$P f_f$  = final average power factor following VVO deployment

**Example:**

**$P f_i = 0.94$ ;  $P f_f = 0.98$ ; % loss reduction = 8.00%**

**If losses before VVO = 4% of total energy consumption, then**

**loss reduction after VVO = 0.32% of total energy consumption**

## Demand reduction due to Power Factor correction

$$\% \text{ Reduction in Electrical Demand} = 100 \times \left(1 - \frac{P_{f_i}}{P_{f_f}}\right)$$

Where:

$P_{f_i}$  = initial power factor at peak load prior to VVO deployment

$P_{f_f}$  = final power factor at peak load following VVO deployment

Example:

$P_{f_i} = 0.96$ ;  $P_{f_f} = 0.98$ ; % peak demand reduction = 2.04%

# Energy savings & Demand reduction due to Voltage Reduction

*Reduction of energy consumption =  $E_{tot} \times CVR_f \times \%V_{red}$*

Where:

$E_{tot}$  = total energy consumed = (peak demand x 8760 x load fact)

$CVR_f$  = conservation voltage reduction factor

$\%V_{red}$  = allowable voltage reduction on average

**Example:** Pk demand = 1000 MW; load factor = 0.6,  $CVR_f = 0.7$ ,  
allowable voltage reduction on average = 2.5%

Reduction of energy consumption = **91.98 GWh**

# Lost Revenue due to Demand Reduction

## Lost revenue associated with energy savings

- Ignore if revenue recovered via revenue decoupling or other rate mechanism
- Treat as negative benefit if not recovered via rates

## Impact on device operations

- May (or may not) increase number of voltage regulator (LTC) operations
- Increased operations in most cases – hence increased maintenance costs (a negative benefit)

# VVO Calculations: Estimated loss reduction savings

<b>MWH Loss Reduction</b>				
<b>ID</b>	<b>Description</b>	<b>Amount</b>	<b>Units</b>	<b>Remarks</b>
A	Distribution Losses at Peak Load	4.0%	%	Input
B	Average Distribution Power Factor	95%		Input
C	Target Power Factor	99%		Controlled variable
D	Peak Load on Distribution System	44.8	MW	# Feeders x peak load
E	MW loss reduction by improving distribution power factor to target value	0.142	MW	$D \times A \times (1 - B^2 / C^2)$
F	Load Factor	0.65		Input
G	Loss Factor	0.457		$.15 \times F + .85 * F^2$
H	Average loss reduction	0.0648	MW	$E \times G$
I	Total MWH Reduction	568	MWH	$H \times 8760$
J	Energy cost per kilowatt-hour	0.055	\$/kWh	Based on marginal energy source
K	<b>Benefit due to electrical loss reduction</b>	<b>31,214</b>	<b>\$/Yr</b>	<b><math>I \times J \times 1000</math></b>

# VVO Calculations: Savings due to Demand reduction

<b>Distribution Primary Capacity Released By Improving Power Factor At Peak Load</b>				
<b>ID</b>	<b>Description</b>	<b>Amount</b>	<b>Units</b>	<b>Remarks</b>
A	Peak load on dist feeder	44.80	MW	# Feeders x peak load
B	Dist Primary Power Factor at Peak	0.980		Input
C	Target Dist Primary Power Factor	0.990		Control variable
D	Capacity Released in Distribution Primary Due to Improved Power Factor	0.5	MW	$A \times (1/B - 1/C)$
E	Value of 1 megawatt peak load	\$ 80,000	\$/MW/Yr	Based on marginal power source
F	Savings	\$ 36,941	\$/Yr	D x E

<b>Distribution Primary Capacity Released By Voltage reduction</b>				
<b>ID</b>	<b>Description</b>	<b>Amount</b>	<b>Units</b>	<b>Remarks</b>
A	Peak load on feeders	44.80	MW	Input
B	CVR factor	0.70		Input
C	Allowable voltage reduction	2.50%		Input
D	Reduction of peak demand	0.78	Mw	$A \times B \times C$
E	Value of 1 megawatt peak load	\$ 80,000	\$/MW/Yr	Based on marginal power source
F	Demand reduction benefit	\$ 62,720	\$/Yr	D x E

# General Overview - Costs

Determine total cost of ownership (TCO) for each application

- Initial costs: Procurement, installation, commissioning
  - DA hardware, software, and services
  - Infrastructure improvements (switched cap banks, automated line switches, etc.)
- Lifecycle/Sustainment costs: O&M, midlife upgrades
  - Handle as annual % of initial costs

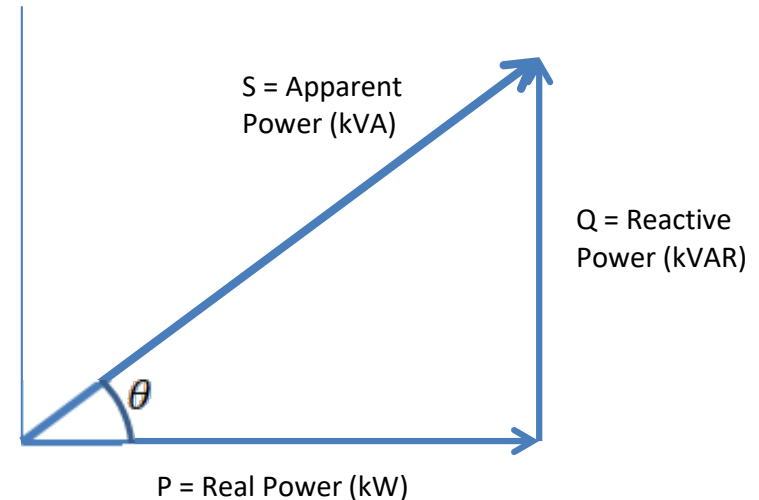
<b>Equipment Costs</b>	<b>Installed Cost</b>	<b>Units</b>	<b>Annual O&amp;M</b>
Cost of 600kVAR Switched Cap bank	\$ 12,000	\$/Sw Bank	2%
Substation processors for substation centered	\$ 300,000	\$/Substation	5%
Central master station for substation centered	\$ 1,500,000	\$/System	10%
Substation RTU for centralized approach	\$ 100,000	\$/Substation	5%
Central master station for centralized approach	\$ 3,000,000	\$/System	10%

# Calculating kVAR needed to raise Power Factor

$$PF = \cos \theta \quad \theta = \cos^{-1} PF$$

$$Q = P \times \tan \theta = P \times \tan (\cos^{-1} PF)$$

Reactive power needed to raise power factor from  $PF_1$  to  $PF_2$  is given by:



$$Q = Q_2 - Q_1 = P \times (\tan (\cos^{-1} PF_2) - \tan (\cos^{-1} PF_1))$$

KVAR Required to Raise Distribution Primary Power Factor To Target PF				
ID	Description	Amount	Units	Remarks
A	Peak load per feeder	5600		Input
B	Number of feeders	8		Input
C	Peak Load on Distribution System	44.80	MW	$A \times B / 1000$
D	Average Distribution Power Factor	0.950		Input
E	Target Power Factor	0.990		Control variable
F	MVAR required to raise PF to target	8.341	MVAR	$D \times \{\tan(\cos^{-1}(D)) - \tan(\cos^{-1}(E))\}$
G	Number of 600kVAR banks required	14		$F / 600$



# **Verification, Assessment and Monitoring Requirements for CVR**

# Evaluation, Measurement & Verification Requirements

- DA applications like VVO have the potential to provide significant benefits
- Need to identify the incremental benefit of DA
- Generally, not possible to directly measure the benefit

# The Challenge

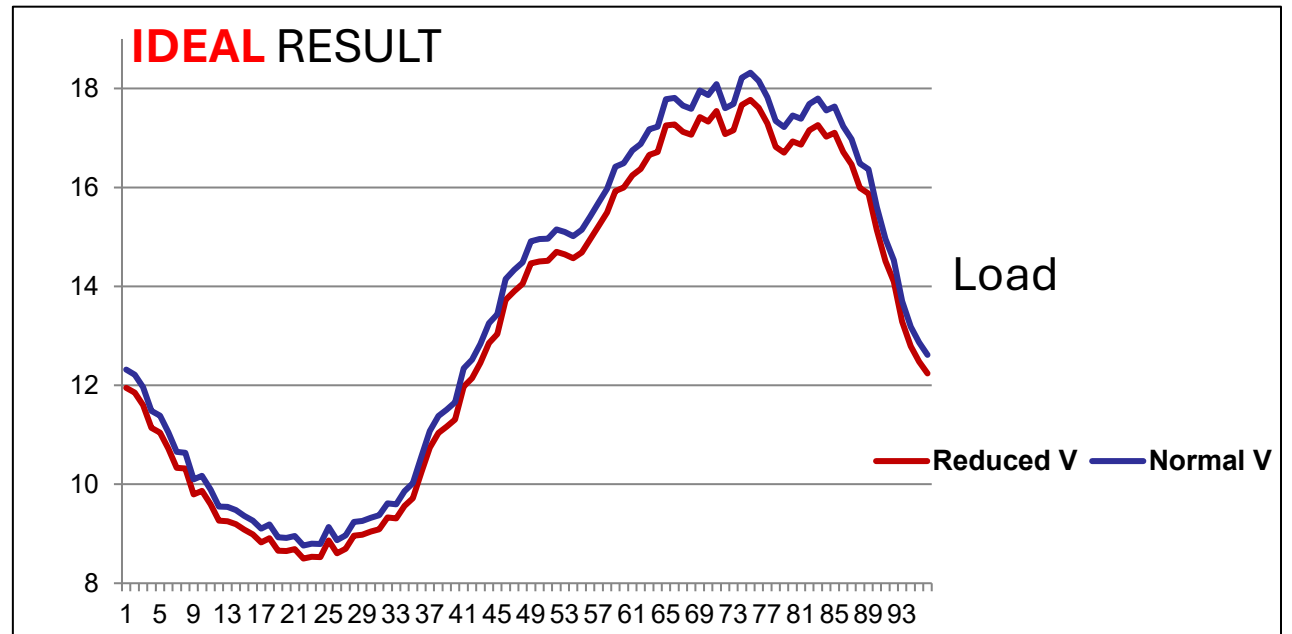
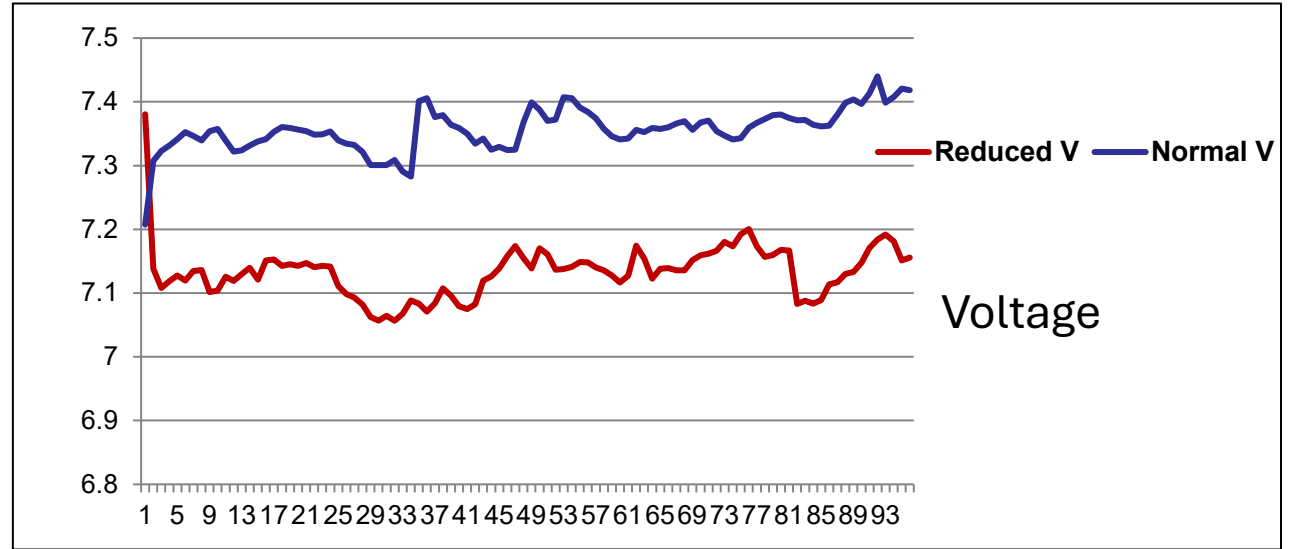
- Incremental benefit = **measured result** minus **result without VVO**
- **Big Question:** What would have happened without VVO?

# Measurement and Verification Problem for VVO

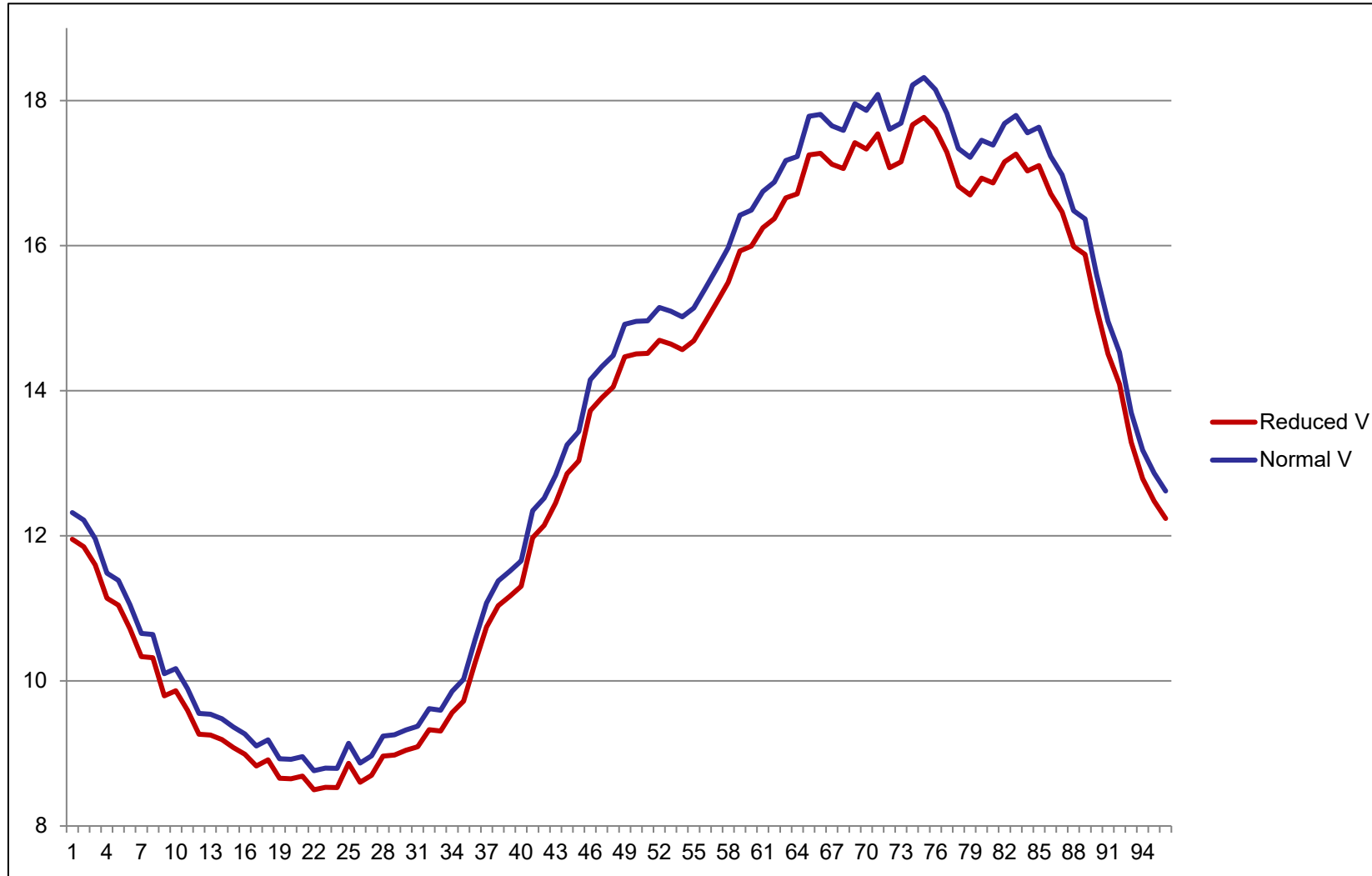
Day 1 – Normal Voltage

Day 2 – Reduced Voltage

Comparison of energy consumption on the two days



# Load versus Time-of-Day Ideal Result (Zoomed in)

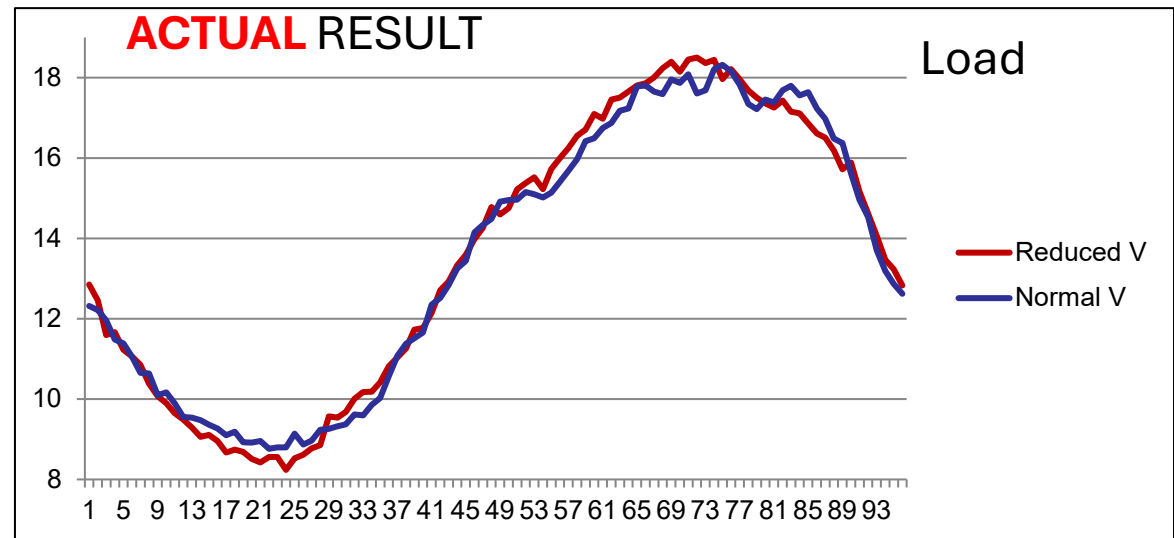
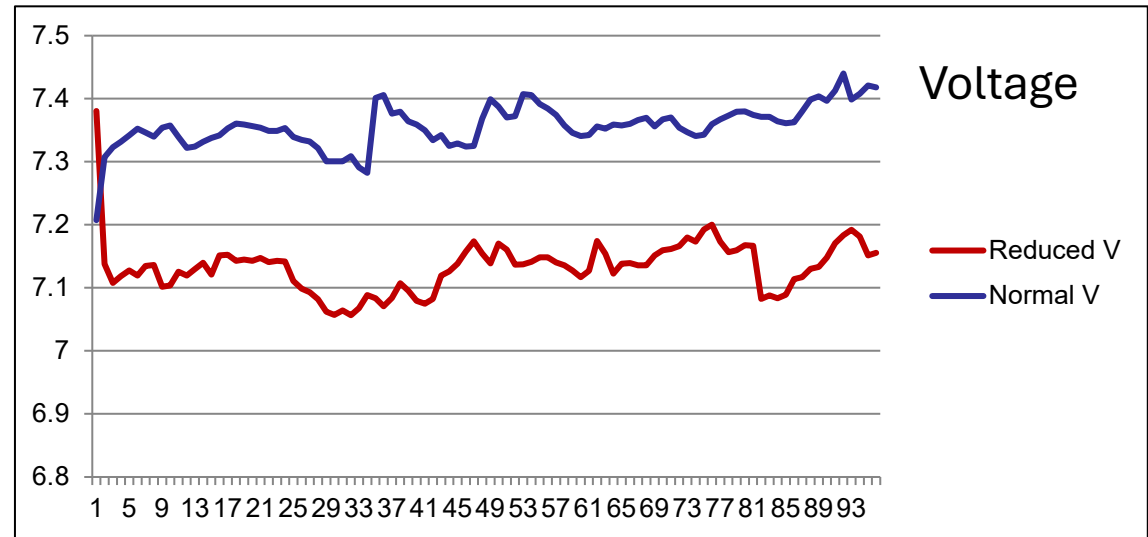


# The Nature of the M&V Problem for VVO

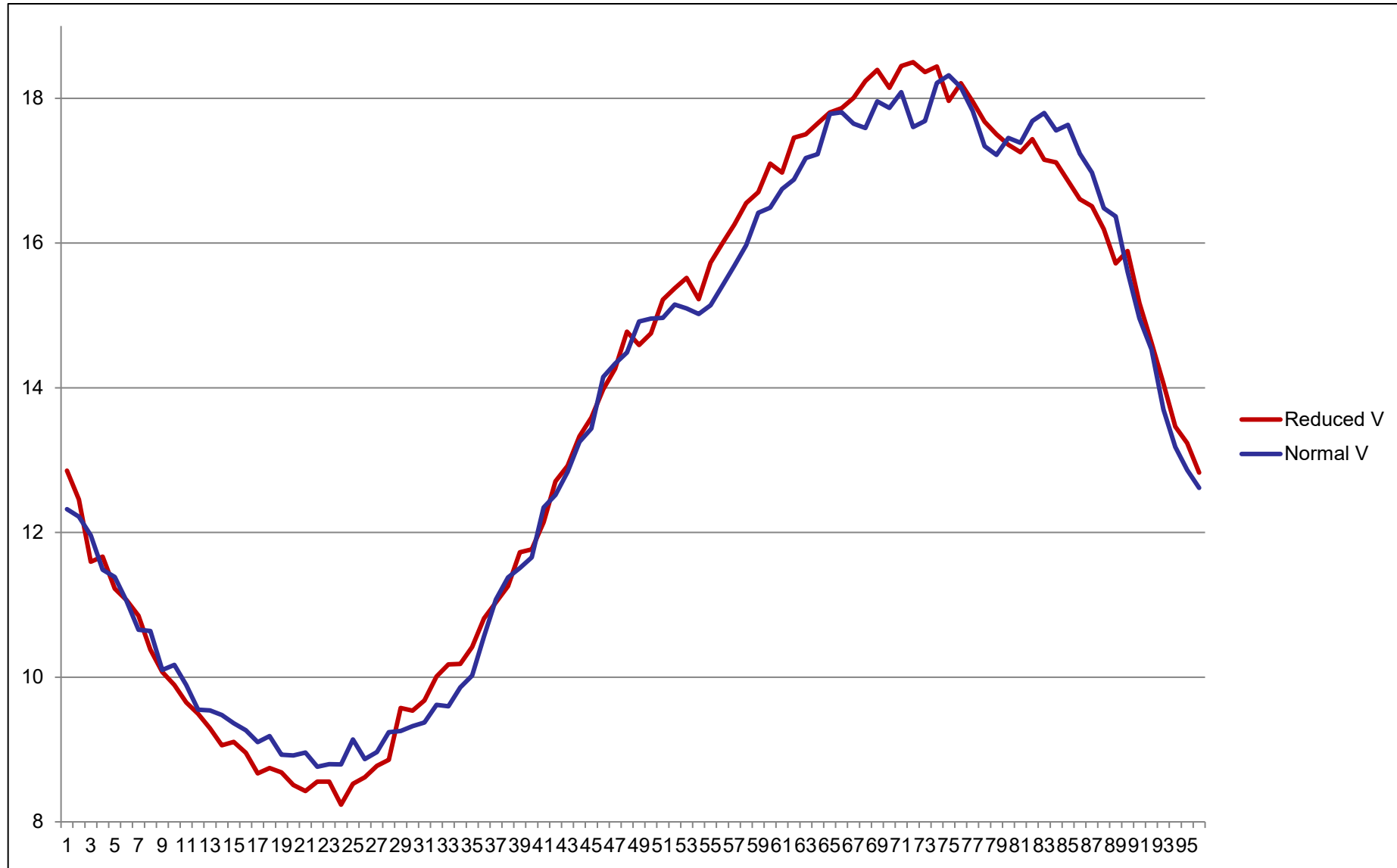
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# Load versus Time-of- Day Actual Measured Result



# The Nature of the M&V Problem for VVO

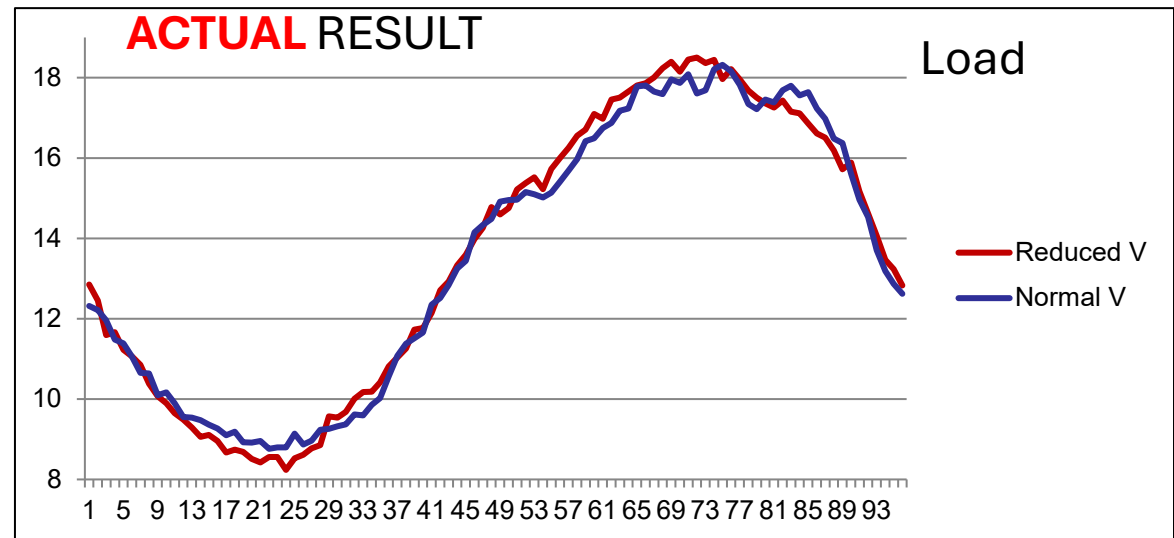
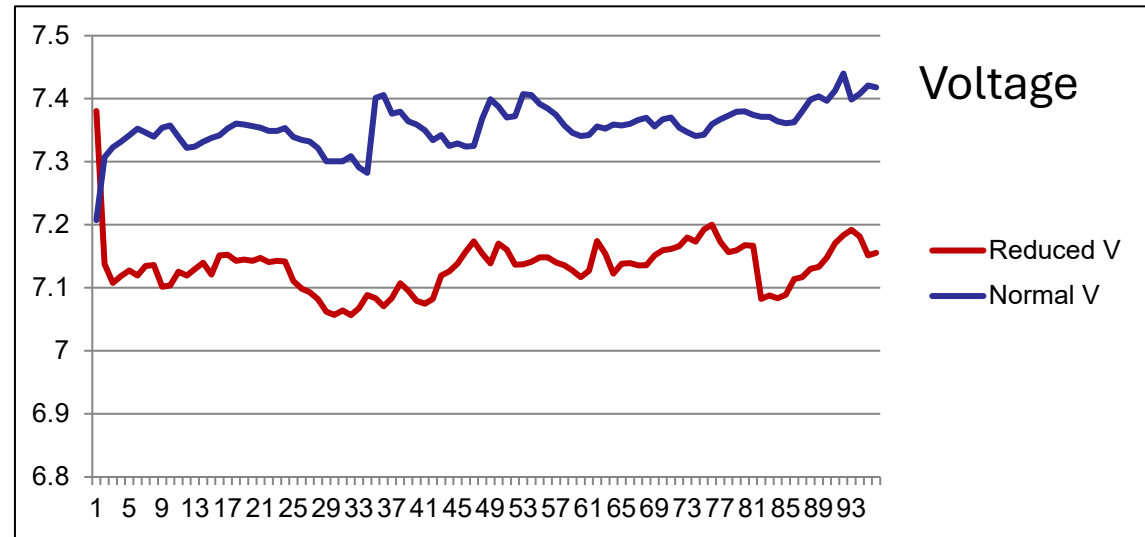
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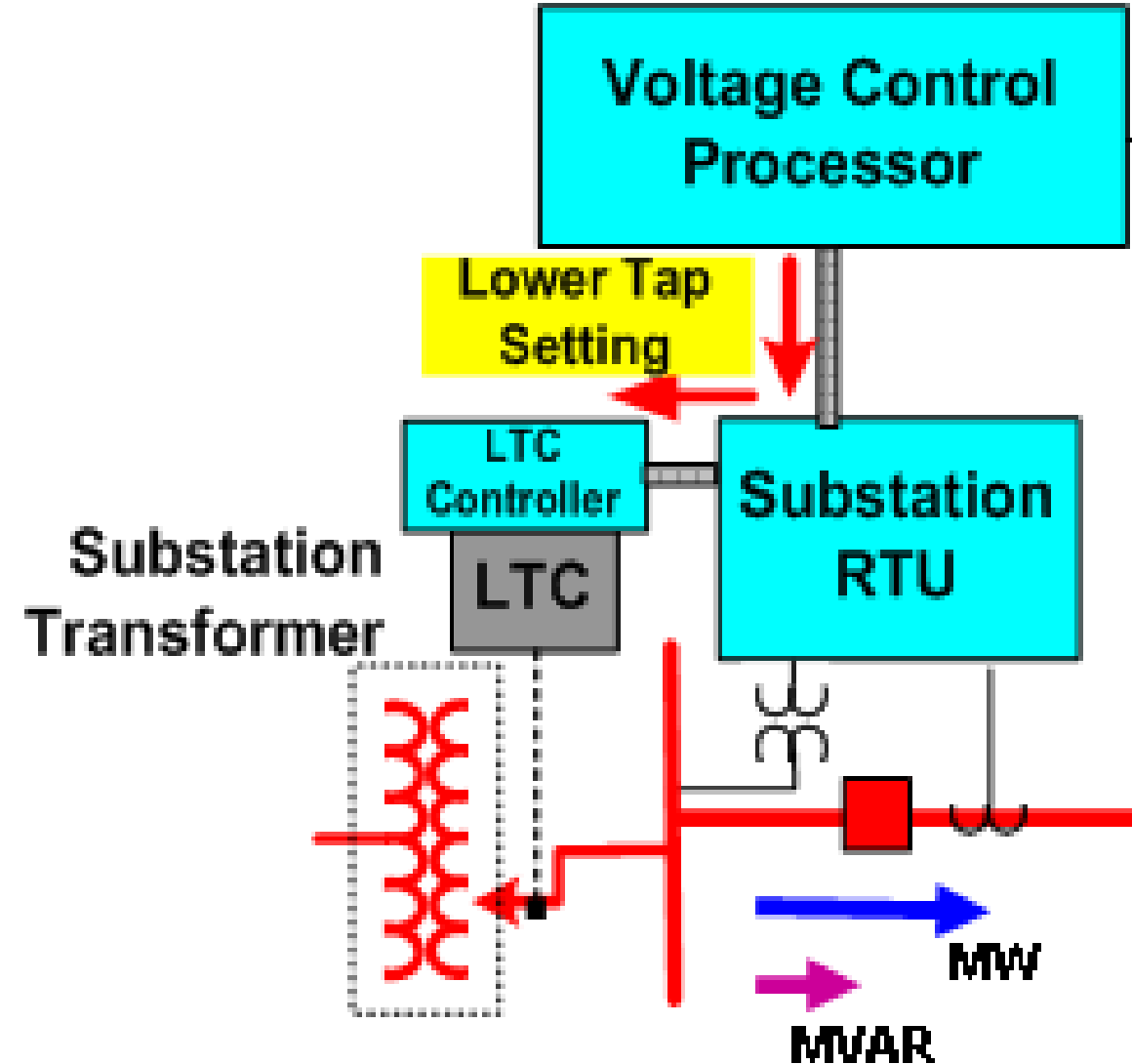
## Key Points

- Voltage not the only thing that's changing
- Other things that impact load:
  - Temperature/humidity
  - Random (stochastic) customer behavior
  - Feeder outages, load transfers
  - Weekday/weekend, holidays



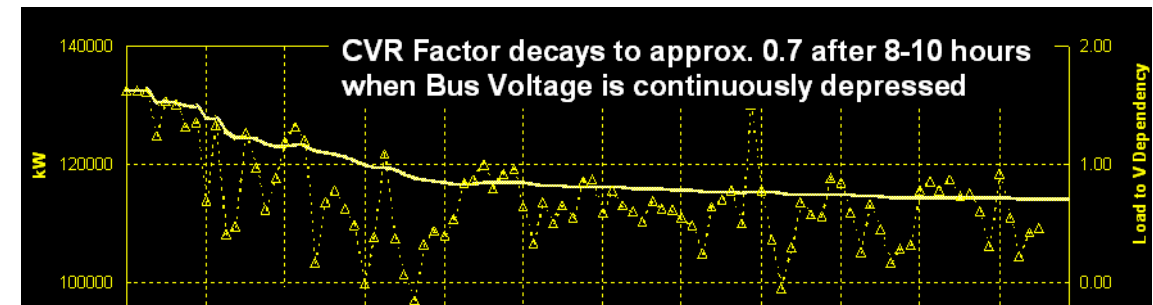
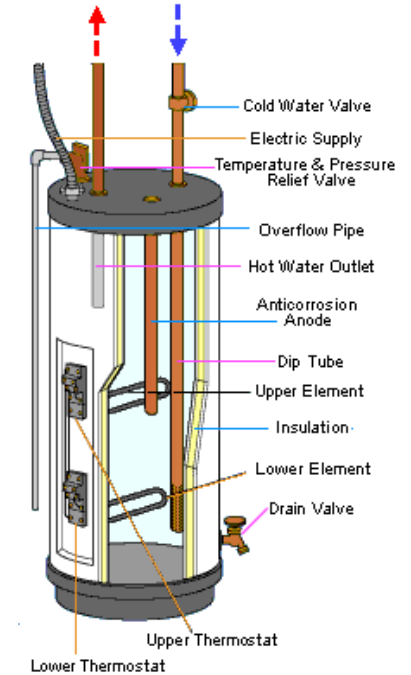
## VVO M&V – “flip the switch” approach

- Basic approach to determine CVR/VVO benefit
  - Lower tap setting by one position on LTC or Voltage regulator
  - Measure the change in load
- Problem with this approach
  - Initial response to voltage reduction is significant drop in load
  - Load reduction benefit usually drops off with time...



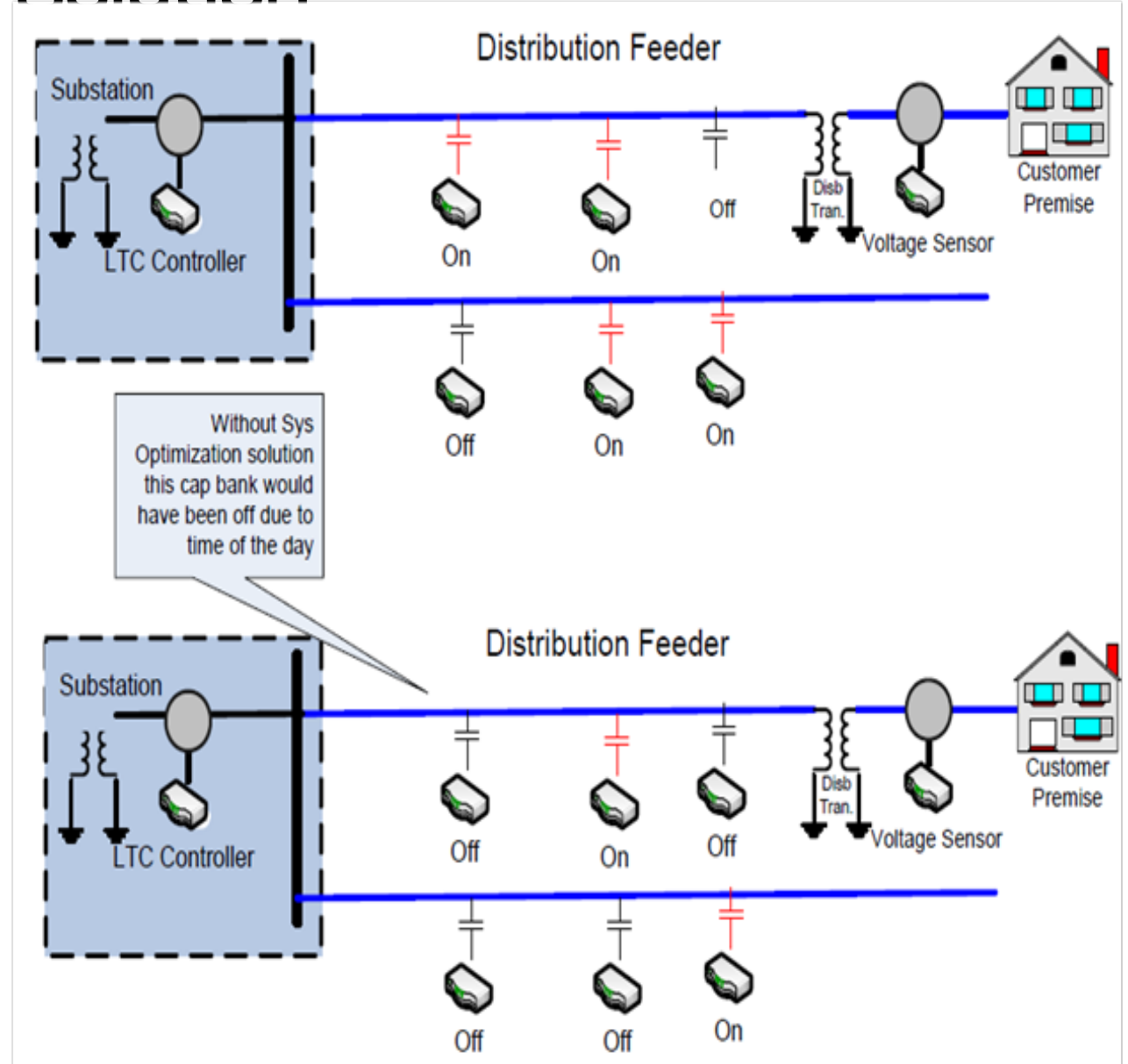
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- Problem with this approach
  - Initial response to voltage reduction is significant drop in load
  - Load reduction benefit usually drops off with time...
    - Devices that run off a thermostat just run longer
    - Loss of load diversity



# VVO M&V – Power Flow Solution

- Use Power flow to determine what “would have happened”
- Requires estimated load-to-voltage sensitivity factor



# Acknowledgements

- We would like to thank **Robert Uluski** of UISOL (presently with ESTA international) for contributing to some of the material in this presentation.