University of Washington's Smart Grid Deployment

*Matt O'Donnell*
*Dean, College of Engineering*

*John Chapman*
*Executive Director, Facilities Services*

## Academic & Administrative Partnership

- UW College of Engineering
- UW Facilities Services

Pacific Northwest SMART GRID DEMONSTRATION PROJECT

- US DOE Grant, ARRA Funding
- 50% Cost Share
- $10 Million UW Project ($178M Total)
- 5 year Duration

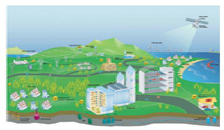
## Utility Participants

- University of Washington
- Avista (WSU)
- Benton County PUD
- City of Ellensburg
- Flathead Electric
- Idaho Falls Power
- Lower Valley Energy
- Milton-Freewater
- Northwestern Energy
- Peninsula Light
- Portland General

*Battelle Memorial Institute (at PNNL), Bonneville Power Administration*

## Smart Grid Project: Research Potential

- Parallel data capture
- Simulated demand response switching
- Efficiency testbed at microscale – dorms
- Testbed for faculty/student research projects



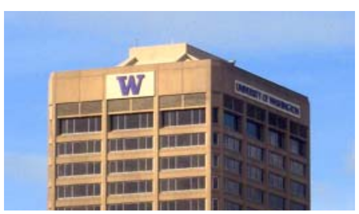
## UW Seattle Campus – Quick Facts

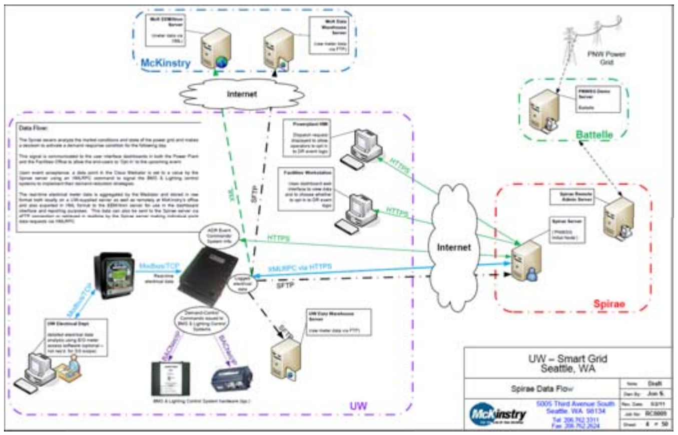
- Over 40,000 Students
- Over 29,000 Faculty and Staff
- Over 16 million GSF
- One Square Mile

## UNIVERSITY OF WASHINGTON SMART GRID PROJECT

**UW - A Laboratory for Smart Grid technologies**

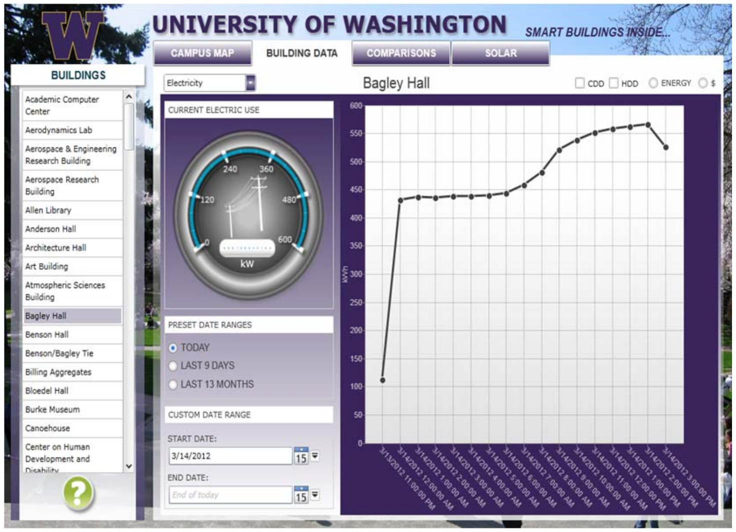
- **Seattle City Light's largest customer**
- **Diverse set of facilities: research, classroom, residential, medical, stadium**
- **Customer-owned electrical distribution system**
- **Students/researchers can use campus as a test-bed for research.**






# Facilities Energy Management System (FEMS)

- Enterprise Platform Interface and Information System
- Metering Data Warehouse
- Energy Dashboards / Energy Trend Analysis
- Activity Based Budgeting Initiative
- Identify Opportunities for Energy Savings

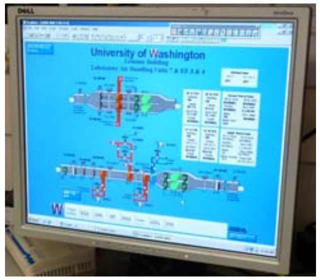



# Transactive Control Power Generation

- Two – 2000 kW Standby Generators
- 5000 kW Turbine Generator
- Incentive Demand Response Testing
- Renewable Energy Integration / Rate Design

## Building HVAC Controls (DDC)

- HVAC Controls – Transactive Control
- Low-Occupancy Set-back
- Cyber Security Issues
- Energy Savings Potential




## Solar PV Generation

## Solar PV Monitoring

## Student Housing Energy Conservation

- Floor by Floor measurement and display of energy use in new dorm
- Room by Room measurement, display and control in 240 rooms
- Behavioral response

## Laboratory, Classroom, and Office Buildings

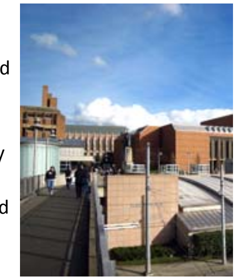
- Electrical Sub-metering within buildings (Computer Science/Electrical Engineering and new Business School)
- Floor-by-floor sub-meter
- Two individual laboratories to be sub-metered at branch circuit level
- Behavioral response

Veris Branch Circuit Monitor

## UNIVERSITY OF WASHINGTON SMART GRID PROJECT

**Anticipated Campus Benefits**

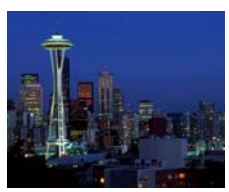
- Up to 5% reduction in electricity use based on building system optimization and awareness campaign.
- Potential to improve how energy costs are allocated to actual end users.
- Platform to test cyber-security issues.
- Provide information to students, faculty and facility operators on energy use in classrooms, dorms, etc.
- Jump start hands-on learning with actual real-world smart grid application and real user data.
- Provide smart grid infrastructure for follow-on research.



## PROJECT BENEFITS BEYOND CAMPUS

**Local and Regional Benefits**

- Test utility-level demand-response strategies, inform electricity rate design.
- Renewable generation integration.
- Findings transferrable to other institutions and businesses.
- One step forward towards developing and deploying a local, regional and national smart grid system.
- Regional reliability improvements



## What will the future bring?

Environment and Communications 50 years ago

## Paradigm Shift

Environment and
Communications today

## Questions?

Matt O'Donnell
odonnel@uw.edu

John Chapman
jchapman@uw.edu

WASHINGTON STATE UNIVERSITY
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# Smart Pullman & WSU Microgrid as part of the PNW Smart Grid Demonstration


**Anjan Bose**
**School of EECS**
**Washington State University**
**Pullman, WA 99163**


**IEEE Northwest Energy Systems Symposium**
**Seattle, WA**
**March 2012**

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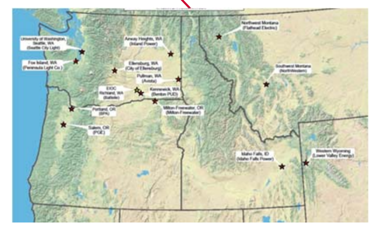
## NW Smart Grid Demonstration Project

Battelle NW

Bonneville Power Administration

3Tier
Areva
IBM
Netezza
Quality Logic



Utility Partners
Avista
Benton PUD
City of Ellensburg
Flathead Electric
Idaho Falls Power
Inland Power & Light
Lower Valley Energy
Milton-Freewater
Northwestern Energy
Peninsula Light
PGE
Seattle City Light

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## Smart Grid Demonstration Project


Itron
SEL
WASHINGTON STATE UNIVERSITY
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hp
Spirae

AVISTA

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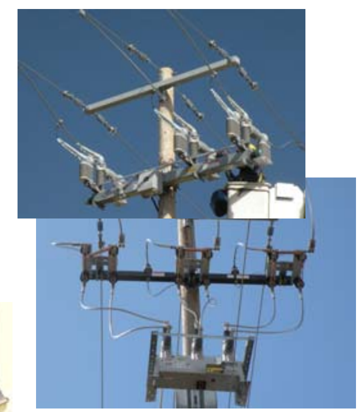
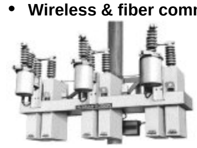
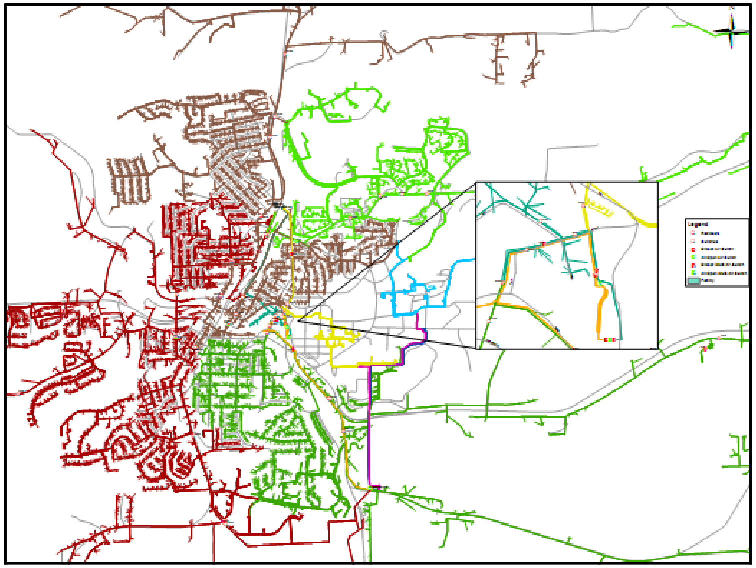
## DMS – Distribution Management System

- **Distributed to centralized control**
- **3 substations**
  - **Regulator controls**
  - **Reclosers/relays**
- **13 feeders**
  - **45 automated line switches & reclosers**
  - **20 switched and fixed capacitor**
  - **Fault Indicators**
  - **Low loss transformers w/ telemetry**
- **Wireless & fiber communications**

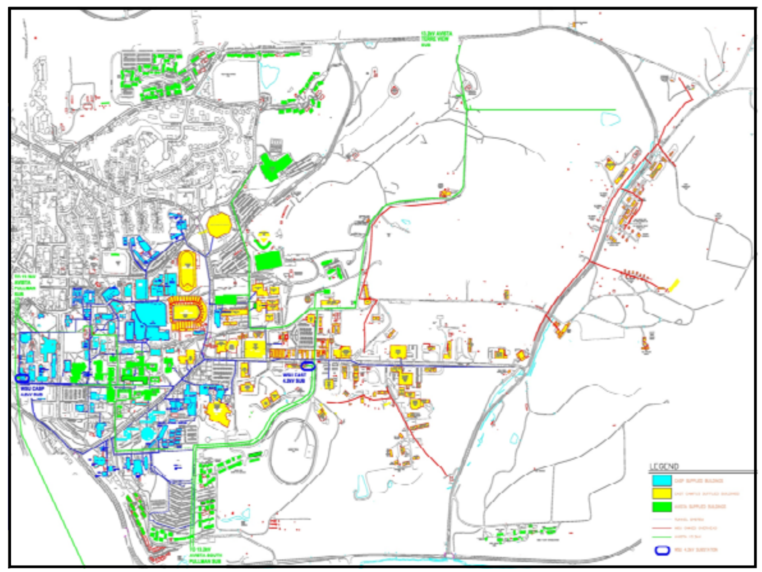






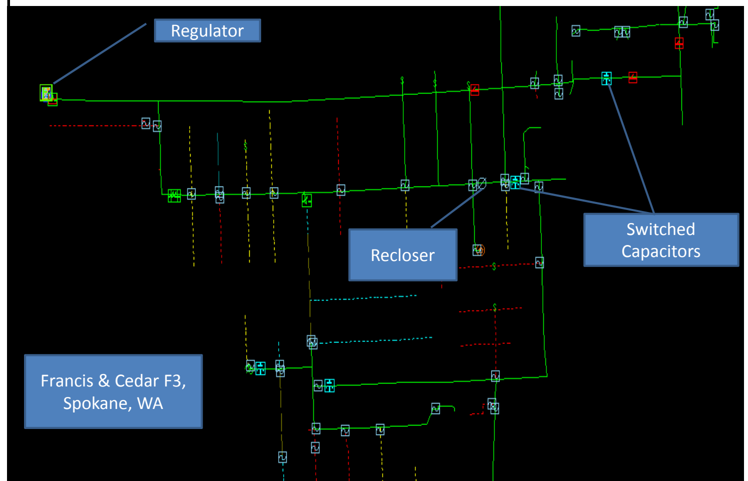
Washington State University

- **WSU Smart Home Research**
- **WSU Analysis & Reporting**



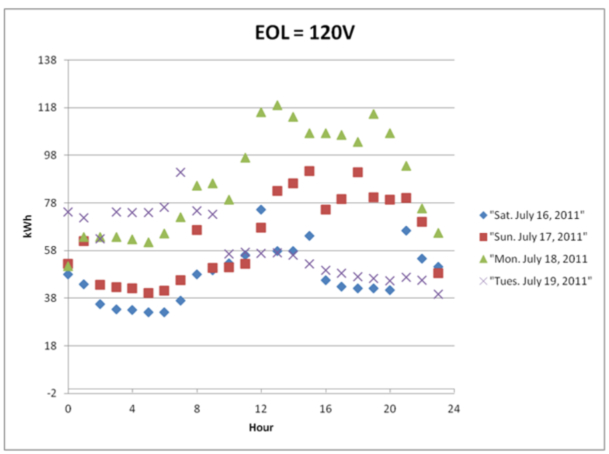
Washington State University

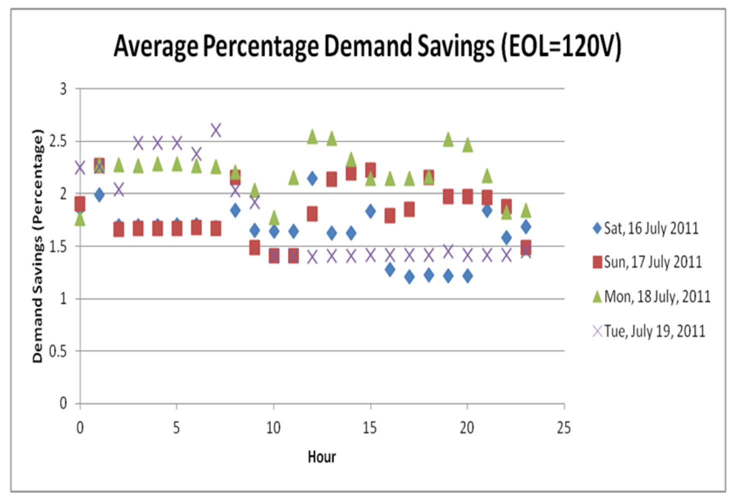
- Grimes Way Generator 1,2 & 3 Dispatch
- Loop Chillers Load Shed
- HVAC Load Shed/EMS/CVR (McKinstry)
- Biotechnology Life-Science Generator Dispatch
- Global Animal Health Backup Power
- College Avenue Steam Plant Automation



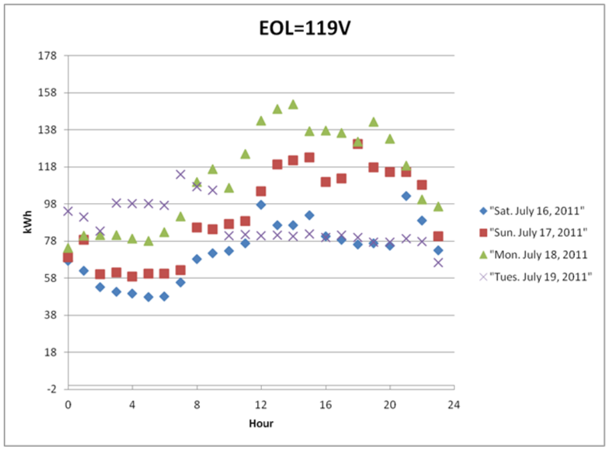

10

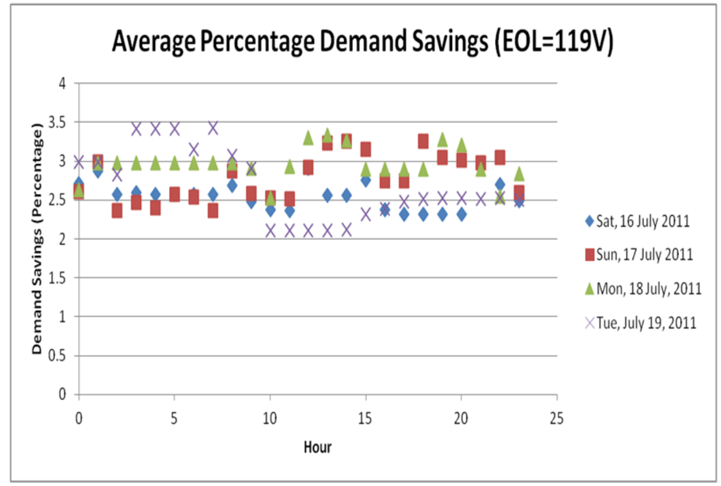
## Feeder F3 with 38.3R, 39.8C, 21.9I



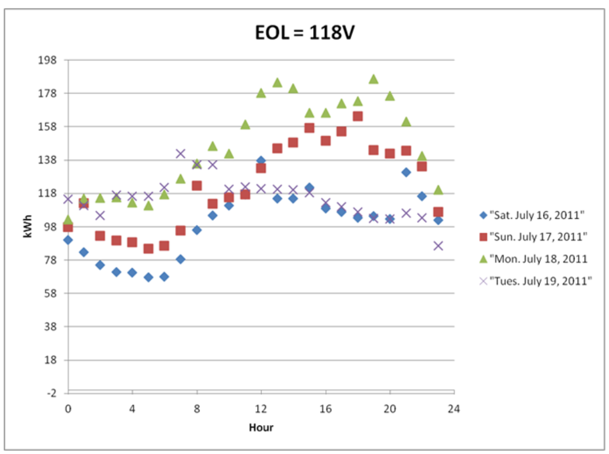



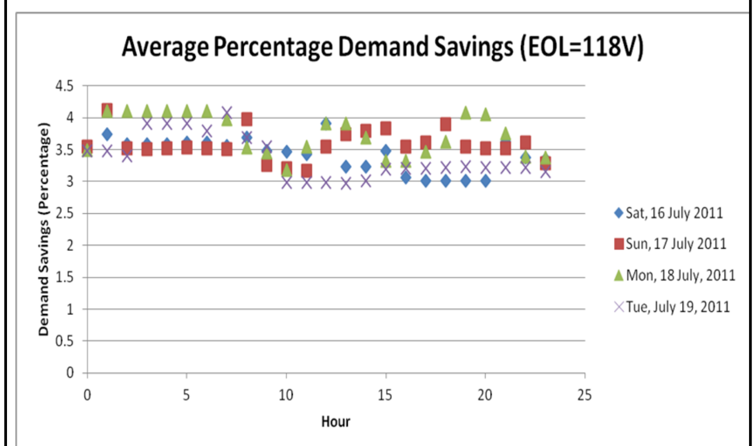
# Feeder F3 with 38.3R, 39.8C, 21.9I



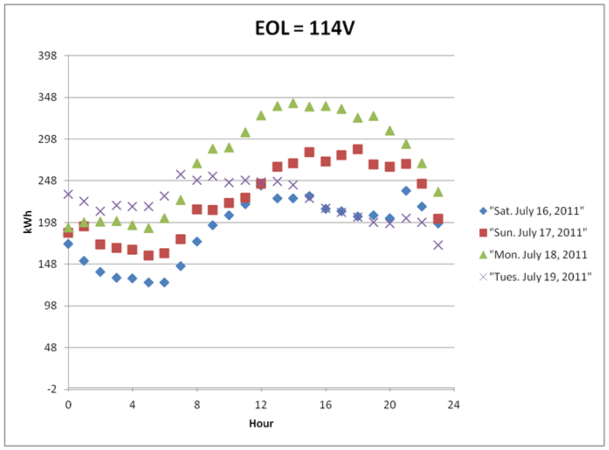



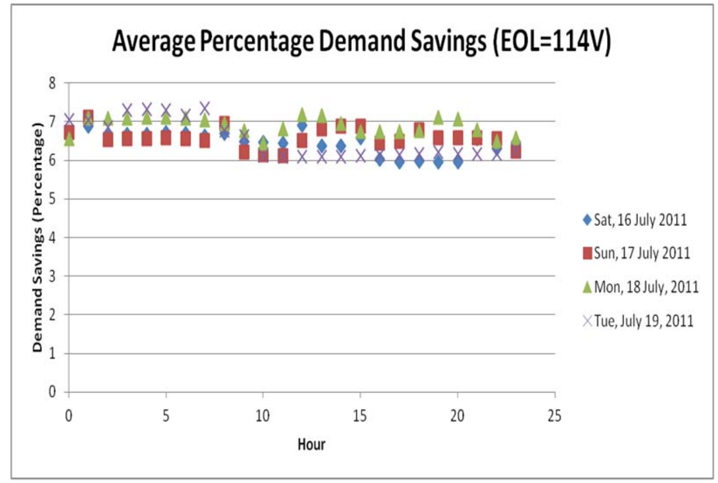

# Feeder F3 with 38.3R, 39.8C, 21.9I

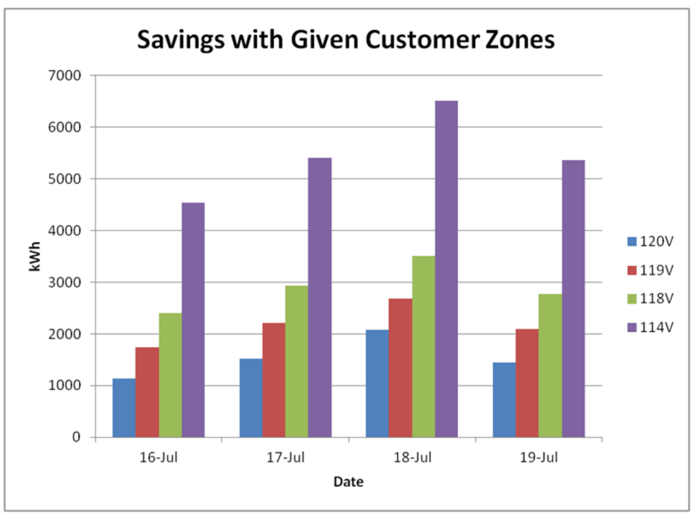


## Feeder F3 with 38.3R, 39.8C, 21.9I

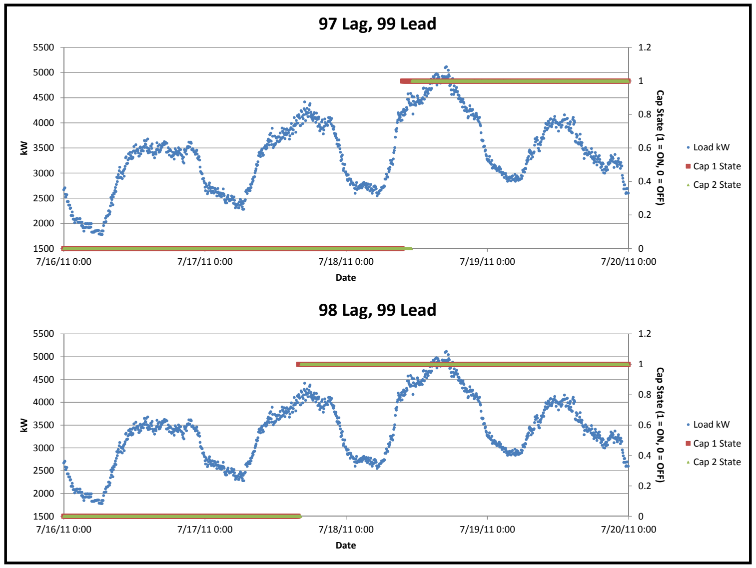


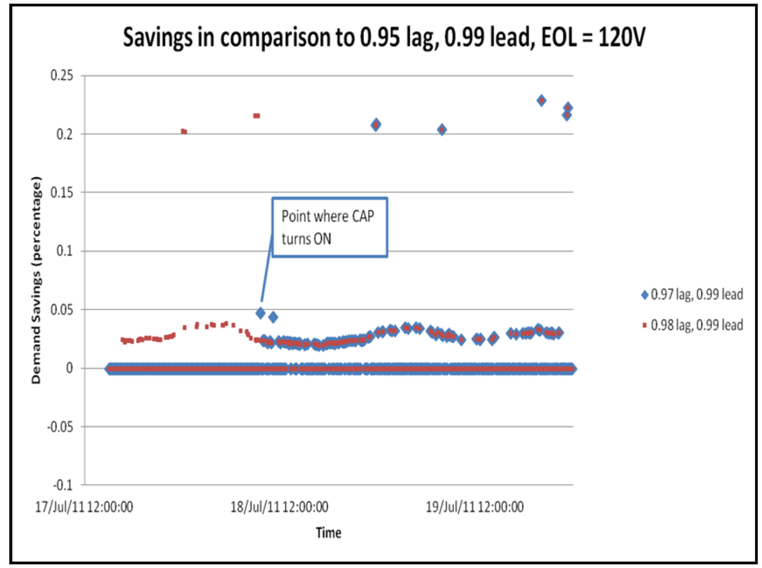




## Average Percentage Demand Savings for July 16, 17, 18, 19

| | EOL = 120 V | EOL = 119 V | EOL = 118 V | EOL=114V |
|---|---|---|---|---|
| **F3** (38.3R, 39.8C, 21.9I) | 1.86% | 2.64% | 3.53% | 6.61% |
| **F6** (56.9R, 43.1C, 0I) | 1.60% | 2.39% | 3.14% | 5.85% |




## 18th July 15:15 ( peak savings with load = 1650kW)

| EOL (V) | Tap Setting (for all phases) | Demand(kW) (manual) – with both caps ON | Our results (kW) (simulation) - no caps ON | Diff (kW) (manual – simulation) |
|---|---|---|---|---|
| 120 | -3 | 4834 | 4843 | 9 |
| 119 | -4 | 4805 | 4814 | 9 |
| 118 | -5 | 4776 | 4785 | 9 |

## 18th July, 00:30 ( lowest savings with load = 973 kW)

| EOL (V) | Tap Setting | Demand(kW) (manual) ) – with both caps ON | Our results (kW) (simulation) - no caps ON | Diff (kW) (manual – simulation) |
|---|---|---|---|---|
| 120 | -4 | 2895 | 2884 | -11 |
| 119 | -5 | 2877 | 2861 | -16 |
| 118 | -6 | 2860 | 2837 | -23 |

## Preliminary Conclusions

- CVR may save about 3% of energy
- IVVC may not save significant energy
- Automatic and remote switching sectionalizers will improve reliability

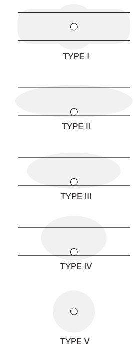
- Load control by WSU can provide efficiency on campus (other customers)
- Load control by Avista can provide emergency assist
- Generation control by Avista can provide emergency assist

# Apple and Oranges
## *Comparing LED and HID Roadway Lights*

- *Gordon Hayslip P.E.*



## HID "Cobra Head" Luminaires




- Primarily high pressure sodium (HPS),
- Available in fixed wattages, i.e. 100W, 250W, 400W.
- Available in fixed lighting patterns, e.g. Type II, Type III, Type V
- Available from established manufacturers like GE, AEL, Cooper Lighting, etc.
- HID lighting is a mature technology.
- HPS street lights are a commodity item.
- 3-4 min. start up, 1-3 min. restrike.
- HPS lamps contain mercury. Must be disposed of as hazardous waste.



## HID "Cobra Head" Luminaires

- Conforms to ANSI C136.14-2004, *American National Standard for Roadway and Area Lighting Equipment — Elliptically Shaped, Enclosed Side-Mounted Luminaires for Horizontal-burning High-intensity Discharge Lamps.*
- Within a particular lamp wattage and lighting pattern, luminaires built to C136.14 will be interchangeable.
- ANSI C136.17 covers interchangeability of refractors.
- ANSI C136.10 covers interchangeability of photocontrols.



## LED Roadway Luminaires

- New to the market, < 5 years.
- Promise higher efficacy and lower maintenance than HPS.
- There is no fixed wattage designation; wattage depends on #LED's and drive current.
- As newer, more efficient LED chips are introduced, the luminaire manufacturers are re-designing their fixtures.
- Offer very precise control over lighting patterns.
- Too many manufacturers to count.
- New ANSI standard C136.37-2011 — *Solid State Light Sources Used in Roadway and Area Lighting*

## Photometric Testing

SSL (Solid State Luminaires) tested per IESNA LM-79-08

- Total Luminous Flux (lumens)
- Luminous Efficacy (lm/W)
- Chromaticity, Correlated Color Temperature (CCT), Color Rendering Index (CRI)
- Luminous Flux Distribution
- Isofootcandle Curves
- BUG Rating
- Output from LM-79 test includes test report and .ies file.
- Absolute Photometry
  - LED chips and fixture tested as a unit
  - Referenced to a calibrated standard lamp

Relative Photometry

- HID fixtures are tested using “relative” photometry (fixture is measure, then lamp and ballast are removed and measured).

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## HPS vs. LED Efficacy

- Luminous Efficacy — measure of light output/input power (lm/W)
- Source Efficacy — efficacy of bare lamp at room temperature
- HPS Source Efficacy ~ 120 lm/W
- LED Source Efficacy ~ 130 lm/W
- 100W HPS Source Efficacy = 9500 lm/133 W = 71 lm/W
- 100W HPS Fixture Efficacy = 71 lm/W x 74% fixture eff. = 53 lm/W
- 66W LED Fixture Efficacy = 5037 lm /66 W = 76 lm/W
- HPS DSS[1] ~ 43%, DHS[2] ~ 31%, Light Loss ~ 26%
- LED DSS[1] % ~ 67%, DHS[2] ~ 33%, Light Loss ~ 0%
- HPS DOE FTE[3] ~ 35 lm/W
- LED DOE FTE[3] ~ 50 lm/W

[1] Downward Street Side (DSS)
[2] Downward House Side (DHS)
[3] Fitted Target Efficacy (FTE) — See http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/fte_performance_metric.pdf

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## LED Efficacy

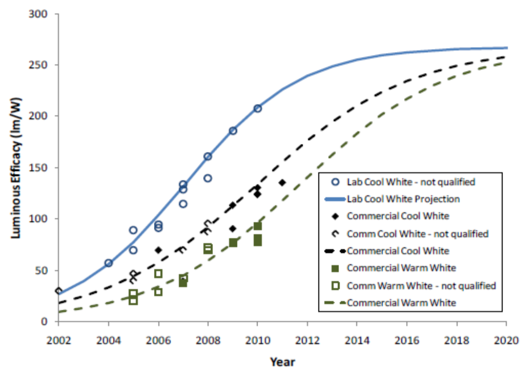


Figure 5.4: White Light LED Package Efficacy Targets[65], Laboratory and Commercial

Notes:

1. Cool White: CRI 70-80; CCT 4746-7040 K
2. Warm White: CRI 80-90; CCT 2580-3710 K
3. Current density: 35A/cm$^2$
4. These results are at 25°C package temperature, not steady state operating temperature. Thermal sensitivity will reduce efficacies by 24% or so in normal operation, depending on luminaire thermal management.

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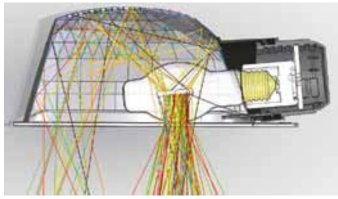
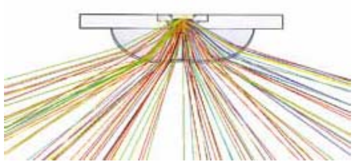
## HPS vs. LED Optics



An HID lamp is a single large point source that relies on the reflector/refractor assembly to direct the light in the required pattern. A large portion of the lamp’s light output is lost or uncontrolled.



With LEDs the light is already traveling down and the small point source allows for precise optical control with very little waste.

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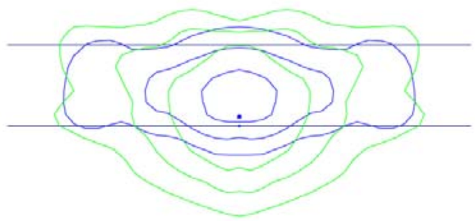
## HPS vs. LED Optics



**Isofootcandle horizontal illuminance graph**

- **150W GE Cobrahead**
- **60 LED 72W Luminaire**

***35' wide roadway with fixtures at 30' mounting height on a 4' arm***

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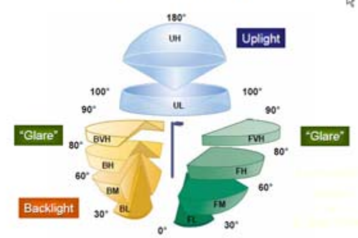
## Dealing with Light Trespass

The LCS System




**Luminaire Classification System (LCS) — IES Standard TM-15-11**

- **Backlight, Uplight & Glare (BUG) Rating System**
- **Replaces obsolete IESNA cutoff classification system**
- **HID light trespass is usually controlled with shields and/or partially obscured refractors**

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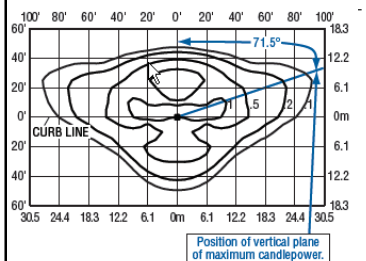
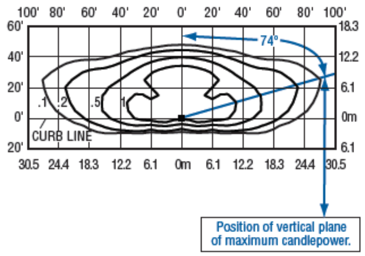
## Dealing with Light Trespass

- **Accuracy of LED photometrics allows more control over BUG rating and light trespass.**
- **May require stocking multiple lights of the same nominal wattage with different patterns.**




**LED Type II Light**




**LED Type II Light w/Backlight Control**

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## Color

**HPS**

- **CCT ~ 2,100°K**
- **CRI ~ 22**
- **S/P[1] ~ 0.6**

**LED**

- **CCT ~ 4,500°K**
- **CRI ~ 75**
- **S/P[1] ~ 1.5-2.0**

[1]Scotopic/Photopic Ratio – See http://www.ecofitlighting.com/files/Photopic%20vs%20Scotopic%20technical%20paper.pdf

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## LED Reliability

HPS

- Rated lamp life ~ 24,000 hours — 40,000 hours (5.5 — 9.1 years)
- Failure mode — lamp cycles on and off

LED

- Claimed lamp life of 50,000 – 100,000+ hours (11.4 — 22.8+ years)
- Failure mode — LED's slowly darken with age
- End of life when light reaches 70% of initial output ($L_{70}$)
- Heat management is critical to ensuring long life

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## LED Reliability

### Standards

- IESNA LM-80-08 — *ESNA Approved Method for Measuring Lumen Maintenance of LED Light Sources*
  - Test procedure for LED chip, not fixture
  - Provided by chip manufacturer
  - 6,000 hour minimum test at various temperatures and drive currents
- IESNA TM-21 — *IESNA Lumen Method Extrapolation*
  - Methodology to extrapolate LM-80 data beyond 6,000 hours
  - Still focuses on LED chip, module or array, not the entire luminaire
  - The luminaires' driver, optics, thermal management or housing design may limit actual service life

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## Luminaire Reliability

Other Potential Sources of Failure

- Surges
- Mechanical Vibration
- Corrosion
- UV
- Ingress Protection
  - IP 65 for fixture
  - IP 54 for electrical components
- Vandalism
- Driver Failure

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## HID Electrical Components

### HID Ballast & Starter

- **Tapped Input Voltage 120V – 277VAC**
- **~ 55V secondary voltage w/new lamp**
- **~ 84V secondary voltage @ end of life**
- **Starter supplies 2500-4000V needed to strike the gas arc. Once arc is struck, starter turns off.**
- **~ 80% efficiency**
- **0.90 power factor**

Wiring Diagram:

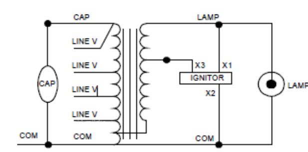


Fig. K

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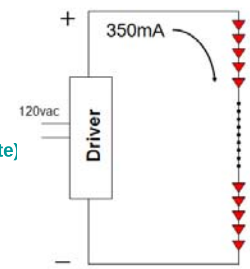
## LED Electrical Components

### LED Driver

- 120V – 277VAC Input Voltage
- Constant Current Output, Fixed or Multiple
- 350mA, 525mA & 700mA
- Secondary voltage "floats"
- ~ 90% efficiency
- 0.99 power factor
- 20% Max. THD
  - ANSI & Energy Star require PF >0.9 & THD < 32%
- > 50,000 hour service life T <= 75°C (5% failure rate)
- > 100,000 hour service life T<= 65°C

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## Things You Can't Do With HID

- Dimmable Drivers (1-10VDC Control)
- Programmable Drivers
  - Constant Light Output
  - Built-in Photocontrol
  - Temperature Monitoring
  - Motion Sensing
- Communicating Drivers (IEEE 802.15.4, ZigBee)
  - Adjust illuminance based on conditions (road work, weather, 911, etc.)
  - Notifications of failures
  - Reporting of power usage, temperature
  - Predictive maintenance

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## References & Resources

### Reference Standards

- ANSI/IES RP-8-00 — *Roadway Lighting*
- ANSI C136.37-2011 — *Solid State Light Sources Used in Roadway and Area Lighting*
- IESNA LM-79-08 — *Electrical and Photometric Measurements of Solid-State Lighting Products*
- IESNA LM-80-08 — *ESNA Approved Method for Measuring Lumen Maintenance of LED Light Sources*
- IESNA TM-21 — *IESNA Lumen Method Extrapolation*
- IES Standard TM-15-11 — *Luminaire Classification System (LCS)*
- NEMA SSL 1-2010 — *Electronic Drivers for LED Devices, Arrays or Systems*

### Resources

- Department of Energy Solid-State Lighting Website
  http://www1.eere.energy.gov/buildings/ssl/
- DOE Municipal Solid-State Street Lighting Consortium
  http://www1.eere.energy.gov/buildings/ssl/consortium.html
  - Model Specification for LED Roadway Lighting

Page 19 March 19, 2012

# Questions??

Page 20 March 19, 2012

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# Seattle City Light

# LED Streetlight Program Case Study

**March 22, 2012**

**Vicki Marsten**
Streetlight Engineering
Supervisor

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## Program Goals

- Reduce energy use by 40% - Actual 48%+!
- Lower maintenance costs (only lens cleaning during fixture life, no relamping, longer life photoelectric cell)
- Improve Customer Service (increased reliability of the fixture, fewer outages)

2

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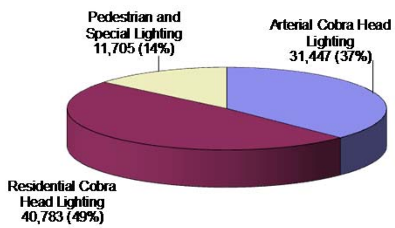
## SCL Street Lighting System Background Types by Use 84,000 Total Fixtures

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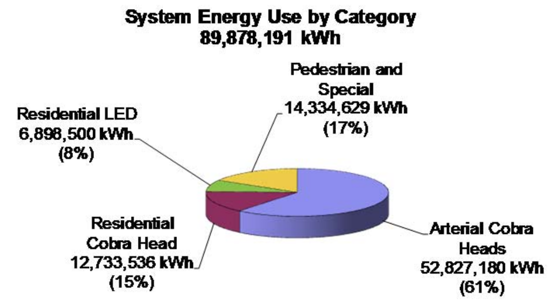
## Current SL System Energy Use by Category

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## The Plan

- **Stage 1 -** Replace 41,000 Streetlights on existing poles in Residential areas beginning in 2010
- **Projected Cost**: $24 million ($18 million, actual)
- **Acquire Funding:**
  - Utility funding | Customer billed
  - $1 million ARRA EECBG Grant

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## COMPLETED

Phase 1 - 2010 Replaced 6k of the 41,000 Residential Streetlights w/in LED – Zone 3

Phase 2 - 2011 Replace Additional 12k Residential Streetlights w/in LED – Zone 4

(18,000 Total by end of year)


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## Research and Engineering

**Locate Pilot Sites**
**Choose Luminaires to test**
**Install Luminaires**
**Perform Illuminance Field Measurements**
**Conduct Customer Survey**

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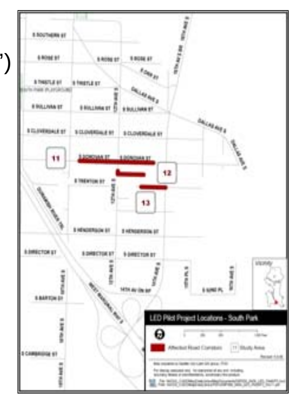
## Review Typical Seattle Roadway

- Typical 32 foot cross-section
- Luminaire mounting height (25' to 30')
- Light pole spacing (150 feet)
- Tree Conflicts



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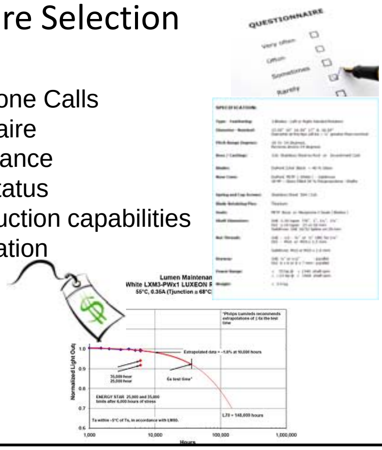
## Luminaire Selection

- Internet Research & Phone Calls
- Manufacture Questionnaire
  - Photometric performance
  - "Made in America" status
  - Manufacturers' production capabilities
- Manufacturers' Specification
- LM 79 & LM 80 Reports
- Pricing

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## Luminaire Selection Outcome

150 Manufacturers
- Initial Phone Contact
- Internet Research

40 Manufacturers
- From Questionnaire
- Specifications Review

5 Manufacturers
- Manuf. Experience
- Price
- Availability

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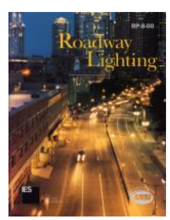
## Photometric Analysis

### Computer Simulation

- Based on the IES RP-8-00, Table 2

  (*American National Standard Practice for Roadway Lighting*)
  - Average maintained illuminance values.
    - 0.4 foot candles (Seattle 0.7 foot-candles)
  - Uniformity ratios (average/minimum).
    - 6:1 with a minimum of 0.2 foot-candles allowed

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## Photometric Analysis

Computer Simulation
- Luminaire Characteristics
  - Type II & III distributions

    Type II - greater pole spacing less light trespass

    (New BUG rating has come out – Backlight, Uplight, Glare)
  - Multiple Wattages tested

| Type | Description | Plan View |
|---|---|---|
| Type I | Narrow, symmetric illuminance pattern | |
| Type II | Slightly wider, more asymmetric illuminance pattern than Type I | |
| Type III | Wide, asymmetric illuminance pattern | |
| Type IV | Asymmetric, forward throw illuminance pattern | |
| Type V | Symmetrical circular illuminance pattern | |
| Type VS | Symmetrical, nearly square illuminance pattern | |

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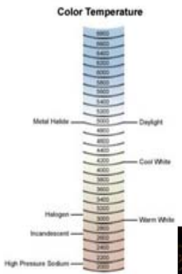
## Photometric Analysis

### Computer Simulation




- Color temperature 4000°K to 6000°K
  - Keyed in on 4000°K to 4300°K
  
  (Based on input from Stage 1 & Lighting Lab install)
- 350 to 525 milliamps operating current
  - Cooler operation to extend life of fixture

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## Photometric Analysis Outcome

5 Manufacturers

- Luminaire Selection

2 Manufacturers
2 Luminaires Each

- Photometric Performance
- Further Price Review

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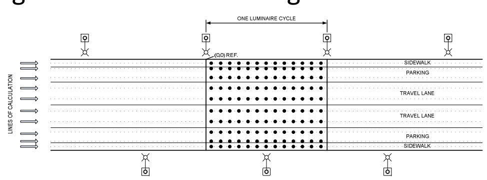
## **Field Evaluation**

### Methodology

•Before and after comparison
•Field Testing Methodology based on RP-8-00
•Field measurements made with sled mounted light meter for efficient and fast data collection
•Testing conducted on clear nights with no clouds or moon

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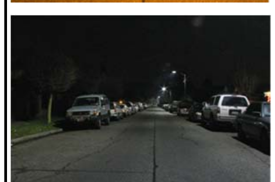
## Field Evaluation

### Photometrics

Before (HPS)

- Illuminance levels of existing HPS system exceeded RP-8-00 minimums
- Uniformity for HPS did not meet RP-8-00



After (LED)

- Illuminance levels exceeded RP-8-00 minimums
- Illuminance levels of the LED fixtures exceeded HPS system levels
- Uniformity for LED did not meet RP-8-00

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## Field Evaluation Outcome

- 3 Manufacturers
  - Field Deployment
- 1 Manufacturer Failed
  - Water inside housing

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## Economic Analysis

Life Cycle - 15 years (assumed)
Energy Rate - $0.053/kWh
Rebate - $0.23/kWh saved

Base luminaire → 100 W HPS Cobra Head

- 25% failure rate
- 30,000 hour lamp life
- Maintenance cycle 4 years

Comparison Luminaires → 39 to 142 Watt LED

- 10% failure rate
- 50,000 hour LED life
- Maintenance cycle 7 years

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## Current Pilot Sites

**Residential**
- Capitol Hill
- South Park
- West Seattle
- Genesee Hill

**Arterial**
- 2nd Ave
- Cherry St

**Structures**
- West Seattle Swing Bridge
- University Bridge

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## Community Outreach

- Pilots in Specific Neighborhoods
- Questionnaire to Every Household
- Noted Major concerns and adjusted fixture selection

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## Implementation

- Jorge Carrasco, SCL Superintendant, Approval
- Mayors Office Support and Approval
- City Council Budget Approval

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## LED SL Program Savings - Residential Streets

| Residentail LED Installations | | | | |
|---|---|---|---|---|
| | Units Converted | Savings Per LED | Monthly Savings | Annual Savings at end of period |
| 2010 Installations | 5000 | $ 4.90 | $ 24,500.00 | $ 294,000.00 |

| | | | | |
|---|---|---|---|---|
| All Residential Streets Installed: | 41000 | | $ 200,900.00 | $ 2,410,800.00 |
| Annual System Management & Cleaning Costs | | | | $ (520,000.00) |
| Total Projected Savings at end of 2014: | | | | **$ 1,890,800.00** |

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## 2010 LED Expenditures

| DESCRIPTION | COSTS |
|---|---|
| Labor | $665,000 |
| Materials – City Funded | $800,000 |
| Materials – ARRA Funded | $1,000,000 |
| **Total Project Cost** | **$2,465,000** |

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## Challenges

1. **Community Acceptance**
   - Quality of Light
   - Light Distribution
2. **Lack of Standards –** No ones ever done this before…
3. **Historical Design Practices**

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## LED Next Steps

- Developed an LED Luminaire Specification
- 2012 – Residential LED Conversion – 12,000 units
- ARTERIAL PILOTS
  - West Seattle Bridge – I-5 to 35th Ave SW
    (SCL | SDOT | Consortium | PNNL Partnership)
  - 15th Ave NW -
    NEEA Acuity Study with Clanton Associates and Virginia Tech
  - Belltown – including adaptive controls
- Arterial Fixture Selection – Initiated in Fall of 2011
- Arterial Conversion Target - Begin Year 2013

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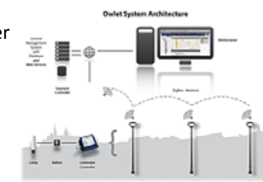
## New Technology Goals

- Remote Monitoring
  - Ability to get real time/ metered power usage for each light
  - Immediate notification of streetlight malfunctioning
  - Quicker response time for repair
- Adaptive Controls
  - Ability to dim or brighten streetlights to meet vehicular and pedestrian demands
  - Set scenes for events and time of day
  - 20%+ Additional energy savings

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## Why LED Street Lighting for Seattle?

"LED street lighting has proven to be a significantly better light source in terms of expected maintenance, energy efficiency, and quality of light."

Edward Smalley, Seattle City Light

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## Seattle City Light – LED Street Lighting Program

**March 22, 2012**

## Thank You…! Questions?

**Vicki Marsten**

Vicki.Marsten@Seattle.gov
http://seattle.gov/light/streetlight/

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# Integrating Variable Energy Resources

*Northwest Energy Systems Symposium – Seattle, WA*

**David Mills**

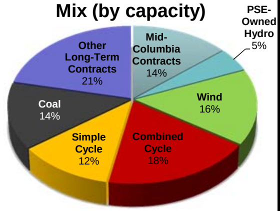
March 21, 2012

## Objectives

- Puget Sound Energy Overview
- Overview of Wind Development in the N.W.
- Challenges of Integrating Wind
- Impact of Wind on PSE operations
- Next steps from a regulated utility perspective

2

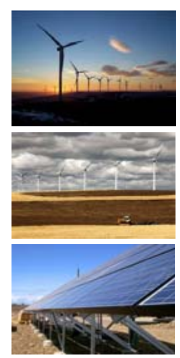
## Puget Sound Energy at a Glance


- PSE serves over 1 Million electric and over 750,000 natural gas customers

3

## Leaders in Renewable Energy Development



- Second-largest utility owner of wind energy in United States (773 MW capacity)
- 157 MW Hopkins Ridge – 2005
- 229 MW Wild Horse – 2006
- 500 kW Wild Horse solar demonstration – 2007
- 44 MW Wild Horse Expansion – 2009
- 343 MW Lower Snake River - 2012

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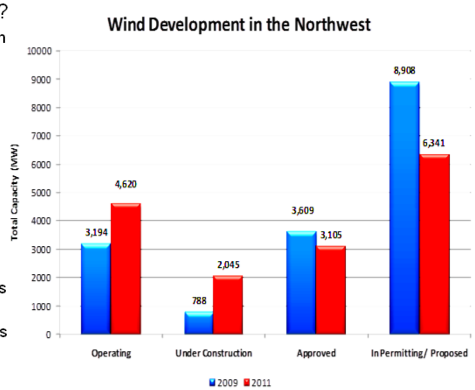
## Wind Development In the Northwest

### Why Renewable Resources?

- In some cases, wind has proven to be the least cost option (Hopkins Ridge)
- Meet state mandated Renewable Portfolio Standard (RPS)
  - 3% by 2012
  - 9% by 2016
  - 15% by 2020

### Wind Development in N.W.

- 45% Increase in operating wind capacity over the past two years
- Over 11,000 MW either under construction or in various stages of approval




5

## Let's define reserves

| Reserves | Operating Reserves Definitions |
|---|---|
| Net Load **Regulation** | Automatic Generation Control (AGC) that balances fast variations in load/wind with generation over short time frames of seconds to minutes. |
| Net Load **Following** | Balance the natural volatility of wind generation and forecast error over longer time intervals of several minutes to hours. |
| **Contingency** | Spinning & non-spinning reserves used in the event of a system contingency such as a loss of a generating capacity.<br>5% of Hydro + 5% of Wind + 7% of Thermal generation |
| Total | Regulation + Following + Contingency |

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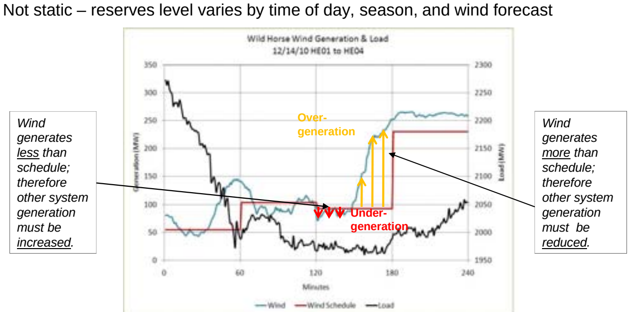
## Wind introduces additional uncertainty and variability to the system, and can impact the reserves need in every hour, not just peak hours.

- Uncertainty – what level of generation will be observed in the future?
- Variability – even with a perfect forecast, wind generation can still fluctuate within an hour
- Not static – reserves level varies by time of day, season, and wind forecast




7

## Challenges of Integrating Wind

- PSE Operates in a Bi-lateral Energy Market
  - No reliable short-term capacity market
  - Market transactions occur on an hourly basis
  - Lack of a consolidated scheduling entity or transmission provider increases wind balancing complexity and reduces the diversity benefits associated with geographically distinct wind plants and load centers
- Over-generation Has Become an Issue in the Pacific Northwest
  - High water events coupled with increasing wind penetrations levels, lack of market flexibility, and a constrained transmission system are the primary drivers
  - High water events have lead to significant wind curtailments

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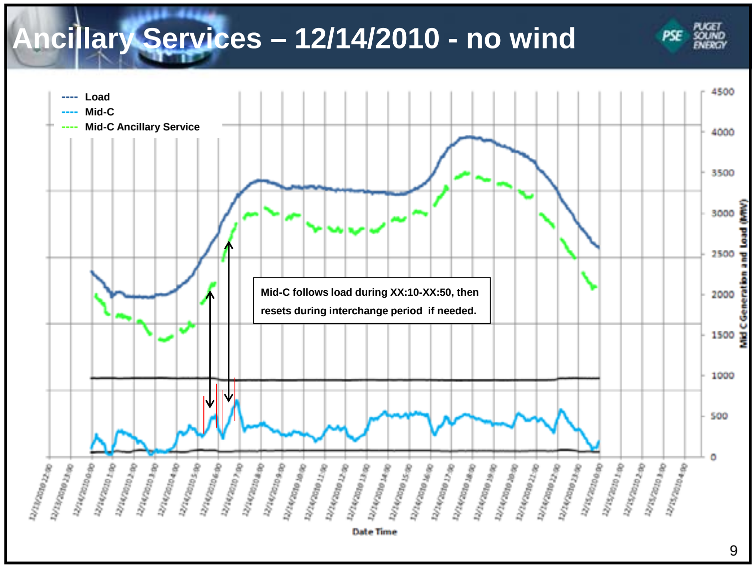
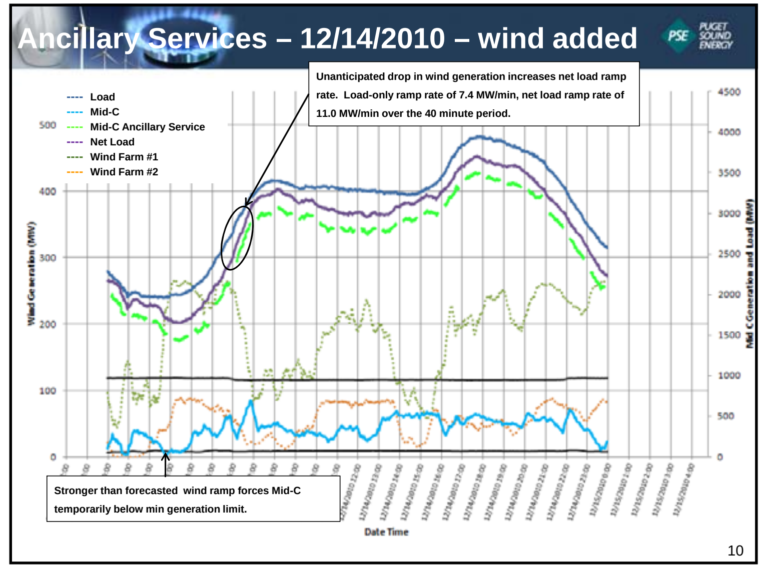
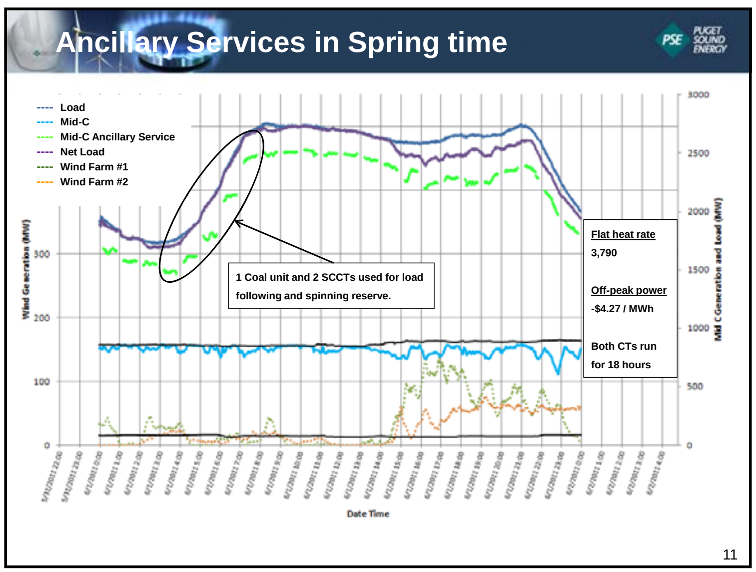
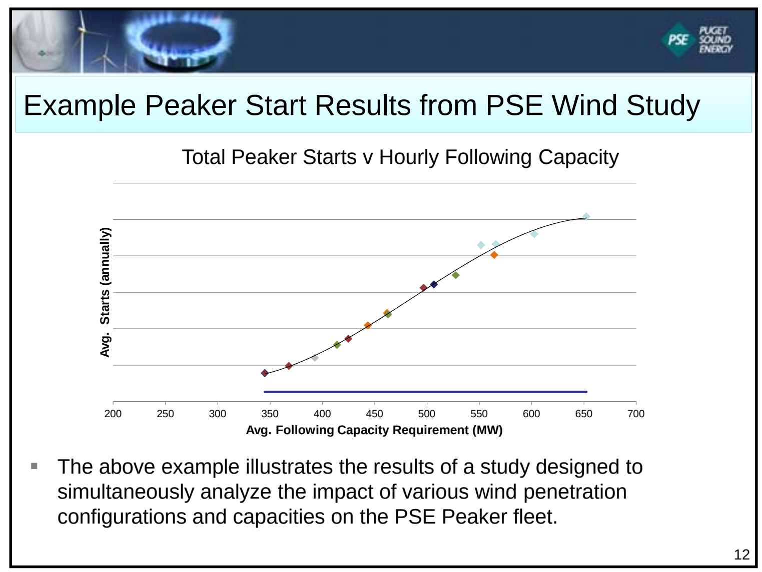

Ancillary Services – 12/14/2010 - no wind
PSE PUGET SOUND ENERGY
Load
Mid-C
Mid-C Ancillary Service
Mid-C follows load during XX:10-XX:50, then resets during interchange period if needed.
Mid C Generation and Load (MW)
Date Time
9


Ancillary Services – 12/14/2010 – wind added
PSE PUGET SOUND ENERGY
Unanticipated drop in wind generation increases net load ramp rate. Load-only ramp rate of 7.4 MW/min, net load ramp rate of 11.0 MW/min over the 40 minute period.
Load
Mid-C
Mid-C Ancillary Service
Net Load
Wind Farm #1
Wind Farm #2
Wind Generation (MW)
Mid C Generation and Load (MW)
Stronger than forecasted wind ramp forces Mid-C temporarily below min generation limit.
Date Time
10


Ancillary Services in Spring time
PSE PUGET SOUND ENERGY
Load
Mid-C
Mid-C Ancillary Service
Net Load
Wind Farm #1
Wind Farm #2
Wind Generation (MW)
MM C Generation and Load (MW)
1 Coal unit and 2 SCCTs used for load following and spinning reserve.
Flat heat rate
3,790
Off-peak power
-$4.27 / MWh
Both CTs run for 18 hours
Date Time
11


PSE PUGET SOUND ENERGY
Example Peaker Start Results from PSE Wind Study
Total Peaker Starts v Hourly Following Capacity
Avg. Starts (annually)
200
250
300
350
400
450
500
550
600
650
700
Avg. Following Capacity Requirement (MW)
The above example illustrates the results of a study designed to simultaneously analyze the impact of various wind penetration configurations and capacities on the PSE Peaker fleet.
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## Future Ancillary Service Capability

- PSE's future resource portfolio:
  - Less hydroelectric generation
  - More gas-fired generation
  - More wind generation
- Meeting Future Ancillary Service Requirements:
  - As hydro capacity decreases, more following will be met by combined and simple cycle gas turbines.
  - Altered operations will increase O&M costs

**How is PSE quantifying future ancillary service requirements and costs?**

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## Ancillary Valuation Model

- Iterative SAS-based model capable of determining:
  - Opportunity cost of balancing variable resources
  - Operational impacts of balancing additional variable resources
    - Unit starts
    - Unit generation
    - Unit run-times (hours of operation)
    - Unit cost
  - Distribution of possible cost and operational impacts

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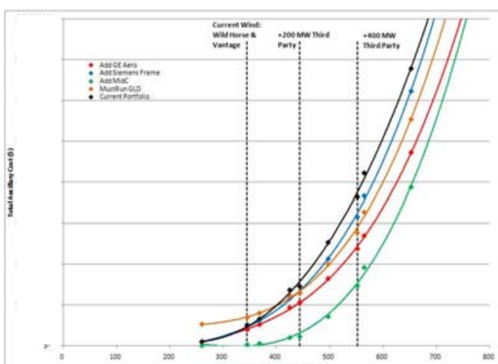
## Example Ancillary Valuation Model Study Results




- Expected ancillary cost does not increase linearly with following reserve requirement.
- Present wind balancing obligations fall to left portion of curves, where system is not overly constrained.
- Remember: ancillary cost includes both load and wind following.

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## Balancing Reserve Conclusions

| Balancing Reserves | Drivers | Impacts of More Wind |
|---|---|---|
| • Regulation | • Regulation is driven by the natural volatility of wind and load as well as the turbine power curve | • Increase in the need for both regulation and following |
| • Following | • Following is driven by the magnitude of the forecast error | • Improvement in wind forecasting will reduce following requirements |

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## Initiatives Intended to Facilitate Wind Integration

- BA reconfiguration/coordination/expansion to enhance the benefits of geographic diversity
- Transmission development
- Dynamic scheduling out of the source balancing authority
- Develop a functioning within hour balancing market
- Improve wind forecasting capabilities

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## Questions?

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# Integration of Renewable Generation

*An Independent Power Producers' Perspective*

Public Generating Pool EIM+ Workshop
Laura Beane
March 21, 2012

*Rugby Wind Farm, Pierce County, North Dakota*

IBERDROLA RENEWABLES

## Iberdrola Renewables, Inc.

IBERDROLA RENEWABLES

**A collection of exceptional assets…**

- #2 developer of wind projects in the U.S. with over 4.8 GWs
- Represents 37% of Iberdrola S.A.'s global wind capacity
- 900 employees at the end of 2011
- 636 MW of CCGT & peaking capacity on the strategic CA-OR border
- Developing utility-scale photovoltaic projects, solar thermal projects, and biomass projects

US Renewables

| Wind | Power | Solar & Biomass |
|---|---|---|
| 4,800+ MW | 536 MW CCGT<br>100 MW peaking | 20 MW Solar<br>55 MW Biomass |

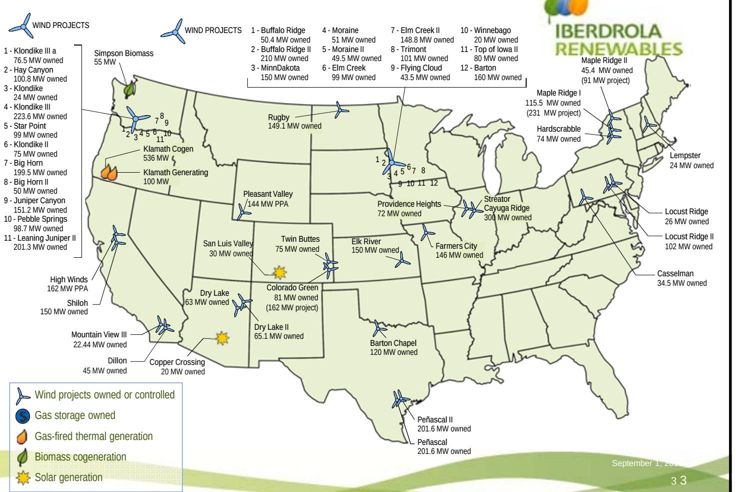
Corporate Support

**… with excellent growth prospects**

Updated January 2012

## US Asset Portfolio

IBERDROLA RENEWABLES




September 1, 2011

3 3

## Wind Energy's Impact to the Power System

IBERDROLA RENEWABLES

- Wind energy has four characteristics that affect how it is integrated into power systems:
  - Output variability
  - Near-zero variable cost
  - Difficulty of forecasting its output precisely
  - Remoteness
- These characteristics can be better accommodated in some markets structures than others
- The diversity of the US markets has made integration a difficult and fragmented effort

## Optimal Wind Integration Conditions

IBERDROLA RENEWABLES

- ➢ Large electric balancing area with access to neighboring markets
- ➢ Robust electric grid
- ➢ Short-term electricity generation markets
- ➢ Access to flexible generation and load
- ➢ Effective integration of wind forecasts into utility operations
- ➢ Flexible transmission services

## IRI's Renewable Integration Goals

IBERDROLA RENEWABLES

**Increase Reliability & Operational Flexibility** → **Minimize Costs** → **Maximize Capability**

**Increase Reliability & Operational Flexibility**

- **Design generator to meet requirements in Interconnection Agreements**
  - *Voltage Support*
  - *Frequency Response*
- **Comply with current and future regional market and operational rules/ requirements**
  - *Bidding/Scheduling*
  - *Meter Data Submittals*
  - *Operational Requirements*
    - Dispatchability
    - Real Time Data Flow
    - Operator training and protocols

**Minimize Costs**

- **All resources should be treated equitably**
  - *Same access to market mechanisms as other generators to mitigate exposure to operational costs*
  - *Penalties should not be unfairly punitive based on unique operating characteristics*
- **Low cost integration solutions implemented prior to higher costs solutions**
- **Lead regional initiatives that result in optimal market structures**
  - *Large BA's with access to neighboring markets*
  - *Short-term electricity generation markets*
  - *Flexible transmission services*

**Maximize Capability**

- **Create new market opportunities**
  - *Ability to participate in ancillary services and capacity markets*
- **Advocate for rules that improve access to market:**
  - *Broad allocation of transmission costs for transmission that meets public policy objectives*
- **Long-term Certainty**
  - *Drive toward regulatory and market rules that create cost certainty.*

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## Market-Type Comparison

IBERDROLA RENEWABLES

| Organized Markets (MISO, PJM, NYISO) | Hybrid Markets (SPP) | Bilateral Markets (West, South) |
| --- | --- | --- |
| Large, single Balancing Area | Coordinate across multiple, smaller Balancing Areas | Small Balancing Areas, with limited coordination across the seams |
| Day-Ahead and Real-Time markets, with access to intra-hour flexibility (load and resources) | Bilateral markets, with access to intra-hour flexibility (load and resources) | Bilateral markets, with limited access to loads and owned resources within Balancing Area |
| Robust regional interconnections; flexible transmission services | Robust regional interconnections; physical transmission service with one fee for transactions across multiple SPP utilities | Physical transmission service, with "pancaked" rates across utilities |
| Robust regional transmission planning and cost allocation processes | Robust regional transmission planning and cost allocation processes | Regional planning done for "information only", limited regional cost allocation processes |
| Centralized forecast used to support system reliability; individual generators incented to submit forecasts (e.g. 4-hour, hourly, 5-minute granularity) | Centralized forecast used to support system reliability; no market-based incentives to use/improve generator forecasting. | No centralized forecasting; limited use of market-based incentives to use/improve generator forecasting. |

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## Summary of Wind Integration Issues in BPA's Balancing Area

IBERDROLA RENEWABLES

- ➢ Wind penetration is rapidly increasing in Balancing Area
  - ▪ Iberdrola Renewables is ~34% of the installed capacity in BPA's Balancing Area
- ➢ The hydro system is less flexible then in previous years
- ➢ Currently there are thousands of MW's of merchant flexible generation on BPA's system which cannot be accessed

## Wind Integration Charge Background

IBERDROLA RENEWABLES

- In 2008 BPA implemented a Wind Integration Charge (WIC) of approximately $3.11/MWh
- In its 2009 rate case, BPA's initial Wind Integration Charge proposal was in excess of $11/MWh – a 350% increase over the initial charge
- Iberdrola Renewables began preparations to file with the WECC and the NERC to become certified as its own Balancing Authority (BA) and leave BPA's system entirely
- Through collaboration with industry stakeholders, BPA implemented changes resulting in a final WIC of approximately $5.89/MWh
- BPA allowed customers the option of self-supplying all or a portion of their required balancing reserves

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## Self-Supply Pilot Introduction

IBERDROLA RENEWABLES

- Iberdrola Renewables elected to self-supply Generation Imbalance Reserves and continues to purchase Regulation Reserves and Following Reserves from BPA
- Iberdrola Renewables worked with BPA over a twelve month period to implement the first Customer Supplied Generation Imbalance (CSGI) pilot that went live September 1, 2010
  - Development and execution of the Participant Agreement
  - Installation of required communications and signaling equipment
  - Completion of comprehensive testing
  - Reconfiguration of settlement systems and processes
  - Execution of Balancing resource contracts
- The initial pilot continued through September 30, 2011 and Iberdrola Renewables elected to extend the pilot through September 30, 2013

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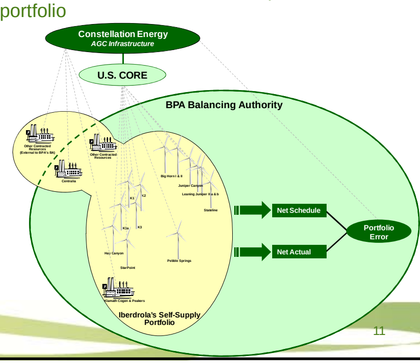
## Self-Supply Pilot Structure

IBERDROLA RENEWABLES

- BPA has allocated a portion of Regulation and Following reserves to Iberdrola's generation portfolio and Iberdrola is responsible to self-supply Generation Imbalance reserves to resolve any remaining Station Control Error (SCE) – the difference between the net schedule and net output of Iberdrola Renewables northwest wind portfolio

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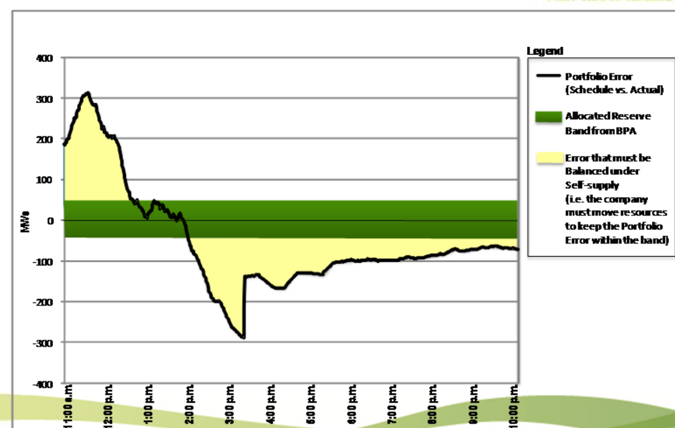
## Self-Supply Balancing Illustration

IBERDROLA RENEWABLES




13

## Self-Supply SCE Management

- Iberdrola Renewables' robust forecasting capabilities help to minimize the error of the northwest wind portfolio
- Iberdrola Renewables' Klamath Cogeneration facilities, including peaking units, are utilized to provide a portion of the needed generation to keep Iberdrola's portfolio balanced
- Iberdrola has also entered into contractual relationships with entities with dispatchable resources to provide additional generation capability
- All balancing generation is provided over dynamic schedules on an intra-hour basis or through the On Demand transmission product

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## Constellation Energy Control & Dispatch

- Iberdrola has engaged Constellation Energy Control & Dispatch (CECD) to provide consulting services and Automatic Generation Control (AGC) infrastructure
- CECD provides balancing services for ~15 Balancing Authorities across the United States including the nation's first wind-only Balancing Authority
- Constellation's Responsibilities
  - Respond on a 4-second basis to the Portfolio Error
    - Execute dispatch of resources per resource stack
  - Monitor and respond to applicable compliance parameters
  - Report all aspects of self-supply portfolio

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## Self-Supply Pilot Assessment & Lessons Learned

- Balancing wind is not for the faint of heart
- Despite challenges, Iberdrola has successfully balanced its nearly 1400 MW of wind and has exceeded performance requirements
- Success has been a team effort requiring cooperation and performance by all parties – Iberdrola, BPA, CECD & Versify
- New balancing agreements are optional with variable price (versus obligation at fixed price)
- Access to dynamic transfer capability is critical to success of CSGI and other initiatives designed to ease burden from BPA
- DSO 216 remains problematic despite Iberdrola's strong balancing performance

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## What's Next?

- BPA's rate case process has already begun for the 2013-2015 rate period and Iberdrola Renewables has developed a proposal for wind balancing services which would replace BPA's existing Variable Energy Resource Balancing Service (VERBS)
  - Variable rate component designed to provide proper incentives for wind generators
  - Elimination of non-reliability based tag curtailments and other punitive penalties
- Iberdrola Renewables is partnering with other Northwest entities to explore implementation of an energy imbalance program at the Mid-C market hub that can ultimately be expanded to a west-wide footprint

***Iberdrola Renewables continues to view the CSGI program as an interim solution until a fully functional balancing market evolves***

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Questions?
Laura Beane
Director, Regional Market Structure & Policy
503-478-6306 (w)
971-344-3047 (c)
laura.beane@iberdrolaren.com
MinnDakota, South Dakota
IBERDROLA
RENEWABLES
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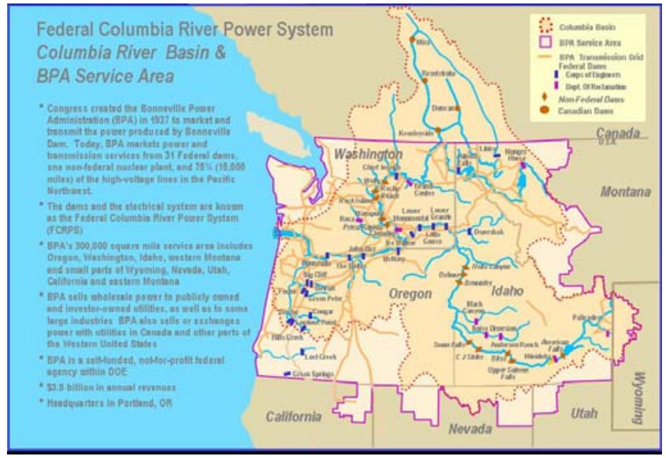
# Integrating Variable Energy Resources

*A Power Marketing Administration Perspective*

Elliot Mainzer
Exec VP, Corporate Strategy, BPA
Northwest Energy Systems Symposium – Seattle, WA
March 21, 2012



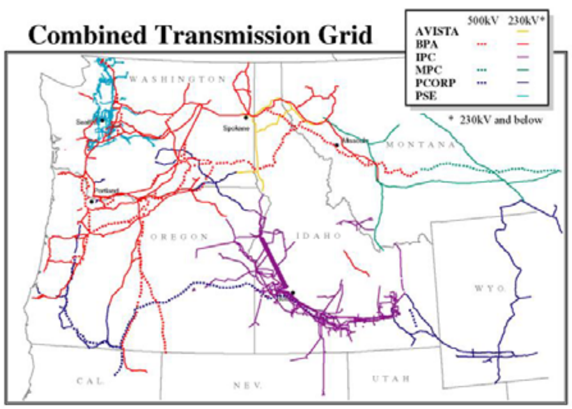
B O N N E V I L L E   P O W E R   A D M I N I S T R A T I O N






B O N N E V I L L E   P O W E R   A D M I N I S T R A T I O N

## Regional High Voltage Transmission Grid



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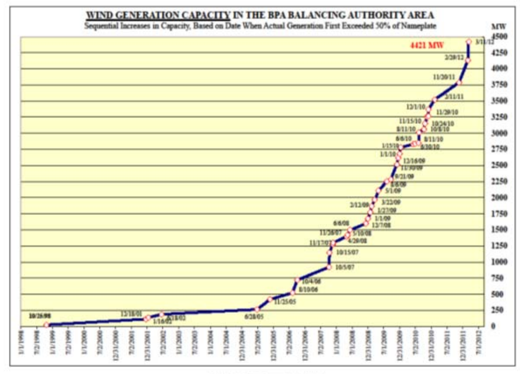
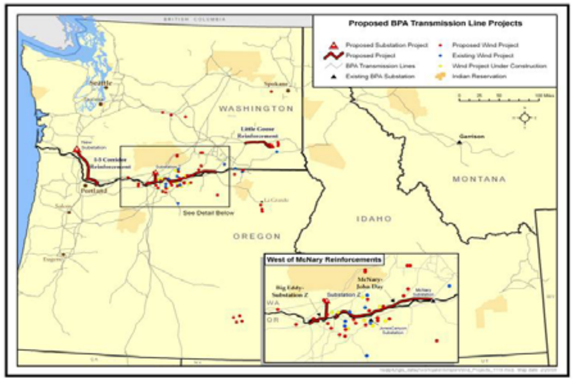
## Growth of wind in the BPA Balancing Authority



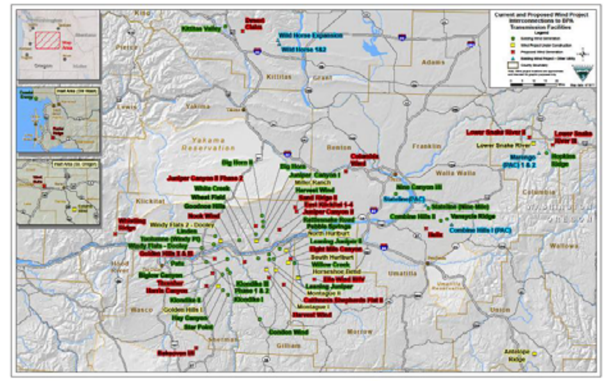
## Geographic Concentration of Wind Resources






B O N N E V I L L E   P O W E R   A D M I N I S T R A T I O N

## Geographic Concentration of Wind Resources





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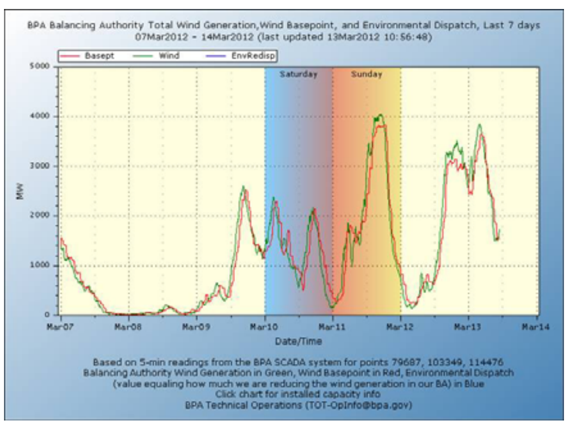
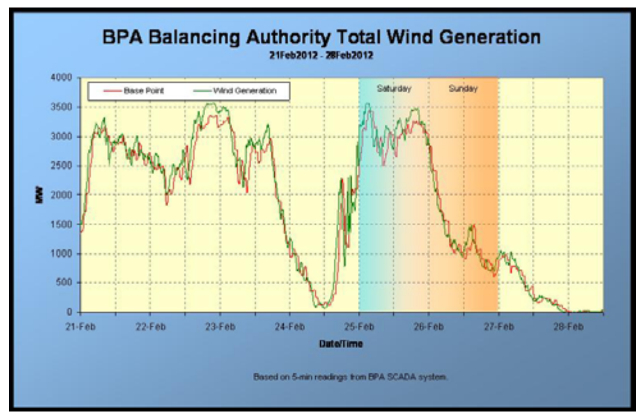
## Ramping Behavior of Wind Fleet

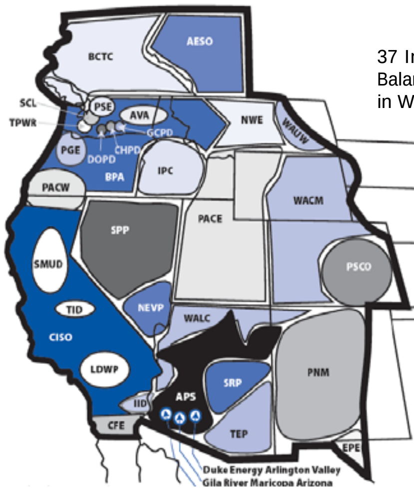





B O N N E V I L L E   P O W E R   A D M I N I S T R A T I O N

## Significant Wind Ramp Event in February 2012






37 Individual Balancing Authorities in WECC





# Regional Balancing Initiatives

| | |
|---|---|
| **Initiatives to Facilitate Shorter Transaction Intervals** | |
| Intra-Hour Scheduling | NTTG/ColumbiaGrid/WestConnect |
| WebExchange | NTTG/ColumbiaGrid/WestConnect |
| Dynamic Scheduling System | NTTG/ColumbiaGrid/WestConnect |
| BPA Committed Intra-Hour Scheduling Pilot | BPA |
| California ISO Intra-Hour Scheduling Pilot | BPA and California ISO |
| **Customer Self-Supply of Generation Imbalance** | BPA/Iberdrola |
| **Initiatives to Leverage Diversity Between Balancing Authorities** | |
| ACE Diversity Interchange Project | Participants in ADI Agreement |
| Variability Energy Resource Diversity Interchange | ColumbiaGrid |
| Reliability-based Control Field Trial | WECC |
| **Flex-Capacity Initiative** | NTTG/ColumbiaGrid/WestConnect |
| **Energy Imbalance Efforts** | WECC, Western PUC Group, WSPP, NWPP member utilities |

# Smart EV Charging

GRID | Eric Sortomme

ALSTOM

## Outline

Introduction

Electric Vehicle Charging Issues

Intelligent Charge Control Technologies

Smart Charging on Distribution Systems

Vehicle-to-Grid Optimization

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## Introduction

Why Electric Vehicles (EVs)?
- Energy I
- Reduce
- Lots of f

"We can brea… d become the first countr… ehicles on the road by 20…
- Preside…

EVs in the U…
- 1500 Tesla Roadsters
- 11000 Nissan LEAFs
- 9000 Chevy Volts (PHEV)

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## Introduction

Additional EVs for sale in the US in 2012
- Mitsubishi MiEV
- Ford Focus EV
- Tesla Model S
- Toyota Rav4 EV
- Honda Fit EV

Potential for tens of thousands of EVs sold in 2012
- Hundreds of thousands of EVs at least by 2015

This will require hundreds of additional MWh per day

This can add hundreds of MW of load

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## Electric Vehicle Charging Issues with the Grid

Energy Requirements:
- 100,000 EVs will require around 1,000 MWh energy per day

Power Requirements:
- With 3.3 kW charging, 100,000 EVs can add up to 330 MW load
- With 6.6 kW charging, 660 MW load

Grid Issues with charging EVs:
- If charging occurs on peak, supply shortages and extreme energy prices can be experienced
- If charging occurs off peak, these problems may be alleviated

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## Distribution System Issues with EV Charging

EVs are more likely to clump in certain neighborhoods which will lead to much higher penetration on the distribution system then on the grid in general
- Loads can grow unexpectedly when EV owners visit each other

Charging on peak can cause:
- Line and transformer overloads
- Increased line losses
- Voltage sags

Charging off peak can still reduce distribution transformer life from eliminating cool down periods

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## Smart Charging Control

Many of the issues with EV charging can be addressed through controlled charging

Controlled charging allows EV loads to be reduced when needed and can facilitate peak shaving

Charging control can also facilitate vehicle-to-grid applications such as:
- Regulation
- Load following
- Spinning reserves
- Non-spinning reserves

Charge control can be either:
- Incremental adjustment of the charge rate
- Discrete switching of EVs

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## Incremental Charge Control

EV charge rate can be set to any level between zero and the charger maximum

Can be accomplished in a variety of ways:
- Special hardware installed in the EV: Utility or an aggregator sends a signal directly to the EVs internal charger to set the power draw level
- Pilot signal adjustment on SAE 1772 chargers: Utility or aggregator sends a signal to the charging station which tells the EV how much power it can draw

Allows:
- Utilities to reduce charging of EVs for peak shaving as needed
- EVs to perform V2G regulation, load following, and reserves

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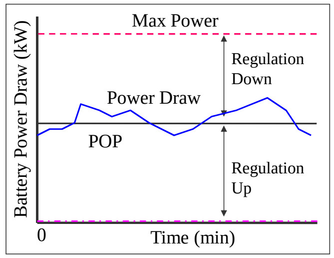
## V2G Through Incremental Charge Rate Adjustment

- Involves adjusting the charge rate around a fixed scheduled rate called the Preferred Operating Point (POP)
- Can perform regulation up and reserves by decreasing from the POP
- Can perform regulation down and reserves by increasing above the POP

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## V2G Using Discrete Switching of EVs

- Involves switching EVs on and off to make the aggregate EV charge rate match the regulation signal but with discrete switching of EVs rather than incremental adjustment
- For each scheduling period, each EV is assigned a target percentage of the total aggregator energy dispatched during that period
  - This is based on the EVs schedule using V2G optimization algorithms
  - Gives each EV a priority level
- The EVs are then divided into two lists based on priority:
  - **Turn Off List:** This list is for the EVs with the highest priority. They start the period turned on to meet the POP. When regulation up is needed the EV with at the bottom of the list is turned off and added to the bottom of the Turn On List
  - **Turn On List:** This list is for EVs with lower priorities. They are initially off. When regulation down is needed, the EV at the top of the list is turned on and added to the top of the Turn Off List
- After a specified number of periods, the priorities are recalculated and the lists reformed

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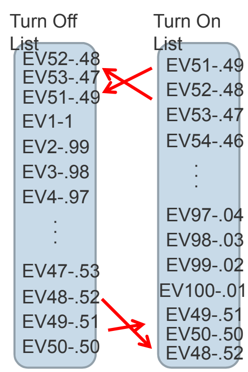
## Visualization with A Group of 100 EVs

- Lists are populated based on priority
- A regulation up dispatch signal is received that requires two EVs to turn off
- A regulation up dispatch signal is received that requires 1 EV to turn off
- A regulation down dispatch signal is received that requires 1 EV to turn on
- A regulation down dispatch signal is received that requires two EVs to turn on

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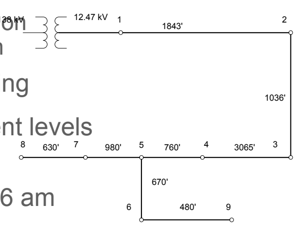
## Case Study: Smart Charging to Flatten Distribution Load Profile and Minimize Losses Using Incremental Charge Adjustment

- Looks at charge control with the objectives of:
  - Feeder loss minimization
  - Feeder load variance minimization
  - Feeder load factor maximization
- Compares with uncontrolled charging
- Uses a nine bus feeder with different levels of PHEV penetration
- PHEVs charge between 6 pm and 6 am
- Each PHEV charges 10 kWh at 1.8 kW

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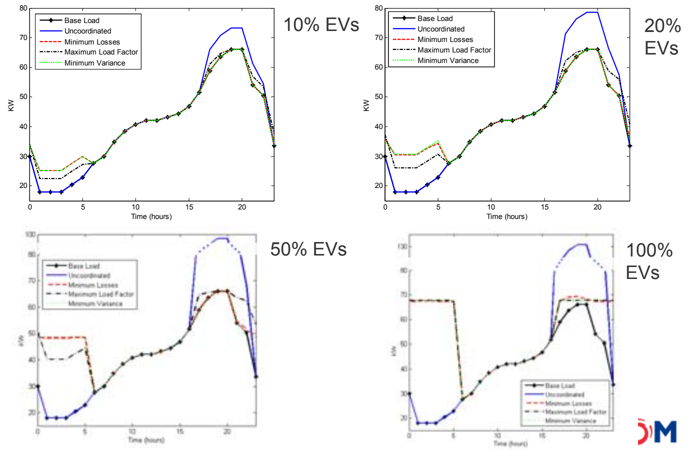
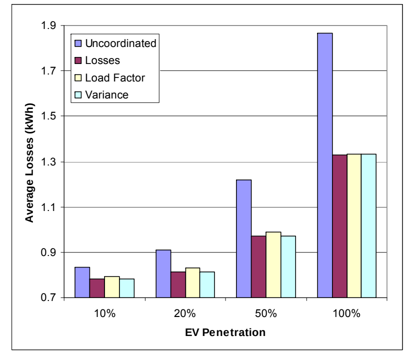
## Results: Charging Profiles




## Results: Losses

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## Case Study Conclusions

- Minimizing losses, maximizing load factor, and minimizing load variance give nearly identical EV charging profiles
- Smart charge control can prevent EVs from charging on peak if possible
- EV smart charging also reduces distribution system losses

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## Optimal V2G Scheduling

- Performed from an aggregator perspective
  - Aggregator can be a utility or a third party
- Maximizes the profits (OptComb V2G Scheduling Algorithm)
  - Assumes revenues come from:
    - A percentage of the V2G services provided
    - Markup on the wholesale price of energy
  - Costs are constant
- Considers selling V2G:
  - Regulation down
  - Regulation up
  - Responsive Reserves

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## V2G Optimization Constraints

- Charger limits
  - Set either by the maximum charge rate of the internal charger or the maximum rate of the charging station
- Battery capacity limits
  - Cannot charge beyond a 90% SOC limit for battery life
  - Often set by OEMs
- EV availability constraints
  - Forecasted transport profiles with associated probabilities
  - Uses the expected values of available EVs
  - EVs can leave unexpectedly and must be compensated
- Ancillary service constraints
  - Regulation up and responsive reserve capacity cannot be greater than the POP
  - POP and all capacities must be greater than zero
- System Constraints
  - System load constraint: Maximum POP inversely proportional to the system forecasted load (OptLoad Algorithm)
  - Real time price constraint: Maximum POP inversely proportional to the system forecasted price (OptPrice Algorithm)

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## Obligatory Equations

$$\underset{POP_i(t), MxAP_i(t), MnAP_i(t), RsRP_i(t)}{\text{maximize}} \quad In - C$$

subject to:

$$\sum_{t=1}^{T_{trip,i}} \left(E(FP_i(t)) Comp_i(t)\right) Ef_i + SOC_{I,i} \leq M_{Ci}$$

$$\sum_{t} \left(E(FP_i(t)) Comp_i(t)\right) Ef_i + SOC_{I,i} - Trip_i \leq M_{Ci}$$

$$(MxAP_i(1) + POP_i(1)) Comp_i(1) Ef_i + SOC_{I,i} \leq M_{Ci}$$

$$MnAP_i(t) \leq POP_i(t)$$

$$RsRP_i(t) \leq POP_i(t) - MnAP_i(t)$$

$$\left(MxAP_i(t) + POP_i(t)\right) Comp_i(t) \leq MP_i(t)$$

$$MxAP_i(t) \geq 0$$

$$MnAP_i(t) \geq 0$$

$$RsRP_i(t) \geq 0$$

$$POP_i(t) \geq 0$$

Where:

*In* is the income of the aggregator

*C* is aggregator costs

*Mk* is aggregator markup over wholesale energy price

*α* is the percentage of regulation revenue taken by the aggregator

$SOC_{I,i}$ is the initial state of charge of the $i^{th}$ EV

$P_{RU}(t)$ is the forecasted price of regulation up for time *t*

$P_{RD}(t)$ is the forecasted price of regulation down for time *t*

*Comp*

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## Support Equations

$$In = \alpha \sum_{t} \left( \left( P_{RU}(t) R_U(t) + P_{RD}(t) R_D(t) + P_{RR}(t) R_R(t) \right) \cdot EVPer(t) \right)$$

$$+ Mk \sum_{i} \sum_{t} \left( E(FP_i(t)) \cdot EVPer(t) \right)$$

$$R_U(t) = \sum_{i=1}^{cars} MnAP_i(t)$$

$$R_D(t) = \sum_{i=1}^{cars} MxAP_i(t)$$

$$R_R(t) = \sum_{i=1}^{cars} RsRP_i(t)$$

$$Comp_i(t) = 1 + \frac{Dep_i(t)}{1 - Dep_i(t)}$$

$$Ex_D = \frac{\int_{RS_{\min}}^{0} RS \cdot \Pr(RS) \cdot dRS}{\int_{RS_{\min}}^{0} RS \cdot dRS}$$

$$Ex_U = \frac{\int_{0}^{RS_{\max}} RS \cdot \Pr(RS) \cdot dRS}{\int_{0}^{RS_{\max}} RS \cdot dRS}$$

$$Ex_R = \frac{\int_{0}^{RRS_{\max}} RRS \cdot \Pr(RRS) \cdot dRRS}{\int_{0}^{RRS_{\max}} RRS \cdot dRRS}$$

$$E(FP_i(t)) = MxAP_i(t) Ex_D + POP_i(t) - MnAP_i(t) Ex_U - RsRP_i(t) Ex_R$$

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## Case Study: V2G Optimization in Houston, TX

- Compared the optimal V2G scheduling algorithms over a from July 20, 2010 to October 21, 2010
  - Aggregator receives 20% of ancillary services revenues and 0.01$/kWh over the price of energy
- Considers 24 hour scheduling of EV charging based on most probable driving profiles
- Uses ERCOT market and system data
- Driving distances taken from National Highway Travel Survey
  - Hypothetical Group of 10000 EVs
    - 500 Tesla Roadsters
    - 2000 Th!nk Citys
    - 2500 Mitsubishi i-MiEVs
    - 2000 BMW Mini-Es
    - 3000 Nissan Leafs

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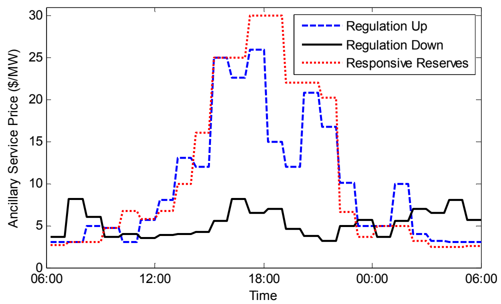
## Examining August 2, 2010

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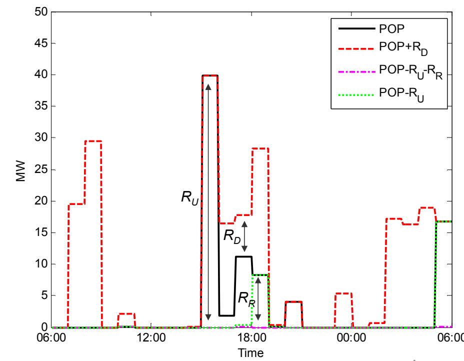
## Profile Results OptComb

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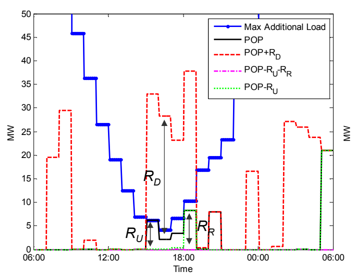
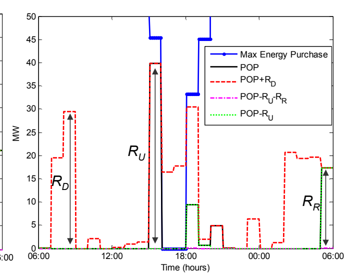
## Profile Results OptLoad and OptPrice

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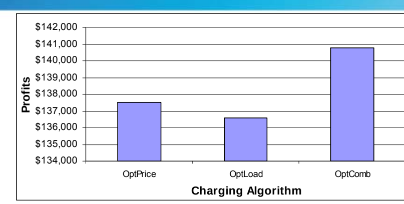
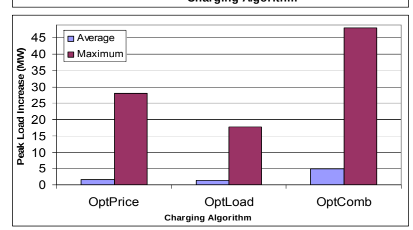
## Quarterly Results

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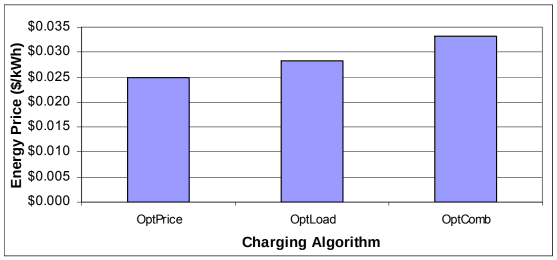
## Customer Costs






## Communication Signals

| Dispatch Algorithm | Avg. Signals Per Car Per Hour |
|---|---|
| Incremental Dispatch | 188 |
| Single Dispatch List Recalculation | 52 |
| Fifth Dispatch List Recalculation | 12 |



## Case Study Conclusions

V2G can provide significant regulation and reserves capacities

V2G generates valuable revenues for both customers and the aggregators

Customers can also receive significant benefits which gives an incentive to participate in V2G programs

Discrete dispatch reduces the communication burden by over 90%



## V2G On Constrained Distribution Systems

The optimization algorithms to not consider distribution system impacts

These can be included through a feeder specific load factor constraint

This load factor constraint can then be developed to integrate into the optimal V2G formulation

- Keeps load factor above a certain desirable level while performing V2G
- Gives the OptFeeder Scheduling Algorithm

## Case Study: V2G on Constrained Distribution Feeders

- Same EV group on the ERCOT system
  - 130 day period
- EVs distributed on 50 test feeders with a penetration level of 50%
  - Three types of feeders
- Compares the four algorithms for
  - Feeder voltages, losses, and overloads

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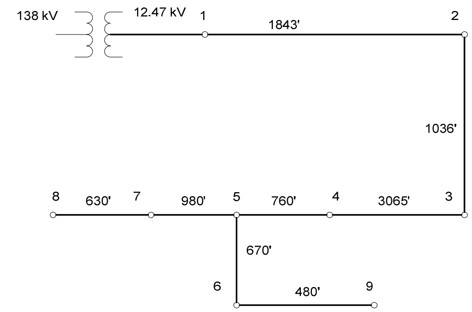
## Feeder Type 1




There are 10 systems of this type. Load buses are 2-9.

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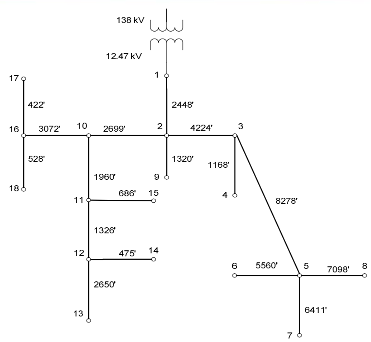
## Feeder Type 2




There are 20 systems of this type. Load buses are 2-18.

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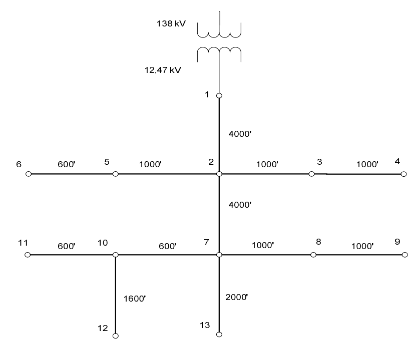
## Feeder Type 3




There are 20 systems of this type. Load buses are 2-13.

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## Case Study Results: Losses

LINE LOSSES BY ALGORITHM (MWH)

| Feeder | Base | OptFeeder | OptComb | OptLoad | OptPrice |
|---|---|---|---|---|---|
| Total | 2,350 | 2,757 | 2,856 | 2,835 | 2,843 |
| T1 | 257 | 301 | 311 | 309 | 310 |
| T2 | 1,146 | 1,353 | 1,403 | 1,392 | 1,396 |
| T3 | 947 | 1,104 | 1,142 | 1,134 | 1,137 |

PERCENTAGE IMPROVEMENT OF OPTFEEDER VERSUS OTHER ALGORITHMS

| Feeder | Vs. OptComb | Vs. OptLoad | Vs. OptPrice |
|---|---|---|---|
| Total | 3.48% | 2.75% | 3.02% |
| T1 | 3.41% | 2.66% | 2.93% |
| T2 | 3.60% | 2.83% | 3.12% |
| T3 | 3.35% | 2.66% | 2.92% |

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## Case Study Results: Line Currents and Overloads

MAXIMUM LINE CURRENTS BY ALGORITHM (A)

| Feeder | Base | OptFeeder | OptComb | OptLoad | OptPrice |
|---|---|---|---|---|---|
| T1 | 69.2 | 75.9 | 91.1 | 88.1 | 95.3 |
| T2 | 141.9 | 154.0 | 199.8 | 187.3 | 199.8 |
| T3 | 104.6 | 109.8 | 145.4 | 134.0 | 139.1 |

NUMBER OF LINE OVERLOADS DURING THE SIMULATION PERIOD

| Feeder | Base | OptFeeder | OptComb | OptLoad | OptPrice |
|---|---|---|---|---|---|
| Total | 0 | 0 | 35 | 3 | 22 |
| T1 | 0 | 0 | 0 | 0 | 0 |
| T2 | 0 | 0 | 32 | 3 | 22 |
| T3 | 0 | 0 | 3 | 0 | 0 |

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## Case Study Results: Voltages

MINIMUM NODE VOLTAGES BY ALGORITHM (PU)

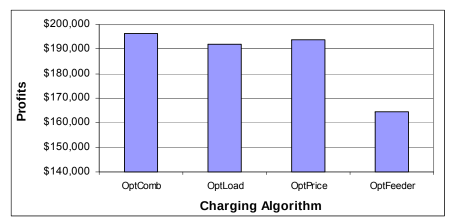
| Feeder | Base | OptFeeder | OptComb | OptLoad | OptPrice |
|---|---|---|---|---|---|
| T1 | 0.956 | 0.953 | 0.943 | 0.946 | 0.940 |
| T2 | 0.957 | 0.953 | 0.939 | 0.943 | 0.941 |
| T3 | 0.953 | 0.950 | 0.933 | 0.938 | 0.935 |

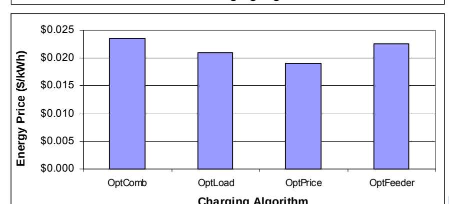
OCCURRENCES OF ANSI C84.1 RANGE A INCIDENTS BY ALGORITHM

| Feeder | Base | OptFeeder | OptComb | OptLoad | OptPrice |
|---|---|---|---|---|---|
| T1 | 0 | 0 | 263 | 51 | 186 |
| T2 | 0 | 0 | 308 | 43 | 220 |
| T3 | 0 | 0 | 2751 | 1083 | 2077 |

GRID ALSTOM

## Economic Results




ALSTOM

## Case Study Conclusions

Feeder load factor constraint:
- Eliminates overloads
- Eliminates voltage sags
- Reduces losses

The total revenues and profits are reduced

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## Final Conclusions

Controlled charging can be implemented in many different ways

Smart charging of EVs can shift peaks and extend equipment life

V2G can be implemented with minimal infrastructure while providing significant benefits to customers and utilities even when the distribution system is constrained

GRID ALSTOM

## Thank you.

Questions?

GRID ALSTOM

# Energy Storage: How much do we need? And how much can we afford?

Michael Kintner-Meyer

Pacific Northwest National Laboratory

IEEE-Northwest Energy Systems Symposium (NWESS)
Seattle, WA

March 22, 2012

Contact: email: Michael.Kintner-Meyer@pnnl.gov
phone: 509.375.4306

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# National Relevance of Storage to Provide a Resilient, Low-Carbon Electricity Supply

*What questions does the DOE Storage Program address?*

- What role could stationary energy storage play in near- and long-term in meeting the Nation's energy objectives?
- To what extent does the value of storage and the need for storage capacity depend on: market designs, regulatory frameworks (such as definition of balancing authorities), and the deployment of variable renewable energy resources?
- What are the optimal technical characteristics for storage technologies in different applications?
- What are the regional differences in the need for energy storage?
- What are the cost performance characteristics for energy storage to be cost competitive at scale?
- What are the challenges to integrate energy storage into grid operations and transmission planning processes?
- What are the best practices, lessons-learned, and success storage of existing energy storage deployments and how can they be applied to guide the future R&D agenda for energy storage?

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# Analysis Fundamental to the DOE Energy Storage Program

## Energy Storage Analysis

### *Grid and Storage Analytics*

- System analysis
  - *Grid modeling*
  - *Case studies*
- Develop cost targets for storage for near- and mid-term by applications
- Develop cost model to identify cost reduction options and guide S&T agenda

### *Evaluation and Market Conditioning*

- Case studies evaluations
- Market conditioning
  - *Education*
  - *Policy analysis, design of markets*
  - *Standards development*
  - *Planning tools development*

### *Today's Grid*

- ≈35GW intermittent
- ≈5% DR
- 0 mill. EVs
- Few PMUs
- Selected ramping challenges

### *2025 Grid*

- ≈300GW interm.
- ≈10-15% DR
- ≈ 15 mill. EVs
- Many PMUs
- Need to address increasing ramping requirements

### *Needs*

- Ramping capabilities
- Clean replacement capacity for plant retirements (old coal, nuclear)
- Transmission expansion to deliver remote wind energy
- Changes in operating procedures
- Innovative market designs to cost-optimally build and dispatch resources

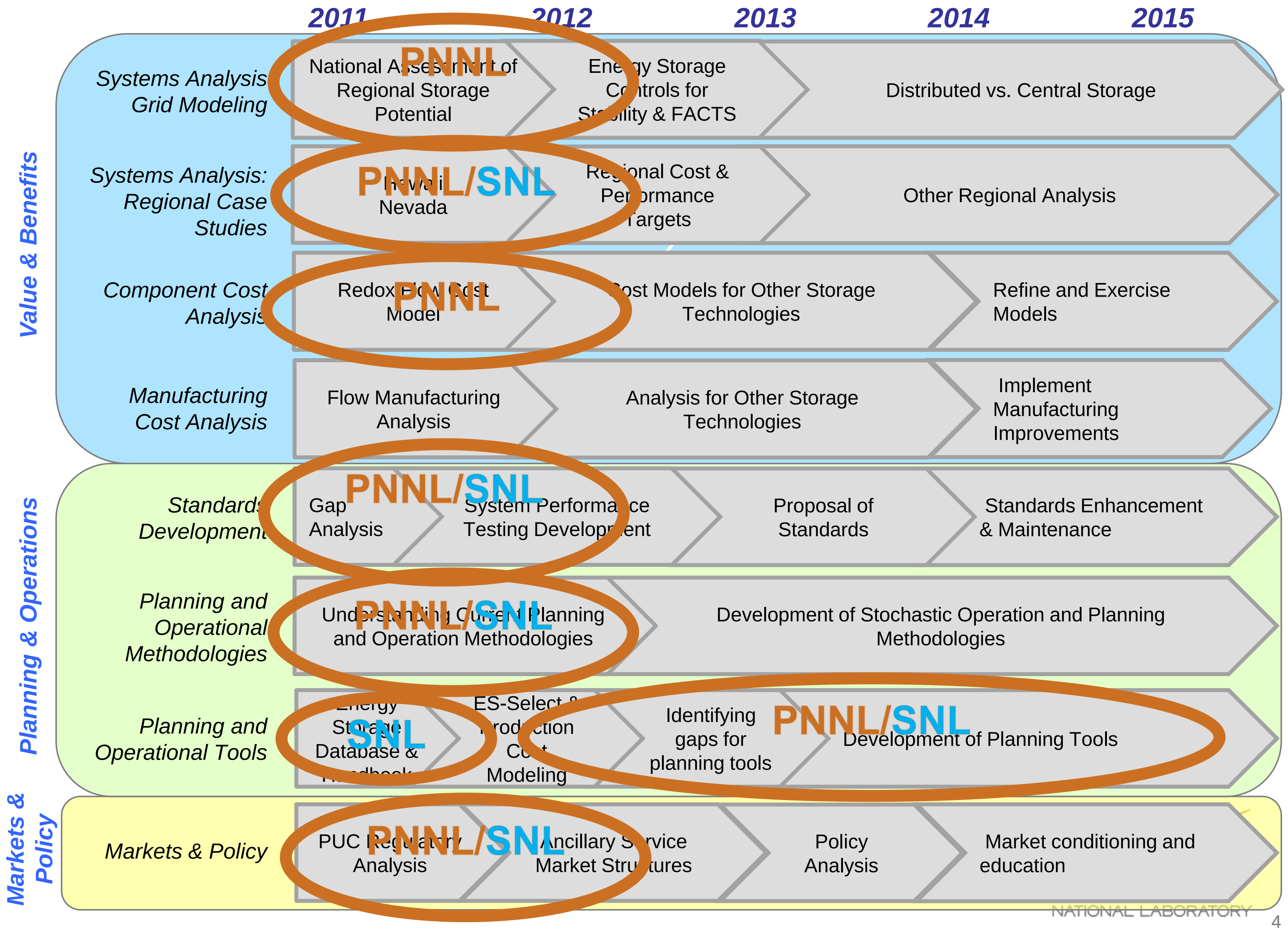
### *Technologies*

- Gas-fired capacity
  - *Combined Cycle*
  - *Combustion Turbine*
- Central Storage
  - *Redox Flow*
  - *NaS*
  - *Li-Ion*
  - *Advance lead*
  - *Others*
  - *Flywheel*
  - *CAES*
- Distributed Storage
- Demand Response
  - *Buildings/industrial*
  - *Electric Vehicles*
- Integration Controls Technologies

### *Deployment*

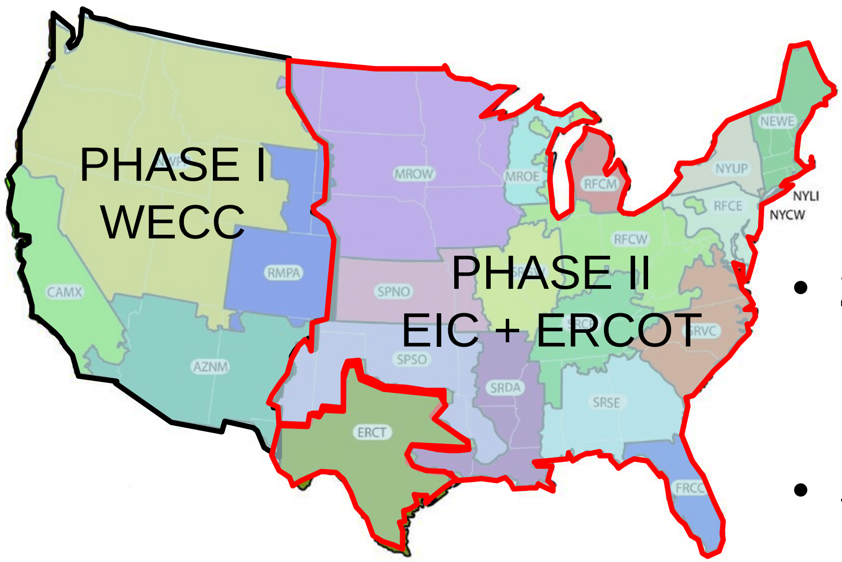
- Fair Market rules to compensate for performance
- Regulatory framework
- Bundling applications
- Identifying location
- Site preparation
- Planning and deployment criteria to match best suited technology for set of applications
- Integration of storage into dispatch strategy

# Timeline of the DOE Analysis Agenda



# PNNL National Assessment of Energy Storage Systems for 2020

*22 NERC Sub-regions*




**PHASE I release in Spring 2012**

**PHASE II release in Summer 2012**

- **Market size potential by cost target and sub-region:**
  - For balancing service (Intra-hour)
    - MW power rating
    - MWh energy capacity
    - ranking of Life-Cycle-Cost by technology
  - For arbitrage
    - MW power rating
    - MWh energy capacity that are economically viable
- **2020 Grid Definition**
  - Nationwide 20% RPS
  - Individual state RPS are honored
- **Sensitivities**
  - Wind forecasting error
  - Low/high natural gas expectations

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# Value of National Assessment

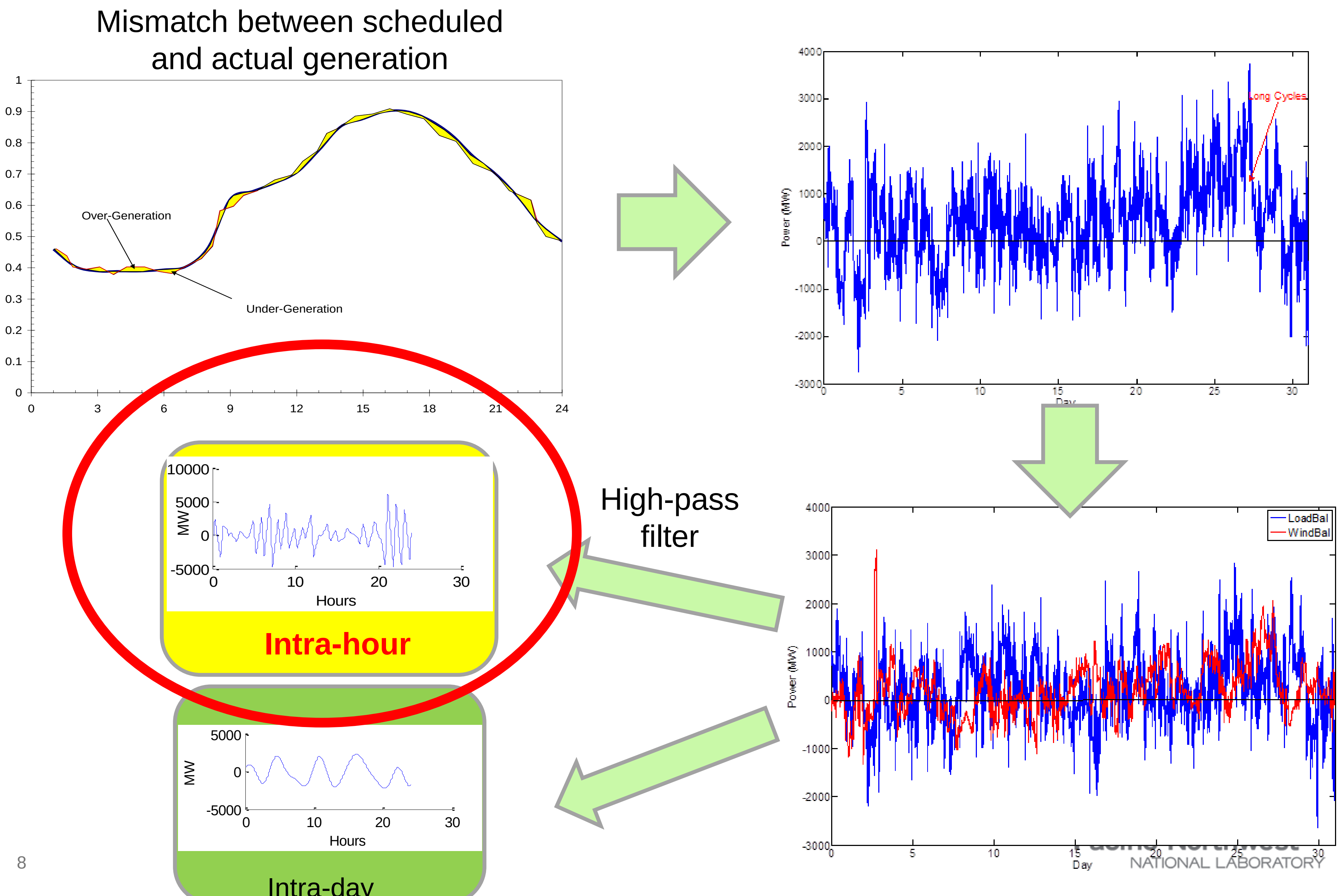
- Provides plausible market potential estimates of energy storage for the investment community and policy makers in a 9-year forecasting time horizon (2020)
- Indicates relative competitiveness among main categories of storage technologies as well as competitiveness versus Demand Response and traditional generation and transmission
  - Allows to estimate/set cost/performance target for specific markets and specific regions
- Differentiates the markets for
  - Short-term storage (< 1h) and
  - Longer-term storage (>6 hours)
- Reveals key assumptions and their influence on the outcome of the analysis

# Balancing Analysis

# and

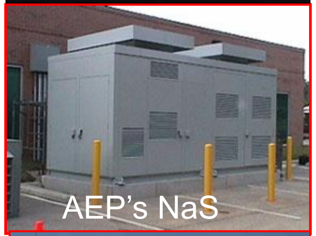
# Storage Opportunities < 1 hour

# Balancing Services Definition

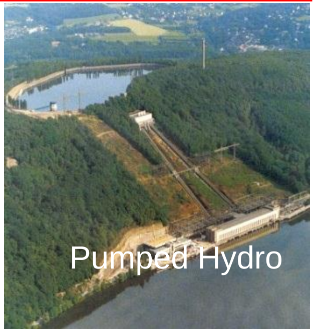


# Scenario Definition:

- Balancing Services:
  - Scope: WECC, 2020
    - Assume 24.0 GW of total installed capacity of wind.
      - Existing wind capacity 9.6 GW
      - Added capacity 14.4GW
  - Technology choices
    - Combustion turbine
    - NAS batteries
    - Li-Ion batteries
    - Redox-Flow
    - CAES
    - Flywheels
    - Demand response (EV)
    - Pumped hydro

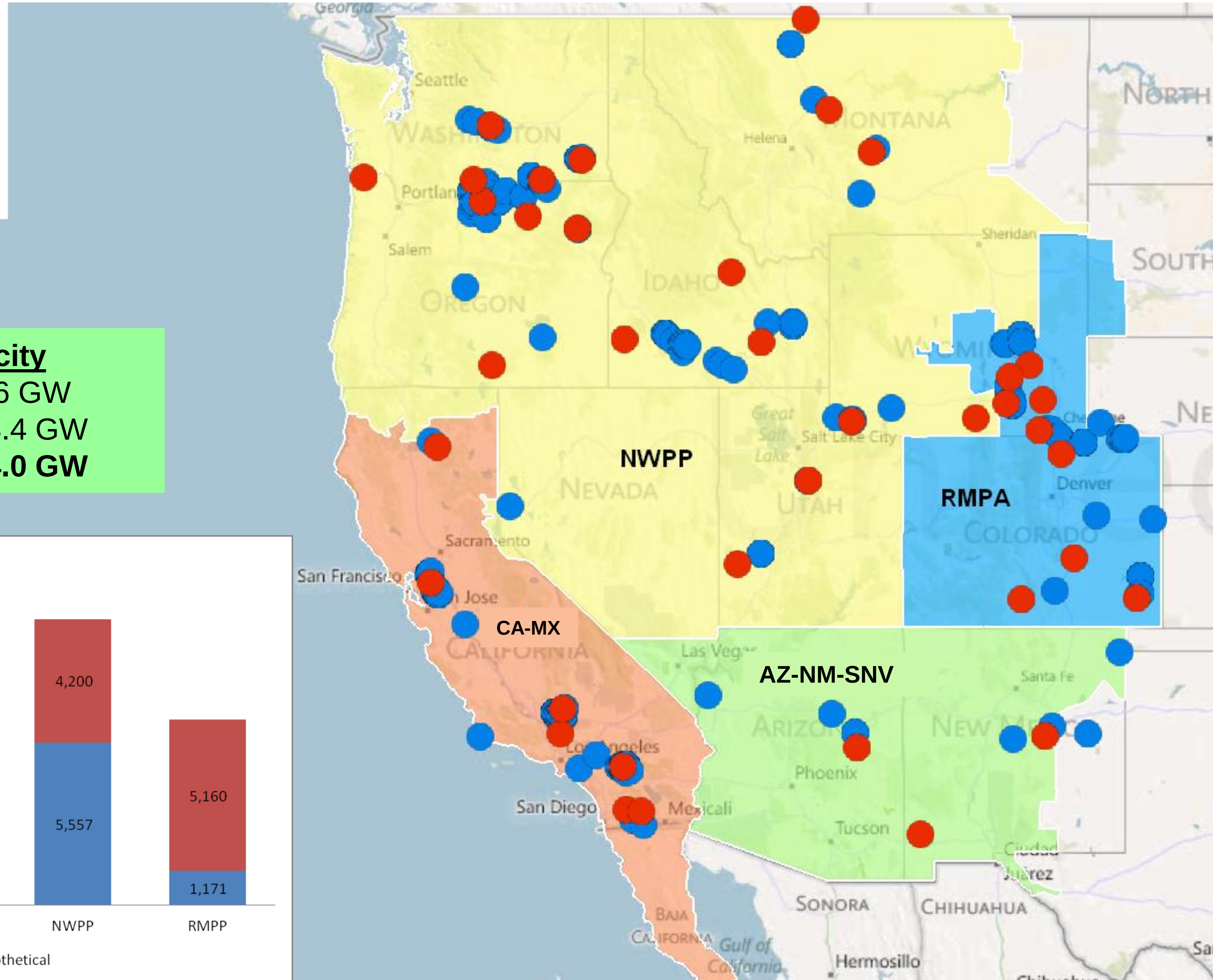


# Assessment for WECC for a 2020 Grid Scenario

Existing Wind Site

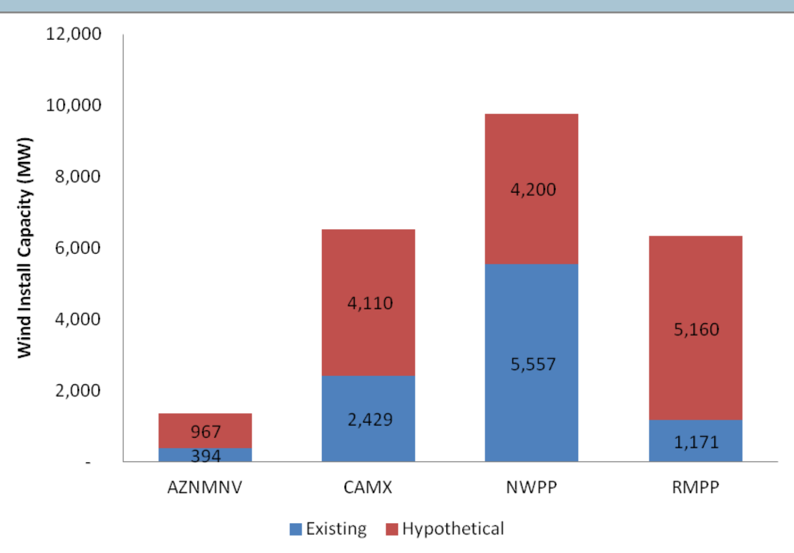
Hypothetical Wind Site



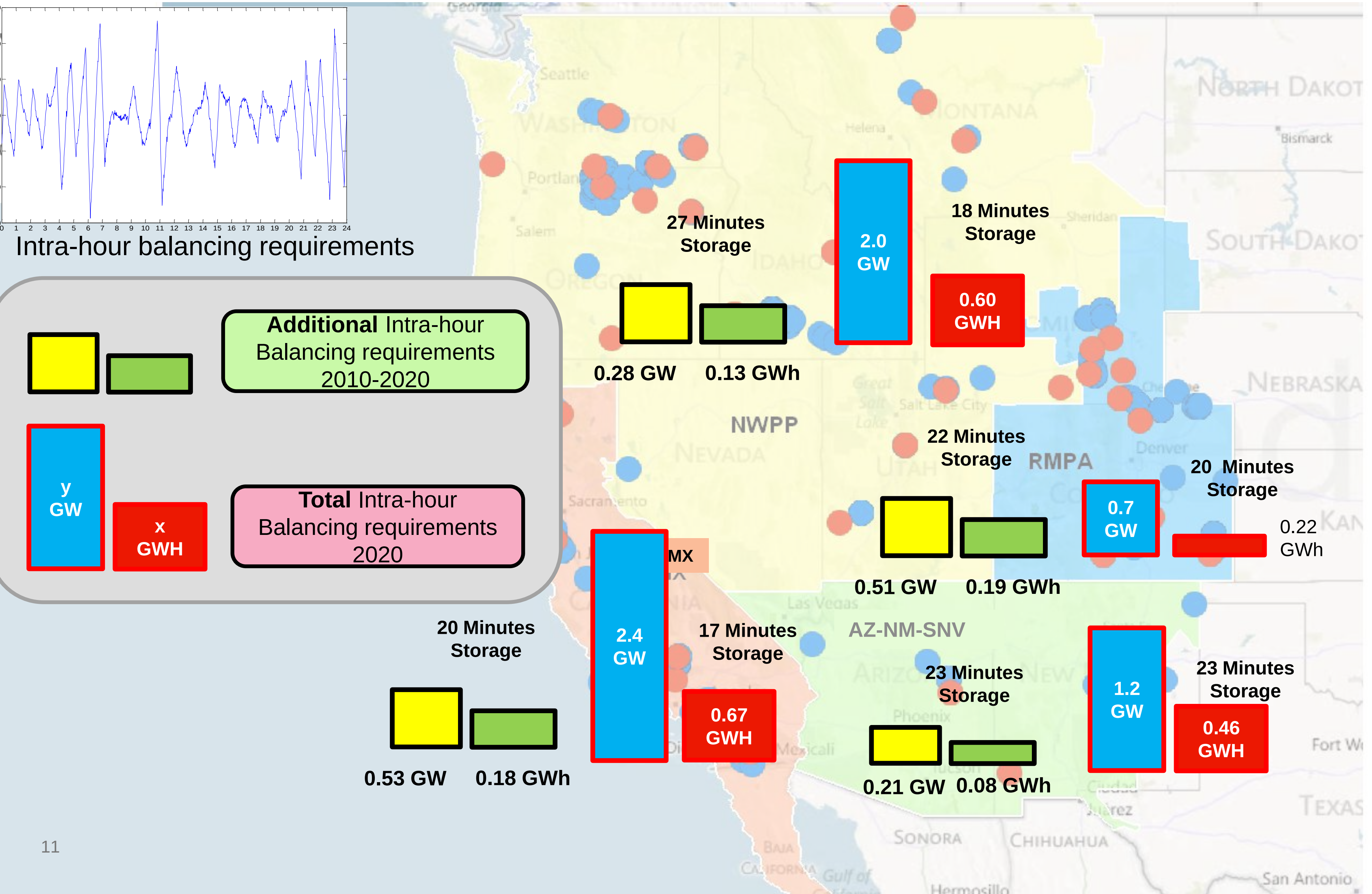

**<u>WECC-wide Wind capacity</u>**

- Existing (2010): 9.6 GW
- New (2011-2020): 14.4 GW

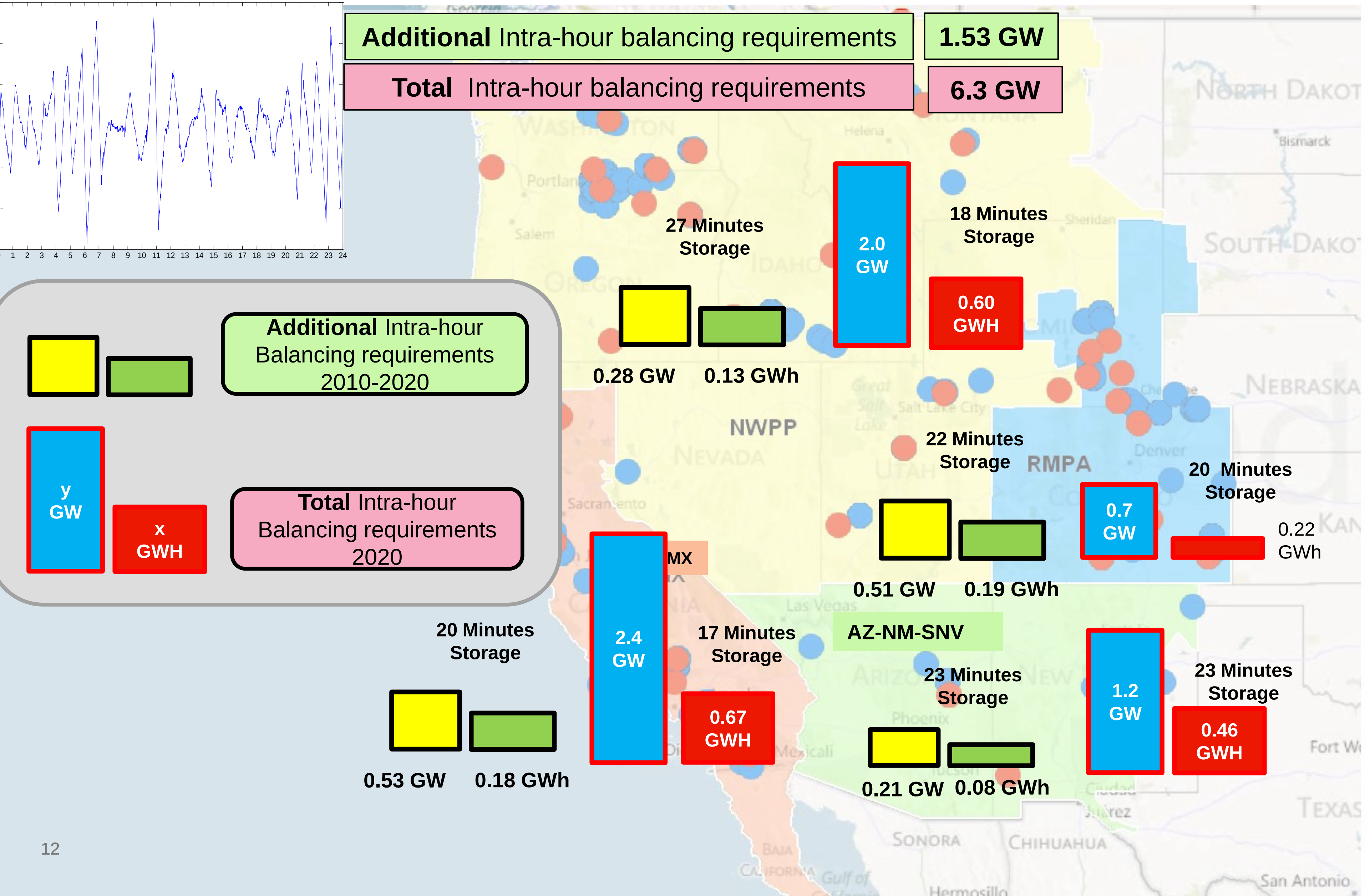
**Total wind capacity: 24.0 GW**



# Intra-hour Balancing Requirements for WECC for a 2020 Grid Scenario



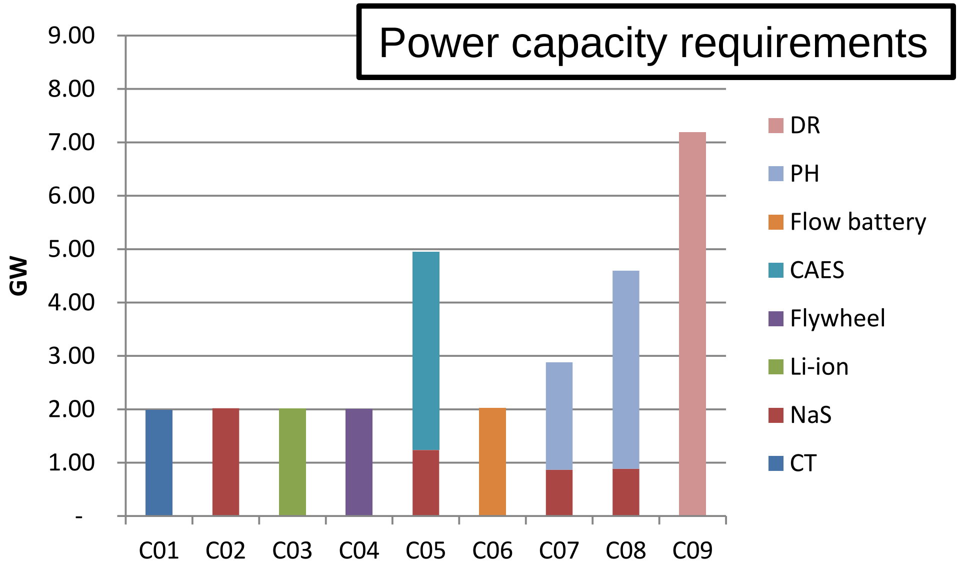
# Intra-hour Balancing Requirements for WECC for a 2020 Grid Scenario

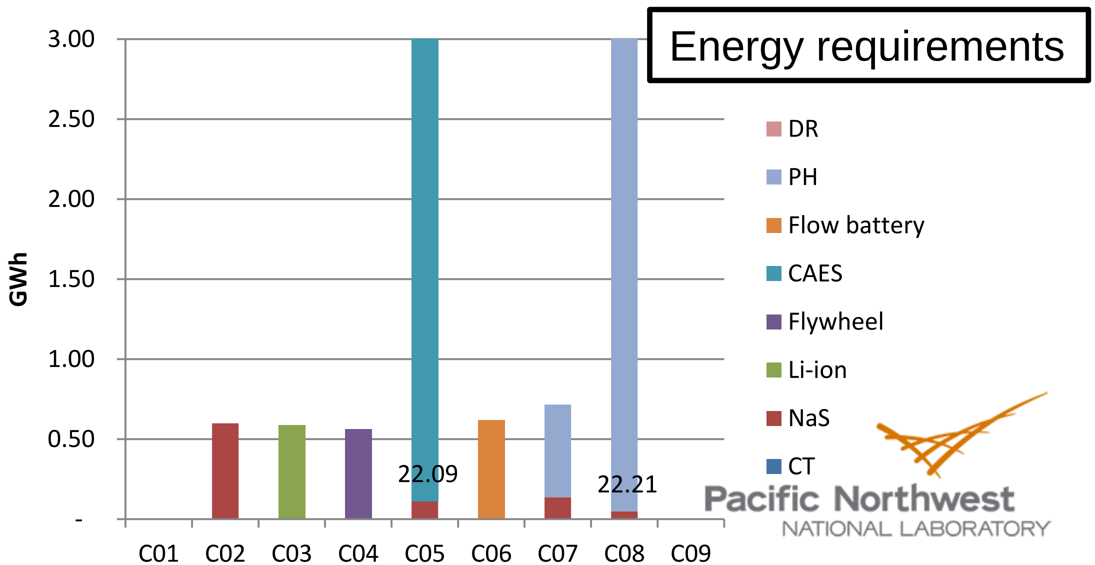


# Capacity and Energy Requirements of all Technologies to meet Total Intra-hour Balancing in 2020

## North West Power Pool

| Case | Technology | GW | GWh |
|---|---|---|---|
| C1 | Combustion turbine | 1.99 | - |
| C2 | NaS | 2.02 | 0.60 |
| C3 | Li-ion | 2.02 | 0.59 |
| C4 | Flywheel | 2.00 | 0.56 |
| C5 | CAES 2 modes | 3.71 | 22.09 |
| | 7 min waiting period, NaS | 1.24 | 0.11 |
| C6 | Flow battery | 2.03 | 0.62 |
| C7 | PH multiple modes | 2.01 | 0.58 |
| | 4 min waiting period, NaS | 0.87 | 0.14 |
| C8 | PH 2 modes | 3.71 | 22.21 |
| | 4 min waiting period, NaS | 0.89 | 0.05 |
| C9 | DR | 7.19 | - |

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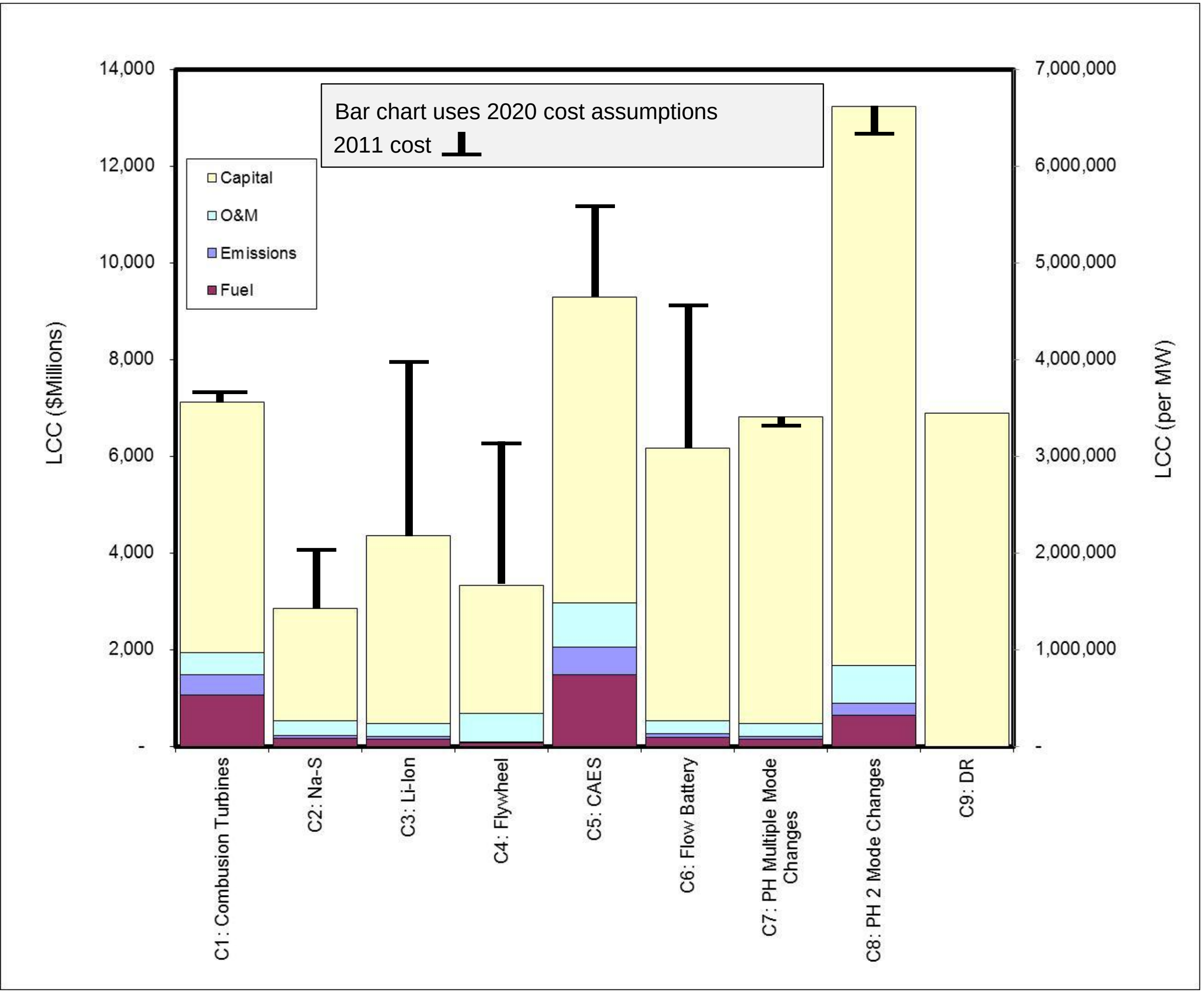
# Cost Performance Characteristics (2020)

| Parameter | NaS Battery | Li-ion Battery | Pumped Hydro | Combustion Turbine | Combined Cycle | Demand Response | CAES | Flywheel | Redox Flow Battery |
|---|---|---|---|---|---|---|---|---|---|
| **Battery Capital Cost – Energy Capacity $/kWh** | 290 (181-331) | 510 (290-700) | 10 | | | | 3 | 115 (81-148) | 131 (88-173) |
| System Capital Cost – Power Demand $/kW | | | 1,890 (1,640-2,440) | 990 | Not Used | 620 | 850 (500-1,140) | 610 (200-820) | 775 (608-942) |
| **PCS ($/kW)** | 150 | 150 | | | | | | | 150 |
| BOP ($/kW) | 50 | 50 | | | | | | 50 | 50 |
| O&M fixed $/kW-year | 3 | 3 | 4.6 | 10.24 | 14.93 | | 7 | 18 | 5 |
| O&M fixed $/kW-year (PCS) | 2 | 2 | | | | | | | 2 |
| O&M variable cents/kWh | 0.7 | 0.7 | 0.4 | 0.9 | 0.4 | | 0.3 | 0.1 | 0.1 |
| Round trip efficiency | 0.78 | 0.80 | 0.81 | 0.315 | | | 0.50 | 0.85 | 0.75 |

Redox flow – assume peak power/rated power = 1.4
Stack cost 2020 - $352-639/kW (average = 496/kW)

# Life-Cycle Cost Results




**Key outcomes**

- Results are capital cost driven
- Na-S, Flywheels, and DR, PH at current cost are cost competitive (LCC) today
- Li-ion, Redox-Flow will be cost-competitive with CT
- Consistent with current activities in the storage market. Primarily 15-20 minute products

# Hybridization Opportunities

- Motivation: identifying cost optimal hybrid system where we pair the complementary technologies (slow and fast responding devices)

- Results
  - Unless there are physical constraints (e.g., ramp limits), the optimal solution is determine solely by capital cost
  - Our minute by minute simulation did NOT find limiting ramp rates of any investigated technologies
  - Unless you looking at power-quality or sharp transients, hybridization may be only driven by cost.
  - Different tools, such as PLSF must be used to analyze advantages of hybrid systems

# Opportunity for

# Storage > 1 hour Duration

# Cost Targets for Storage >1 Hour Duration

Net revenue (energy+capacity) > cost recovery

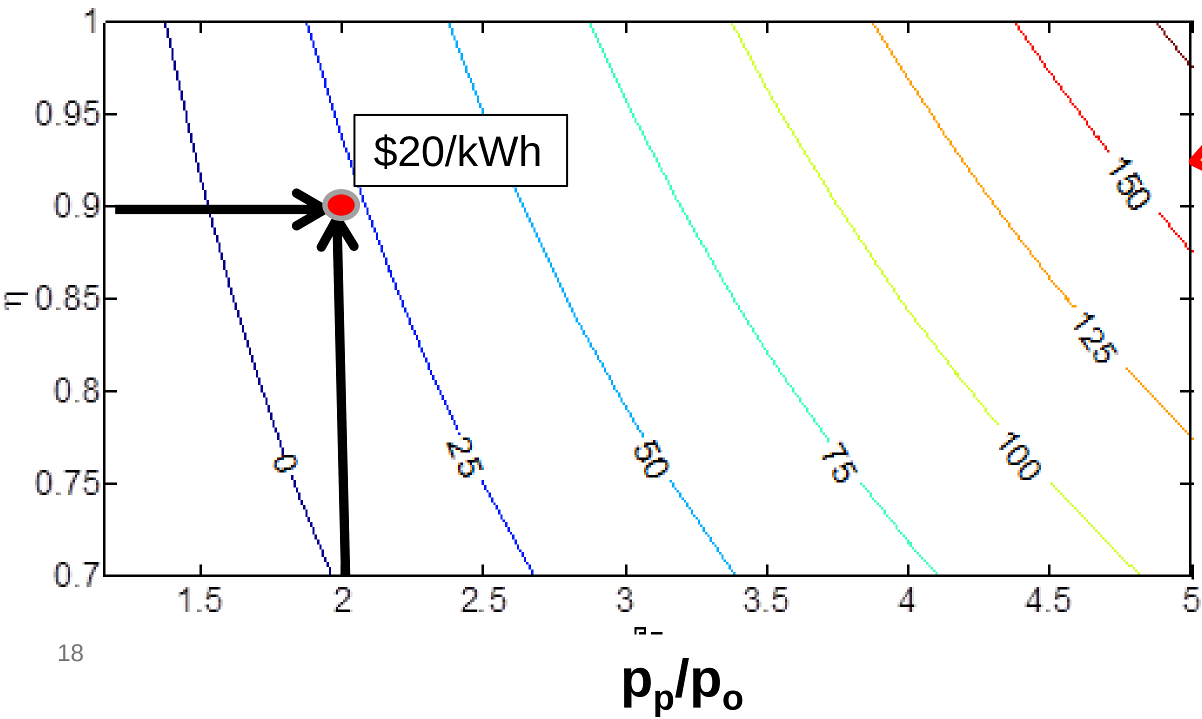
Annual net revenue = $f\,(\eta, p_p, p_o, No\ of\ days)$

Annual Cost recovery = $f\,(C_{PCS}, C_{Sto}, \alpha, d)$

Assumptions

- $C_{PCS}$ = \$150/kWh
- $D$ = 260 days
- $d$= 8 hour
- $\alpha$ = 0.12
- $p_o$ = \$40/MWh

## Incremental capital cost of storage [\$/kWh]

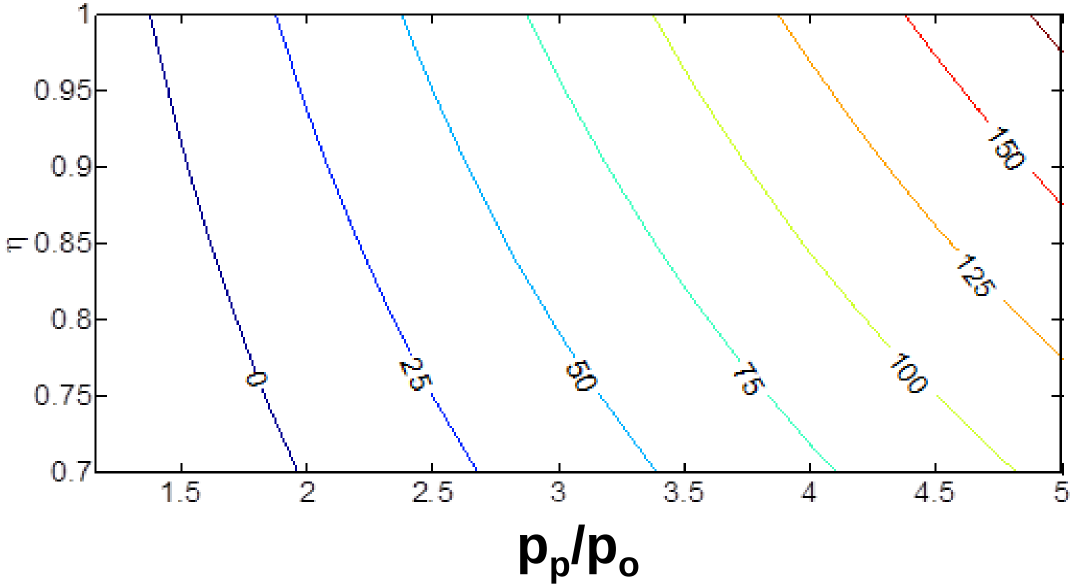



**Key Outcomes**

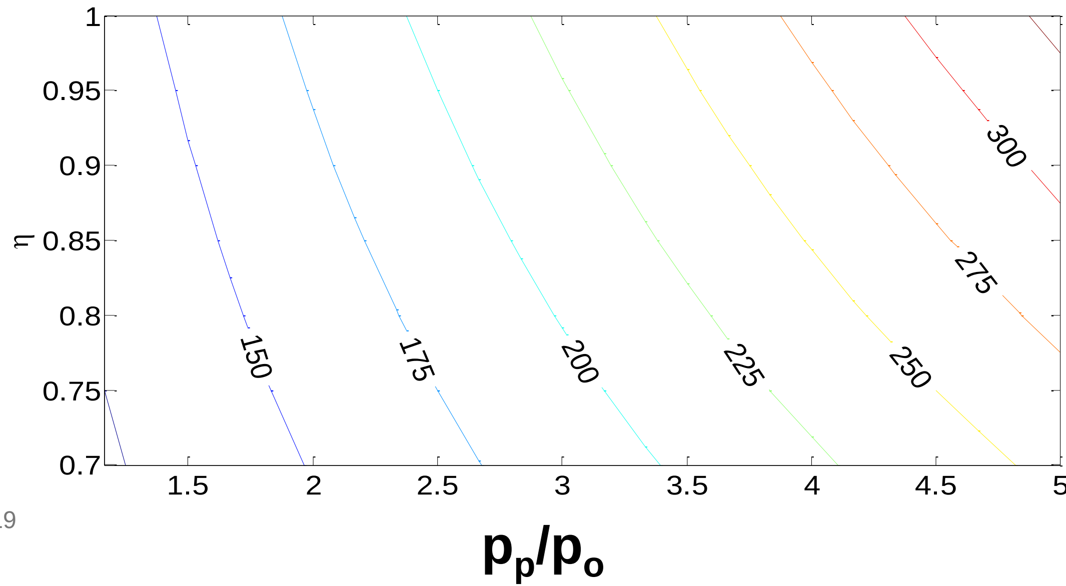
- **Energy** low value, thus cost targets must be unrealistically low (>\$100/kWh)
- currently incr. capital cost \$300-\$1000/kWh
- **Capacity** value must be utilized for 4-8 h storage to be economically viable

# Cost Targets to Justify Storage for Energy Arbitrage?

Incremental cost of storage [$/kWh]

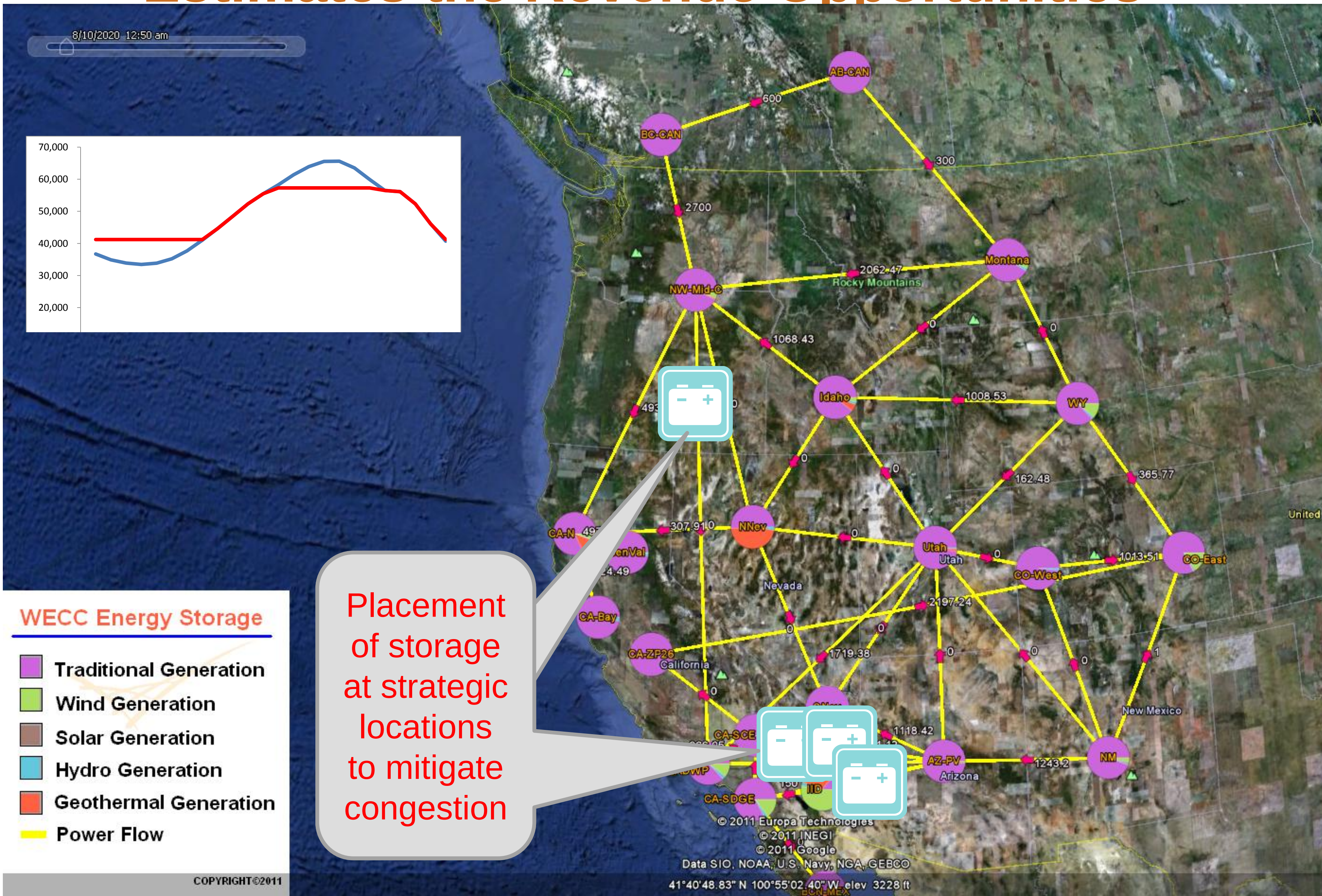



Cost target based on
- **Energy** value only

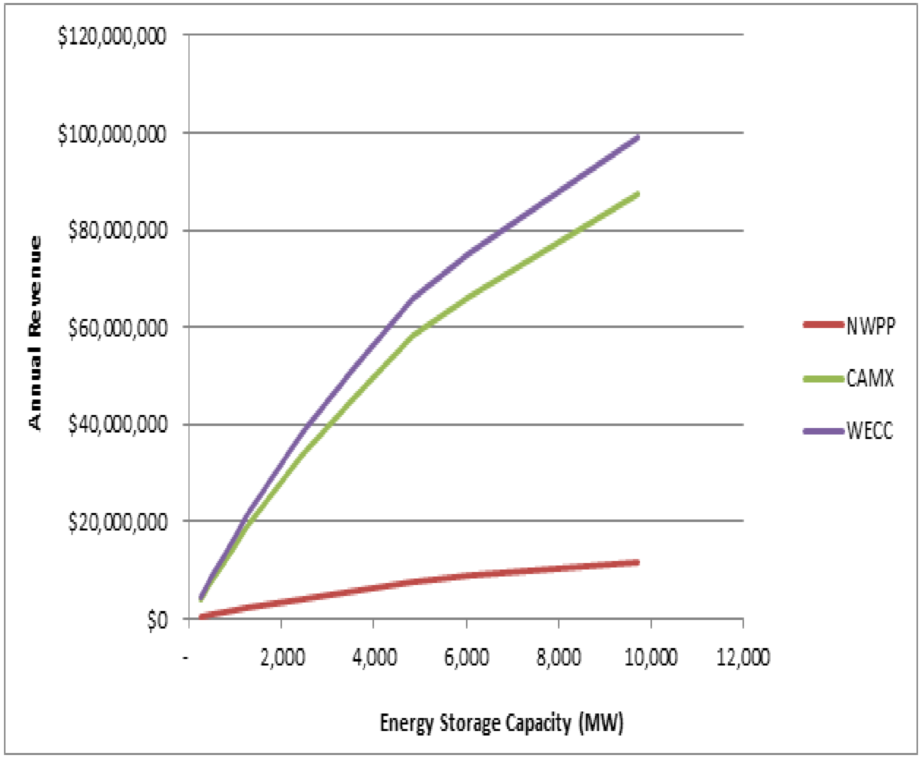


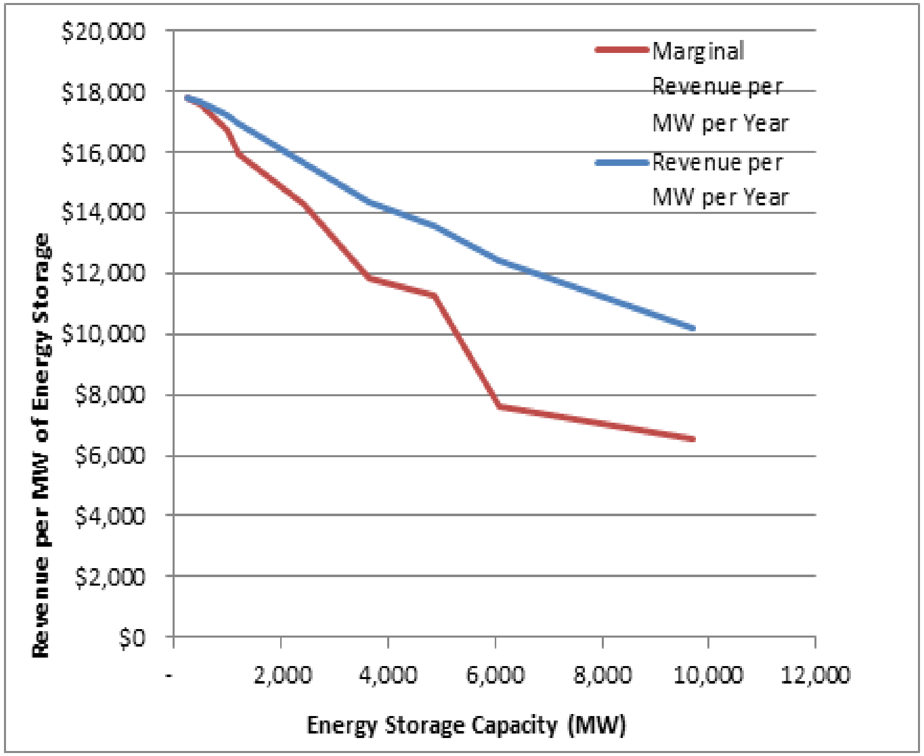

Cost target based on
- **Energy** value and
- **Capacity** value of $150/kW-yr

# Detailed Production Cost Modeling Estimates the Revenue Opportunities



# Revenue Expectations from Energy Arbitrage

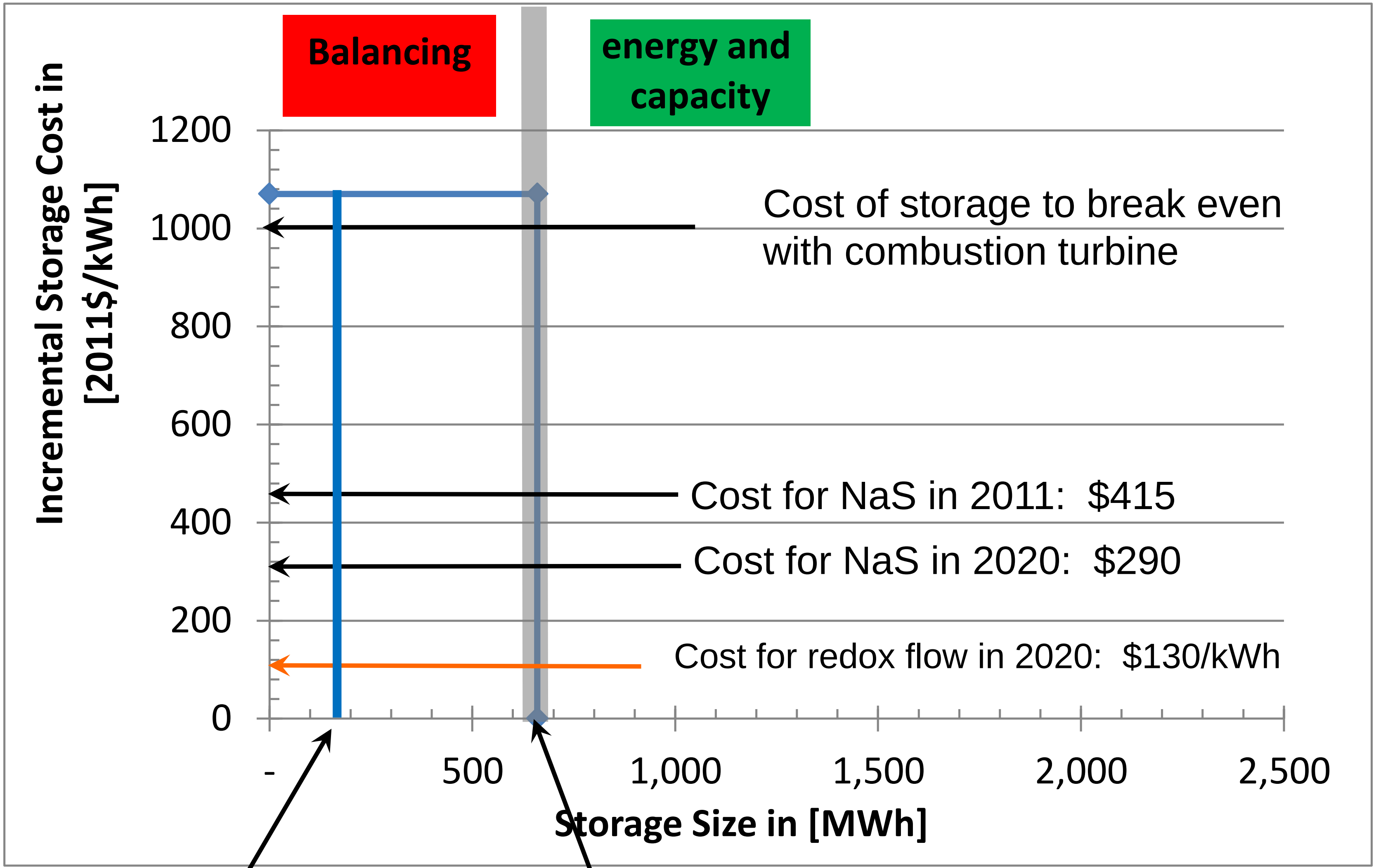



**Key Outcomes**

- **Wholesale <u>energy value</u> is low and is insufficient to solely justify storage >1 hour**
- **<u>Capacity value</u> necessary for business case of storage >> 1hour**

# Market Potential for Storage in NWPP




130 MWh for add. intra-hour Balancing 2010-2020

600 MWh for total intra-hour Balancing 2020

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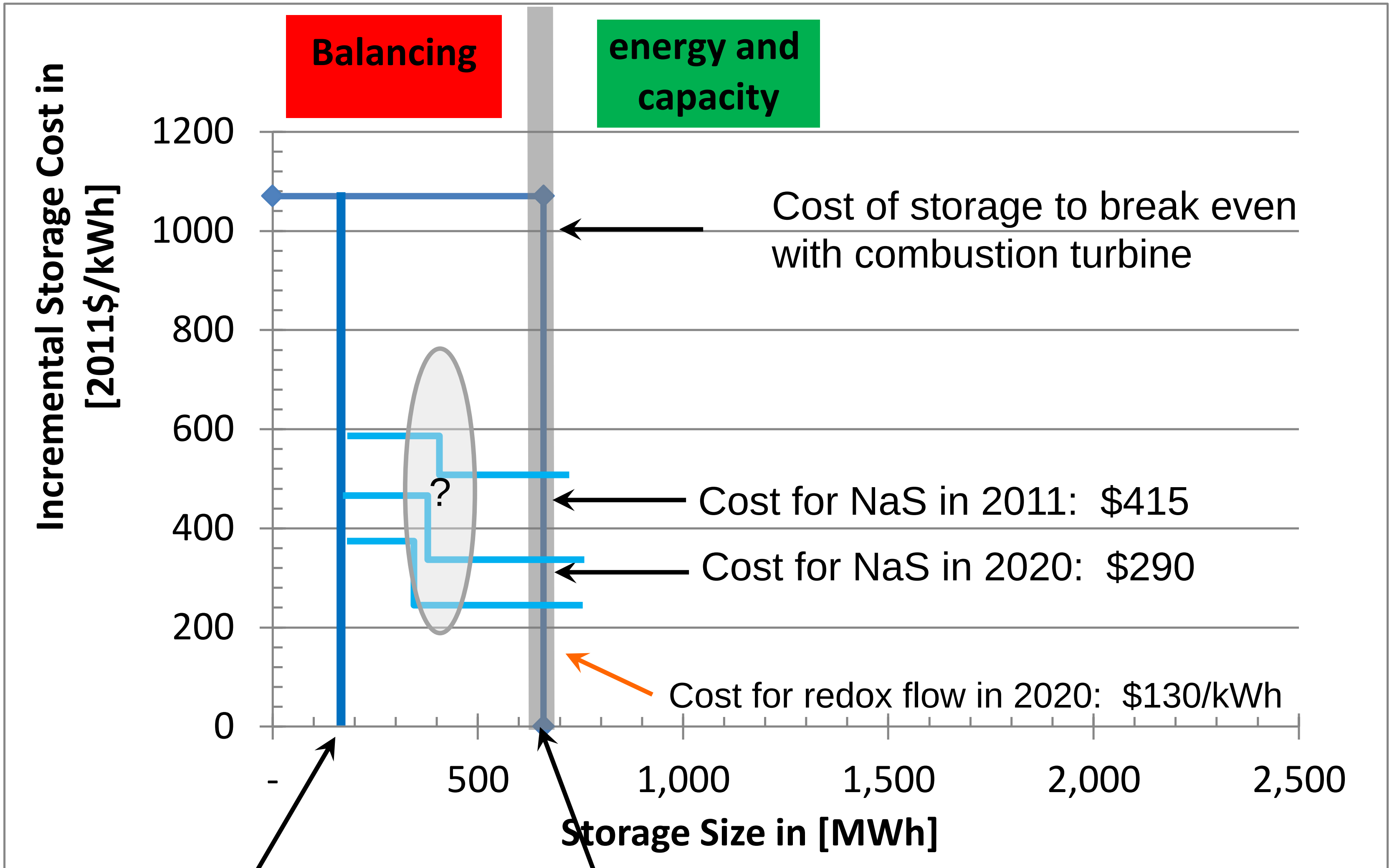
# Market Potential for Storage in NWPP




130 MWh
for add. intra-hour
Balancing 2010-2020

600 MWh
for total intra-hour
Balancing 2020

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# Portland General Electric

## NW Energy Systems Symposium
## Electric Vehicles and the Grid
## March 22, 2012


# Topics

1. About Portland General Electric
2. Types of Vehicles
3. Charging Levels
4. Load Shapes
5. Load Forecasting
6. Infrastructure Projects

Baldock Solar Highway Project
1.75 MW
Portland General Electric
Oregon Department of Transportation

# Portland General Electric

- 4,000-square-mile operating area
- 43% of Oregonians depend on PGE for electricity
- More than 200 Level 2 charging stations and 3 DC Quick charge stations



Sunway Solar Highway Project
104 kW
Portland General Electric
Oregon Department of Transportation


Portland General Electric
• 821,000 Customers
• 52 Cities served
• All time Peak Load 4078 MW
• 10.1 cents /kWh average residential rate
© Portland General Electric 4 4

# Types of Electric Vehicles

| Attributes | Hybrid | PHEV<br>Plug-in Hybrid | NEV<br>Neighbor-hood | BEV<br>Battery Electric Vehicle |
|---|---|---|---|---|
| Plug-In | No | Level 1, 2 | Level 1 | Level 1, 2<br>DC Quick Charge* |
| Range | 4-500 mi. | 4-500 mi. | 40 mi. | 80 – 240 mi. |
| All Electric Range | n/a | 12-40 | 40 mi. | 80 – 240 mi. |
| Examples | Prius<br>Escape<br>many others | New Prius<br>GM Volt,<br>Conversions | GEM<br>Miles | Nissan Leaf *<br>Ford Focus<br>Mitsubishi I *<br>Tesla Roadster |

# EVs in Oregon

## Here Now

Staples

Frito-Lay

Smith-Newton Delivery Trucks

Tesla Roadster

Smart Car ED

Nissan Leaf

Ford Transit Connect Fleet

Mitsubishi I

Chevrolet Volt

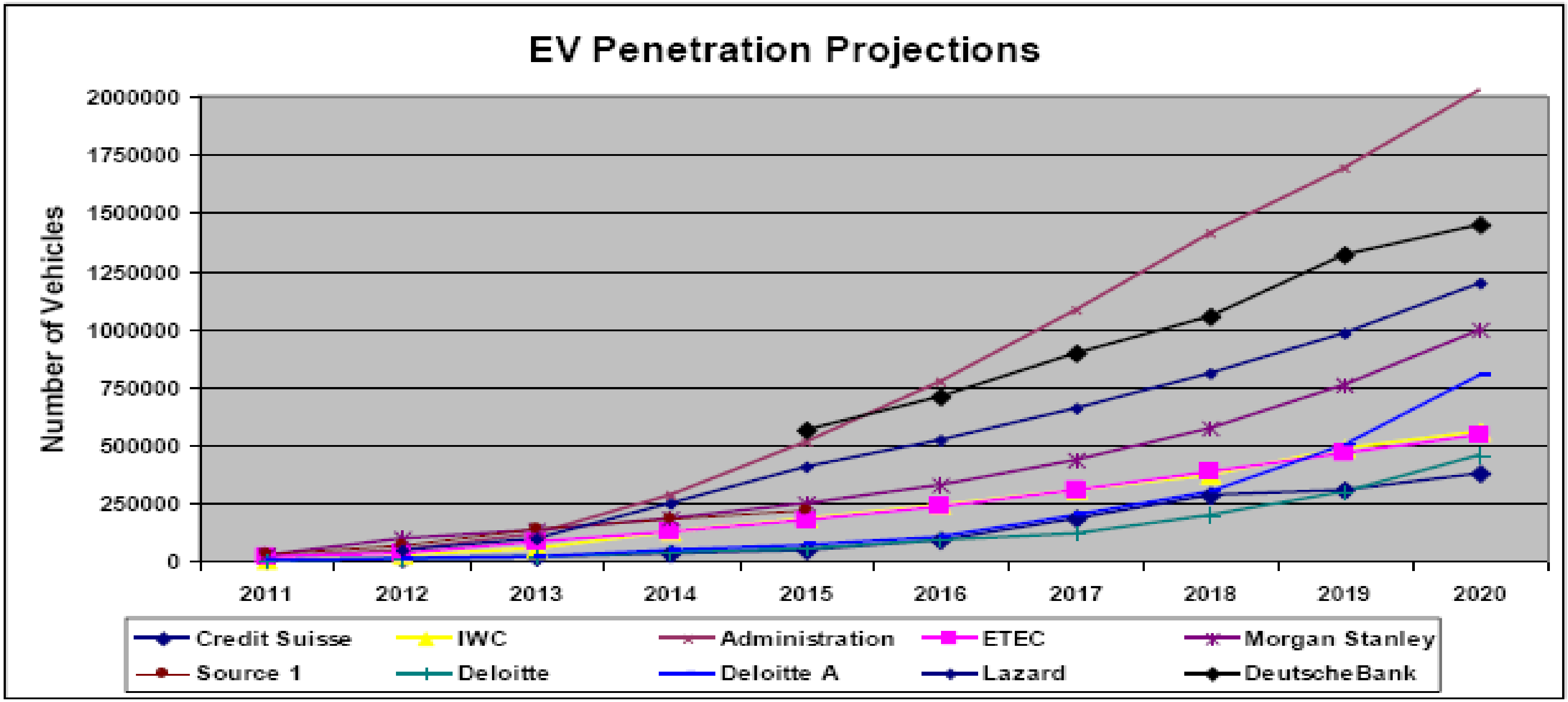
## Coming in 2012

Ford Focus

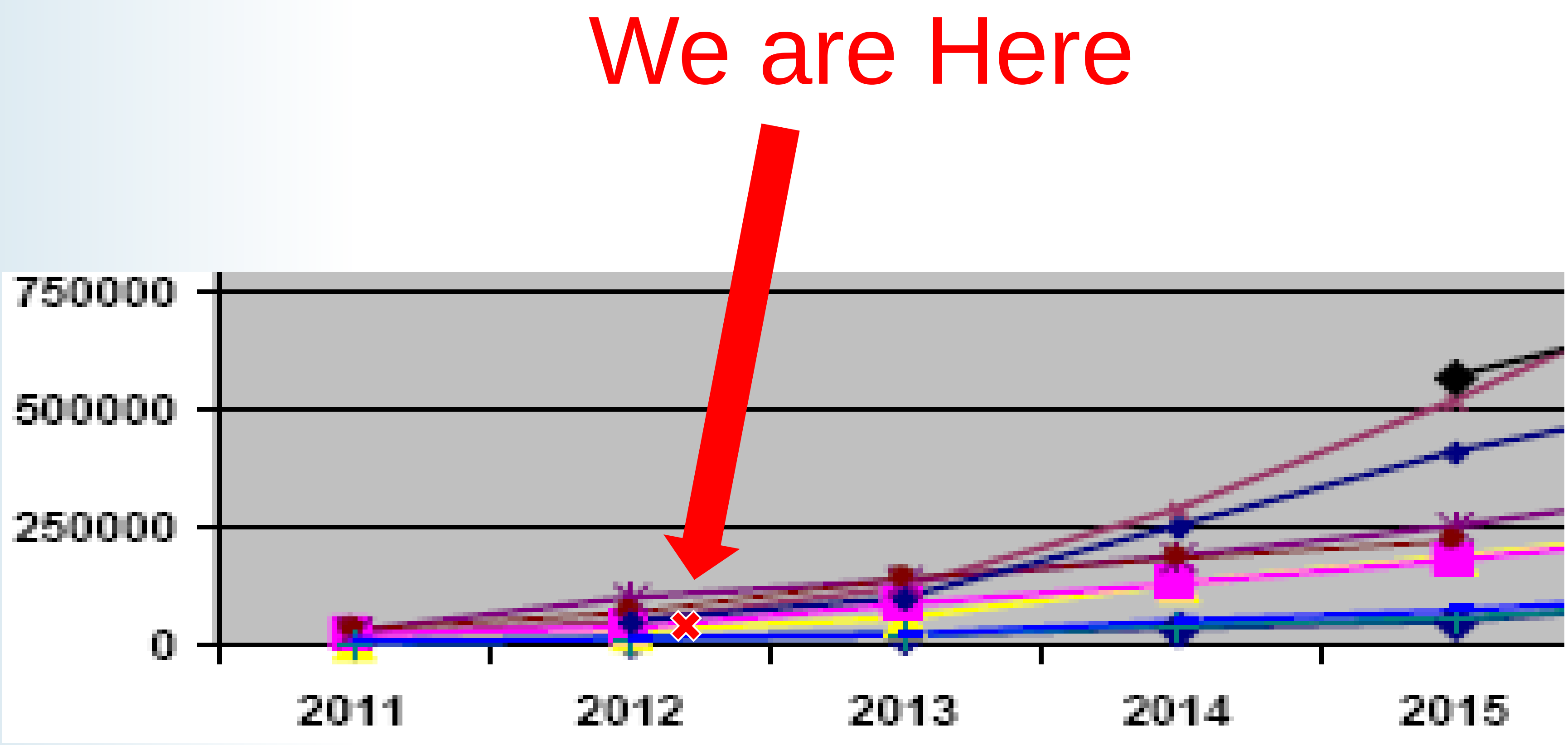
Toyota Prius
10 Demo cars in Oregon now

Tesla Model S

# Vehicle Sales Projections in U.S.



# Vehicle Sales Projections



# Charging Levels

| Level | Input Voltage | Typical Charging Times* (miles added per unit of charge) | Breaker Size (A) | Electrical Loads (kW) |
|---|---|---|---|---|
| 1 | 120 V | 12+ hours<br>(4 miles per hour of charge) | 15-20 | 1.65 |
| 2 | 240 V | 2 – 4 hours<br>(12 - 24 miles per hour of charge) | 40 amp typical | 3.3 - 6.6 |
| DC Quick Charge | 480v or 208v<br>3 phase | 20 – 40 minutes<br>(4 miles per minute of charge) | Varies | 20-60+ |

*Typical Charging times vary. They depend on how far the car was driven

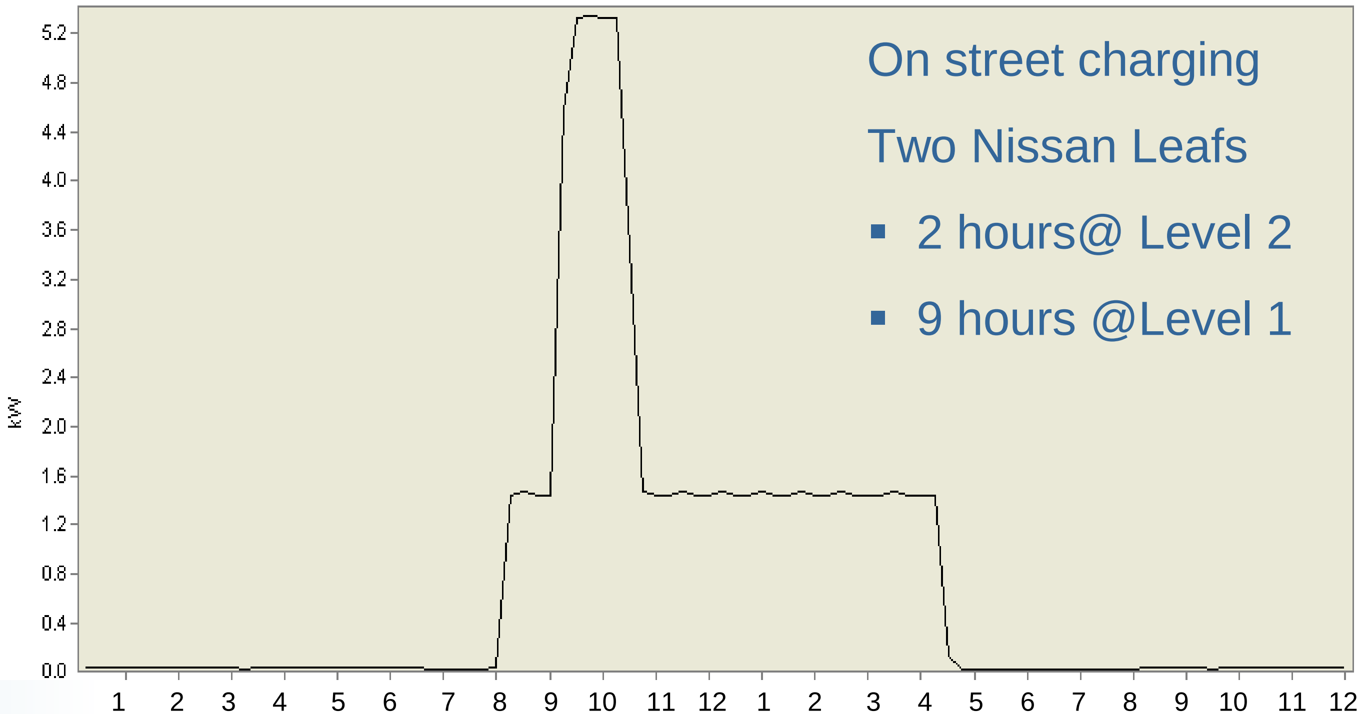
# Will all charging locations work with my car??

| | | | |
|---|---|---|---|
| **Level 1** | **120 volts**<br>**Dedicated outlet** |  | **Most new vehicles will come with a special cordset** |
| **Level 2** | **208 or 240 volts**<br>**Special Connector** |  | **Most new vehicles will use this standard connector**<br> |
| **DC Quick Charge** | **3 Phase Power** |  | **Nissan Leaf**<br>**Mitsubishi i-Miev** |

# 4 different Levels charging at once


| | | | |
|---|---|---|---|
| **Tesla** | **A123** | **Mitsubishi** | **Nissan** |
| **Roadster** | **Prius** | **i MiEV** | **Leaf** |
| **208 volts** | **120 Volts** | **208 volts** | **390 volts** |
| **70 amps** | **12 amps** | **16 amps** | **81 amps** |
| **Level 2** | **Level 1** | **Level 2** | **DC Quick Charge** |

# Charging Profiles- Level 1 and 2 Charge


Level 1= 1.44 kW

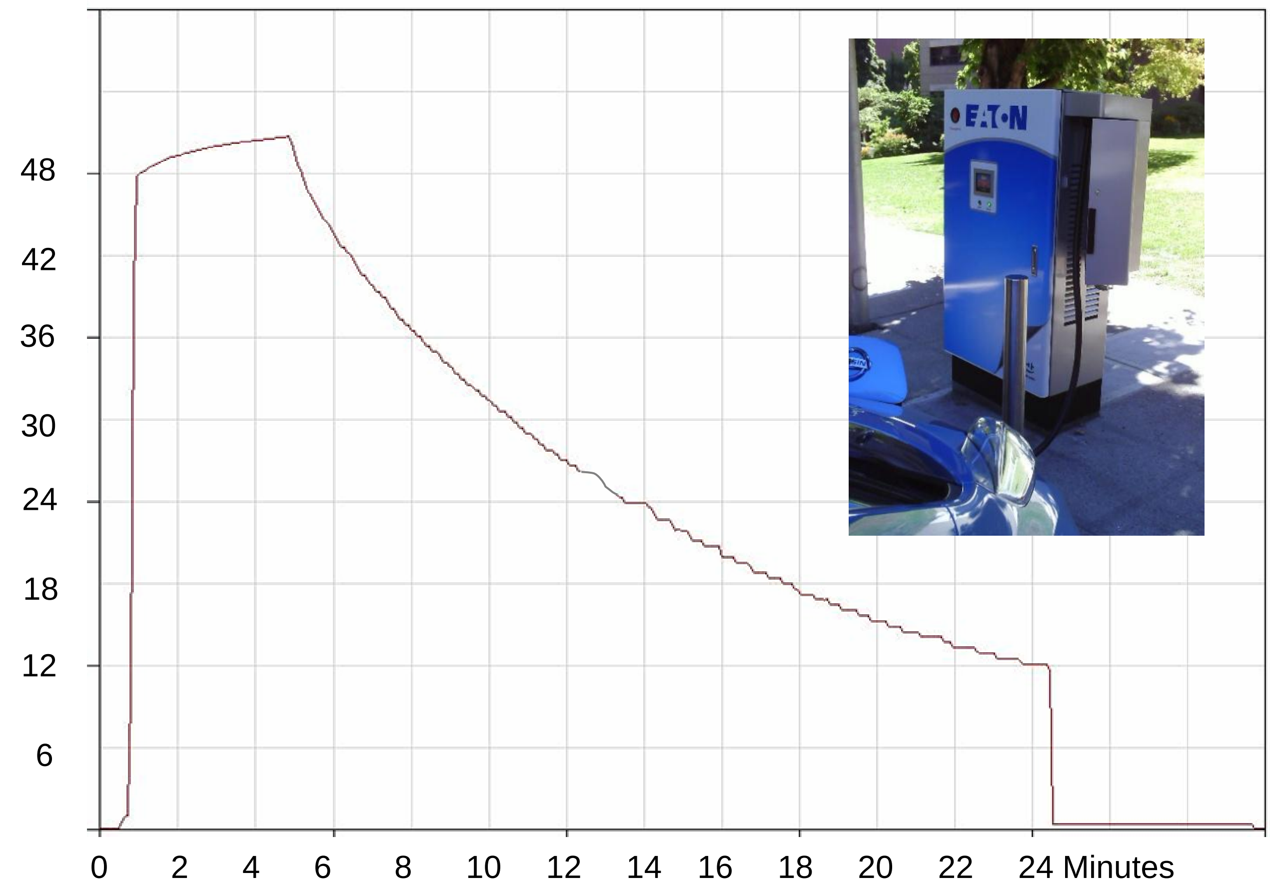
Level 2= 3.8 kW

Total Charge was 17.2 kWh

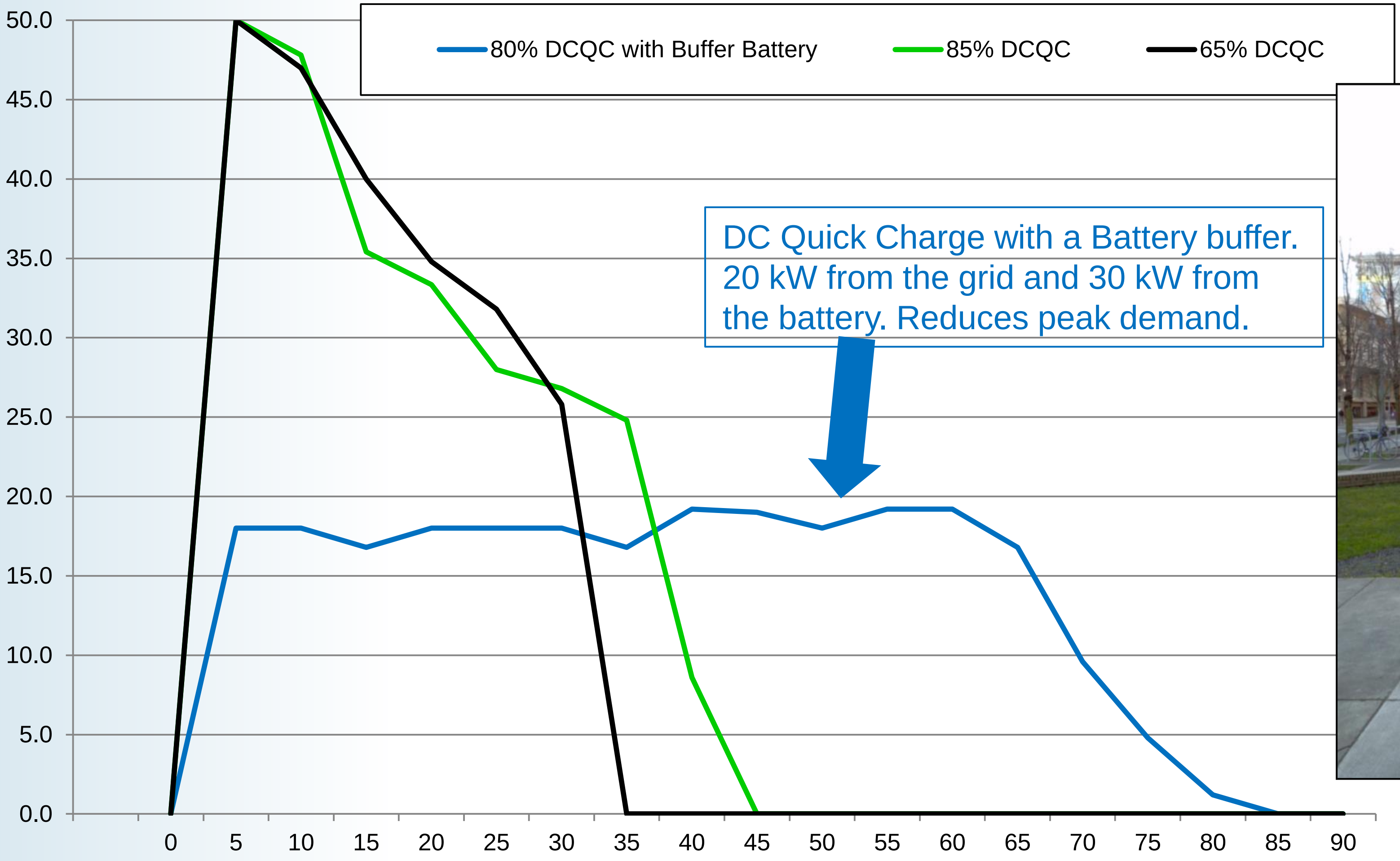
# Charging Profiles- DC Quick Charge

DC Quick Charger

- 50 kW
- 11 kWh in 23 minutes
- ~ 4 miles per minute of charge in the first 10 minutes



# Charging Profiles- DC Quick Charge




# How much load is added for a residential customer with an EV?

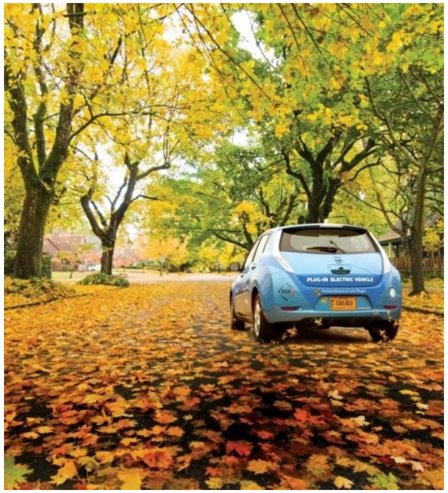
## Assumptions:

- 10,000 miles driven per year (some say 12-15k)
- All charging done at home (Probably not true)
- Approx 3-5 miles per every kWh used

## Answer:

10,000 miles/4 miles per kWh = 2500 kWh/year

# How much load is added for all residential customer EVs by 2015?



## Assumptions:

- 10,000 miles driven per year
- All charging done at home (worst case)
- Approx 4-5 miles per every kWh used
- 25,000 EVs in Oregon (Oregon 1% of US Population but with 2.5 times the adoption rate of other areas.)

## •Answer:

10,000miles/year x 25,000 vehicles / 4 miles/kWh / 8760000 kwh/MWa=**7 MWa**

# What will be the peak demand when EVs are charging?

## Assumptions:

- 25,000 cars in 2015
- All plugged in at the same time and charging at full rate
- Vehicle types and charge levels:
  - 20% PHEV at 1.6 kW = 25,000 x (.2 x 1.6kW) = 8,000 kW
  - 30.8% charging at 3.3 kW = 25,000 x (.308 x 3.3kW) = 25,410 kW
  - 39% charging at 6.6 kW = 25,000 x (.39 x 6.6kW) = 64,350 kW
  - 10% on the road = 25,000 x (.1 x 0 kW) = 0 kW
  - .2% charging at 50kW = 25,000 x ( .002 x 50kW)= 2,500 kW


## Answer:

**= (8,000+25,410+64350+0+2,500)/1000 = 100 MW**

# What will be the peak demand when EVs are charging during the day? (Let's be more realistic !!)

## Assumptions:

- 25,000 cars in 2015 (2.5 times the adoption rate of other areas)
- Daytime 70 % of the people are at work or shopping not charging, more using quick charge stations but are only at 30 kW after 10 min
  - 4% PHEV at 1.6 kW = 1,620 kW
  - 6.8% charging at 3.3 kW = 5,610 kW
  - 9% charging at 6.6 kW = 14,850 kW
  - 10% on the road = 0 kW
  - 70% at work or shopping = 0 kW
  - .2% charging at 30kW = 1,500 kW Total = 24 MW

- Only 1/2 of the people charging at level 1 or 2 overlap their full charge time, since they have only driven 30 miles in the day and their charge time is over or their charge rate is lower when others plug in.

## Answer: 13 MW

# What will be the peak demand when EVs are charging during the night? (Let's be more realistic !!)

## Assumptions:

- 25,000 cars in 2015
- Nightime 20 % of the people are at work or shopping not charging, very few using quick charge stations but are only at 30 kW after 10 min
  - ➢ 16% PHEV at 1.6 kW = 6,400 kW
  - ➢ 24% charging at 3.3 kW = 19,800 kW
  - ➢ 29.95% charging at 6.6 kW = 49,418 kW
  - ➢10% on the road = 0 kW
  - ➢20% at work or shopping = 0 kW
  - ➢.05% charging at 30kW = 375 kW Total = 76 MW

➢Only 1/2 of the people charging at level 1 or 2 overlap their full charge time, since they have only driven 30 miles in the day and their charge time is over or their charge rate is lower when others plug in.

## Answer: 38 MW

# Assumptions that will change


**Adoption rate**

- Fuel Prices, Media reports, Incentives, vehicle pricing

**How far people drive**

- 3 months after ownership users are more range aware

**When they charge**

- TOU rates, Critical Peak Pricing, customer habits

**Where they charge**

- Costs at public charging stations, availability of charging

**Charging rates**

- Types of vehicle availability

# Research in the works

**The EV Project**

- Ecotality
- 60+ Project Partners (Idaho National Lab, Nissan, GM, Utilities)

**Questions they will answer:**

- When do people charge
- Where do people charge (home, work, public charging)
- Length of Charge

**Other Things we would like to know**

- How far do they drive (per trip, monthly annually)
- How do these vary (length of ownership, fuel pricing, other???)

# The EV Project 4th Qtr 2011 Report

**Data collected so far on approximately**

- **4,000 Vehicles**
- **160,000 charging Events**
- **1.3 GWh energy consumed**
- **14 Million miles driven**

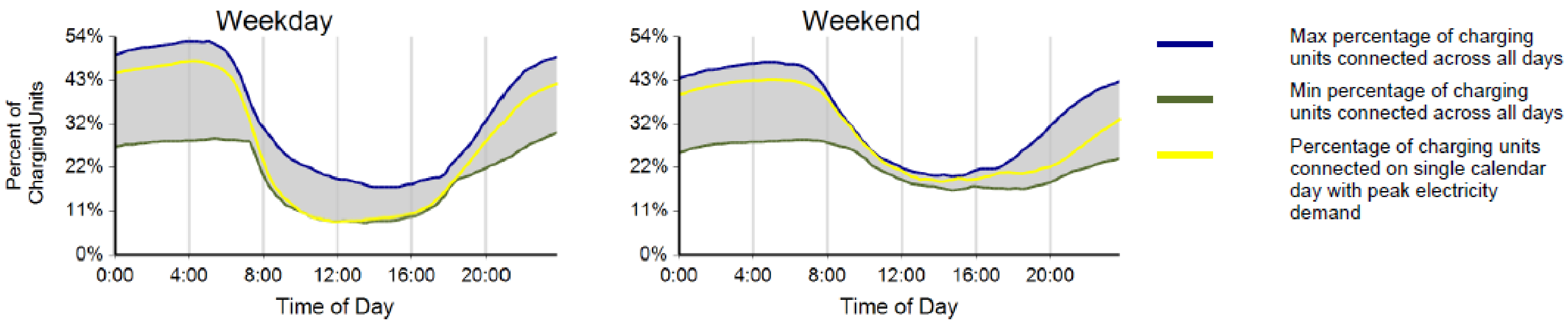
**Questions they will answer:**

- **When do people charge**
- **Where do people charge (home, work, public charging)**
- **How far do they drive (per trip, monthly annually)**
- **How do these vary (length of ownership, fuel pricing, other???)**

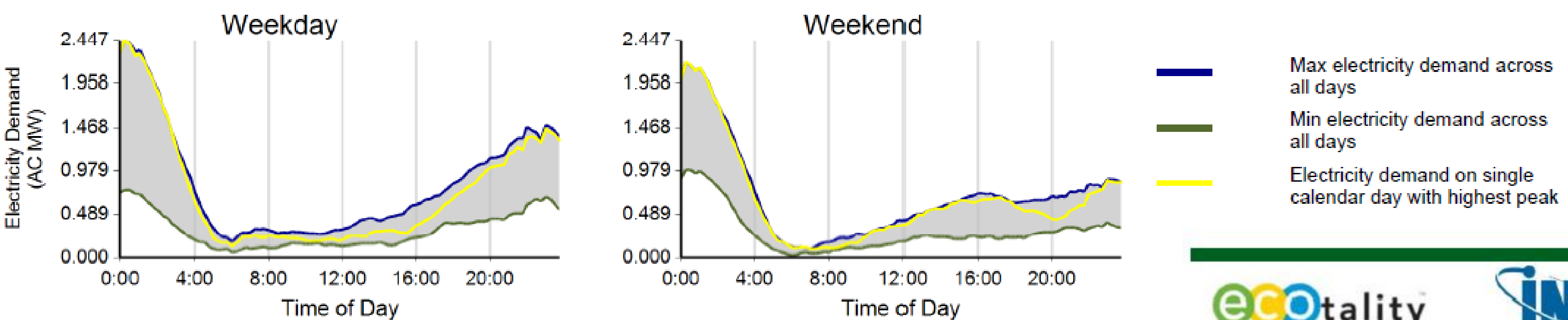
http://www.theevproject.com/documents.php

# The EV Project 4th Qtr 2011 Report

## Charging Availability: Range of Percent of Charging Units with a Vehicle Connected versus Time of Day[3]




## Charging Demand: Range of Aggregate Electricity Demand versus Time of Day[4]




ecotality NORTH AMERICA



INL Idaho National Laboratory

[1] Includes all charging units that were in use by the end of the reporting period

[2] A charging event is defined as the period when a vehicle is connected to a charging unit, during which period some power is transferred

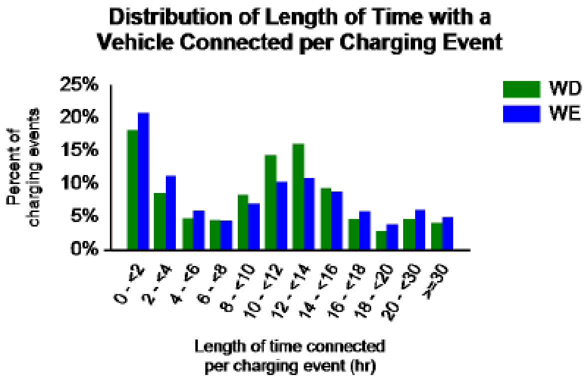
[3] Considers the connection status of all charging units every minute

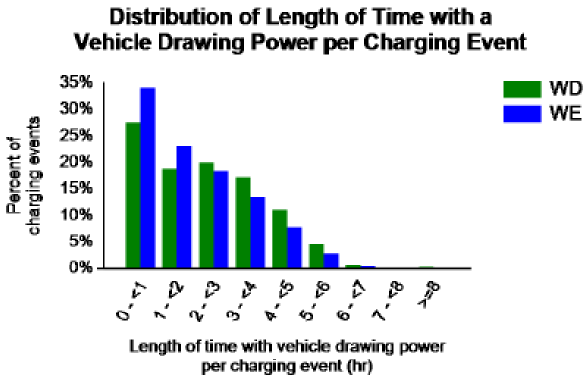
[4] Based on 15 minute rolling average power output from all charging units

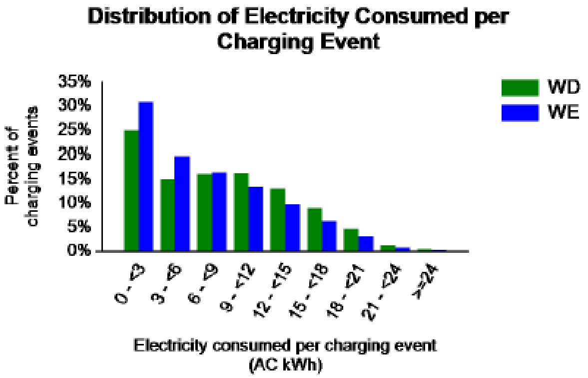
PGE

# The EV Project 4th Qtr 2011 Report

| Individual Charging Event Statistics | Weekday (WD) | Weekend (WE) | Overall |
|---|---|---|---|
| Average length of time with vehicle connected per charging event (hr) | 11.6 | 11.4 | 11.5 |
| Average length of time with vehicle drawing power per charging event (hr) | 2.3 | 1.9 | 2.2 |
| Average electricity consumed per charging event (AC kWh) | 8.3 | 6.9 | 7.9 |



# Infrastructure Projects

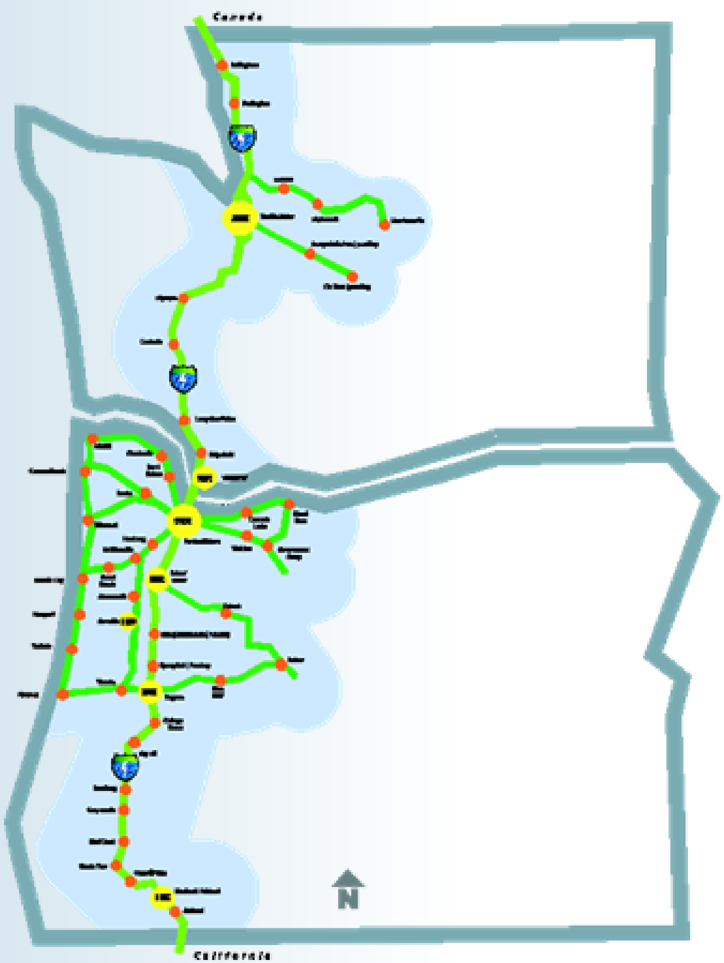


# WEST COAST ELECTRIC HIGHWAY


## West Coast Electric Highway Initiative

- The West Coast Electric Highway is the nation's most extensive, multi-state network of electric vehicle DC fast charge stations under development.
- Provide travelers with electric vehicle charging from "BC to Baja"
- The first part of the network, will span the 585 miles through Washington and Oregon along Interstate-5 from Canada to California with DC quick charge stations every 40 to 60 miles.
- Unique west coast driving experience with consistent infrastructure, branding and signage.

# Teaming up with other projects underway




**Washington DOT EV charging network:**

- 11 DCQCs along I-5, US 2 and I-90

**Oregon DOT I-5 Highway Project**

- 10 DCQCs along I-5 station USDOE, ODOE ~ $1m

**Electric Vehicle Corridor Connectivity Project**

- 22+ DCQCs- Western Oregon, USDOT, TIGER II (Transportation Investment Generating Economic Recovery) $3.4m

**The EV Project**

- ECOtality $40M to install cahrging in 6 regions of the country including Oregon and Washington
- ~2,000 public and fleet charging stations, including 40-60 Quick Chargers and 1800 residential stations for Nissan LEAF and GM Volt owners

**Charge America**

- Coulomb awarded $37M to install 5,000 charging stations in 37 regions, including eastern King County (Bellevue).

# Hope to see you down the road on the Electric Highway


## Rick Durst

**Portland General Electric**

**Transportation Electrification**

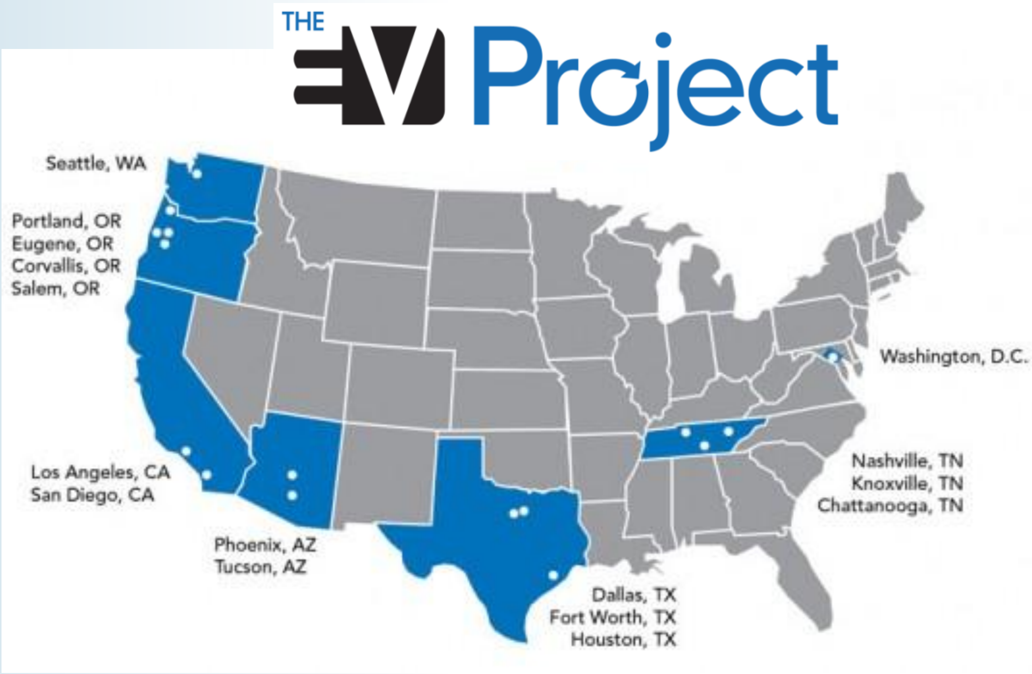
**Project Manager**

**Rick . Durst @ PGN.com**

**503-464-7631**


# US Dept of Energy's Transportation Electrification Project:

## $200+ million for EV Infrastructure




**•Nation-wide:**

•**14,000** Level 2 (240V) chargers

•**300 - 400** DC Fast Charger (480V) ports

•**5,700** Nissan LEAF cars

•**2,600** Chevrolet Volt cars

•**60+** project partners

•**1,200** new jobs by 2012 and

•**5,500** new jobs by 2017

•**18** major cities and metropolitan areas

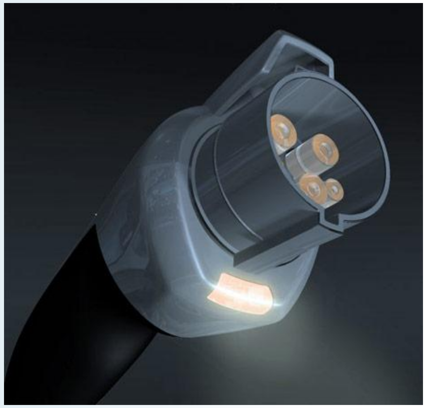
# AC Level II Charging Station

- 208/240VAC, SAE J-1772 connector
- Typically 6.6 kW maximum
- Tesla could be 14 kW charger, but requires a special connector


Blink - Ecotality

Aerovironment

Coulomb



SAE J1772 Connector

Shorepower


GE

Eaton

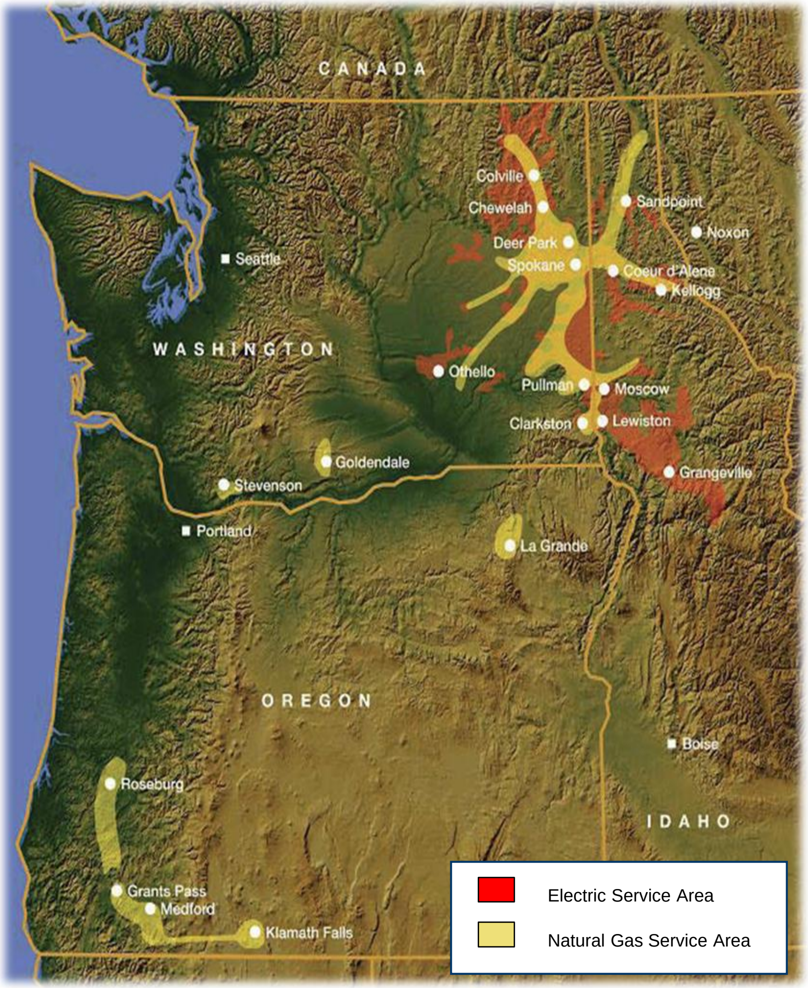
Evr-Green/ Leviton

# The Northwest's First Smart Grid Community Pullman, WA

*March 22nd, 2012*
*Curtis Kirkeby, PE*
*Sr. Electrical Engineer*
*Technology Strategy*
*Avista Utilities*

# Who Is Avista?

- Founded in 1889 as Washington Water Power
- Investor-owned, regulated gas and electric utility, headquarters in Spokane, Washington  USA
- 1,554 employees serving 359,000 electric and 319,000 natural gas customers in the states of Washington, Idaho and Oregon





AVISTA

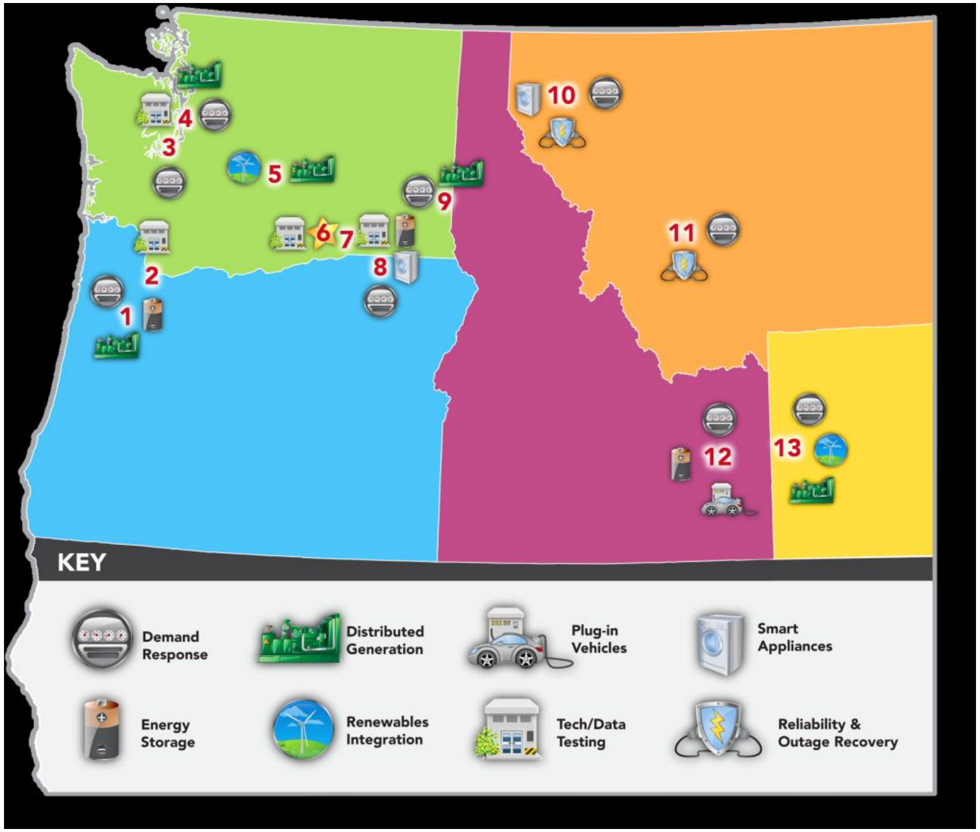
# Pacific NW Demonstration Project

**What:**

- $178M, ARRA-funded, 5-year demonstration
- 60,000 metered customers in 5 states

**Why:**

- Quantify costs and benefits
- Develop communications protocol
- Develop standards
- Facilitate integration of wind and other renewables




**Who:**

Led by Battelle and partners including BPA, 11 utilities, 2 universities, and 5 vendors

Website: http://www.pnwsmartgrid.org/

# Avista's Demonstration Project Scope


- 13 Circuits (59 circuits in Spokane)
- 3 Substations (14 more in Spokane)
- 13,000 Electric Customers (110,000 more in Spokane)
- 5,000 Gas Customers

*(Focused on Reliability, Energy Efficiency, and the Customer Experience)*

# The Opportunity for Reliability

**Demonstration Project (40 Months)**

### All Outages

- 650 Incidents
- 97,074 Customer-hrs
- ~ $970,740 Customer Cost

### FDR Lockout

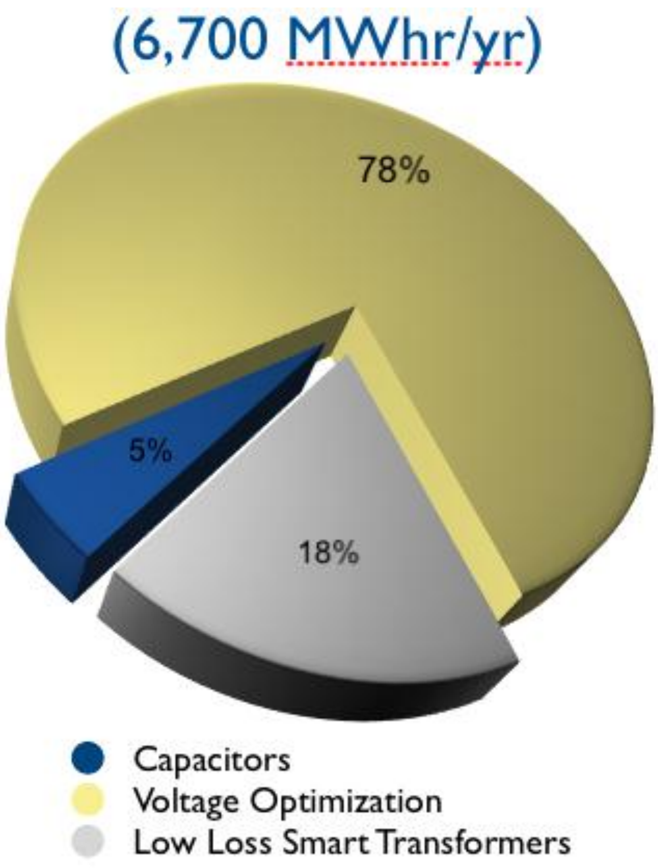
- 24 Incidents (4%)
- 88,201 Customer-hrs (91%)
- ~ $882,010 Customer Cost

### Reduction

- 24 Incidents (4%)
- 44,100 Customer (45%) Outage Hours
- ~ $440,100 Customer Cost (SAVED)

# The Opportunity for Energy Efficiency

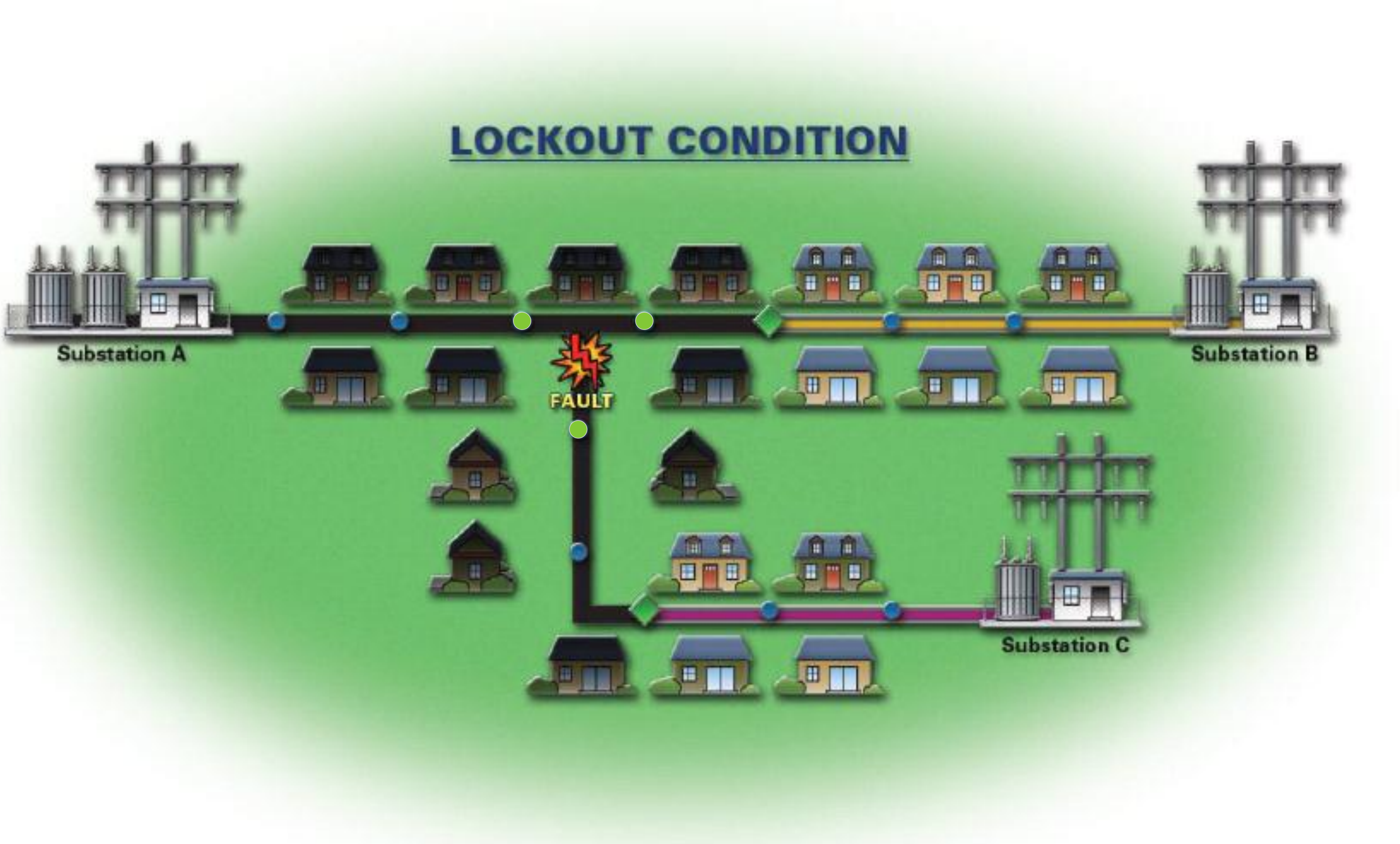
- Real-time, all the time
- Approximately 2% savings in load and losses
- Approximately 95% of savings is reduced customer loads
- Small reserve available for demand response
- Automated Optimization via Distribution Management System



# The Opportunity for Customers

- Understand energy consumption
- Understand how to affect energy consumption
- Gain budget control of energy usage
- Participate in a national experiment for transactive grid response
- Gain insight into energy savings opportunities via home upgrades such as insulation, windows, etc
- Encourage competition between neighbors, friends, blocks, co-workers, etc

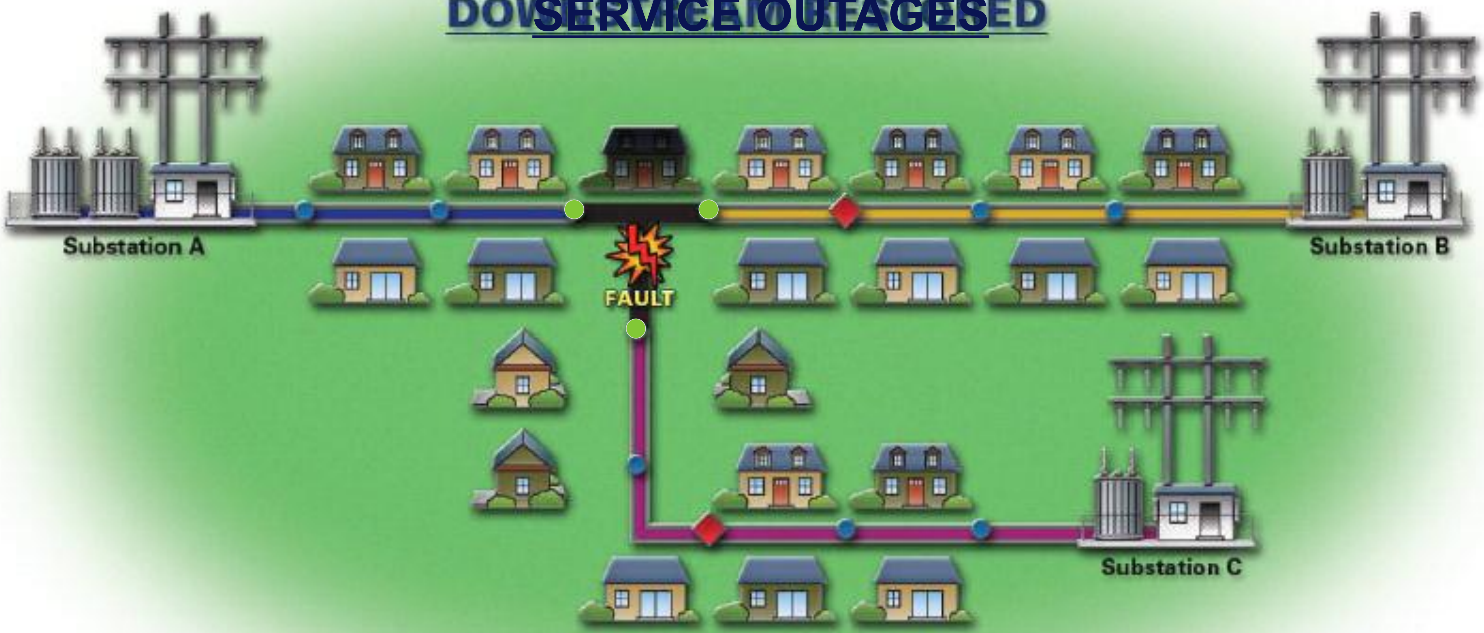
# Reliability Scenario


LOCKOUT CONDITION
Substation A
Substation B
FAULT
Substation C

# Reliability Scenario

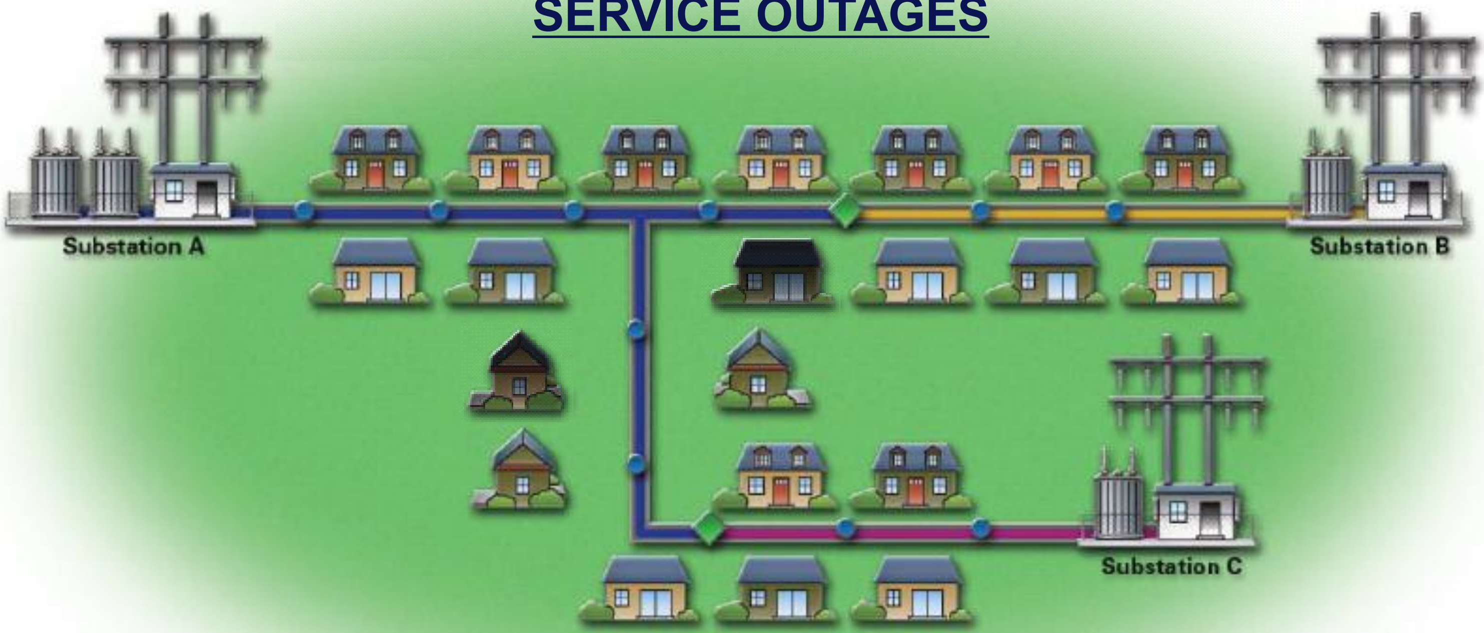
# Reliability Scenario

**AMI IDENTIFIES**
**SERVICE OUTAGES**



# Reliability Scenario

**AMI IDENTIFIES**
**SERVICE OUTAGES**

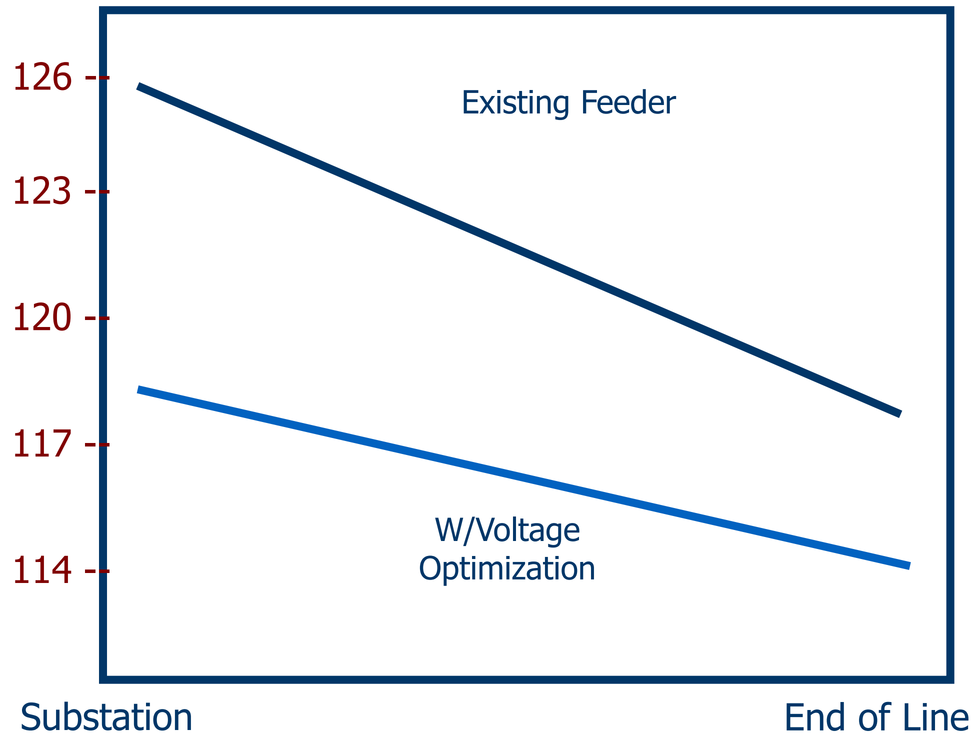


# Energy Efficiency-Smart Transformers

- High Efficiency Exceeding National Standards
- Real-time Sensors for Watts, VArs, Voltage, Winding Temperature, Loss of Life
- Equipped with Wi-Fi Routers to Extend the Control Communications Network

# Energy Efficiency-Voltage Optimization

- Power Factor Correction to Near Unity (fixed and switched capacitor banks)
- Voltage Regulation on Each Phase at Head End of Feeder
- Measures at Each Switch, Cap Bank, Voltage Regulator, Smart Transformer, and AMI Meter
- Automated Optimization via DMS




- AMI low & high voltage alarms for calibration of voltage optimization

# The Customer Experience

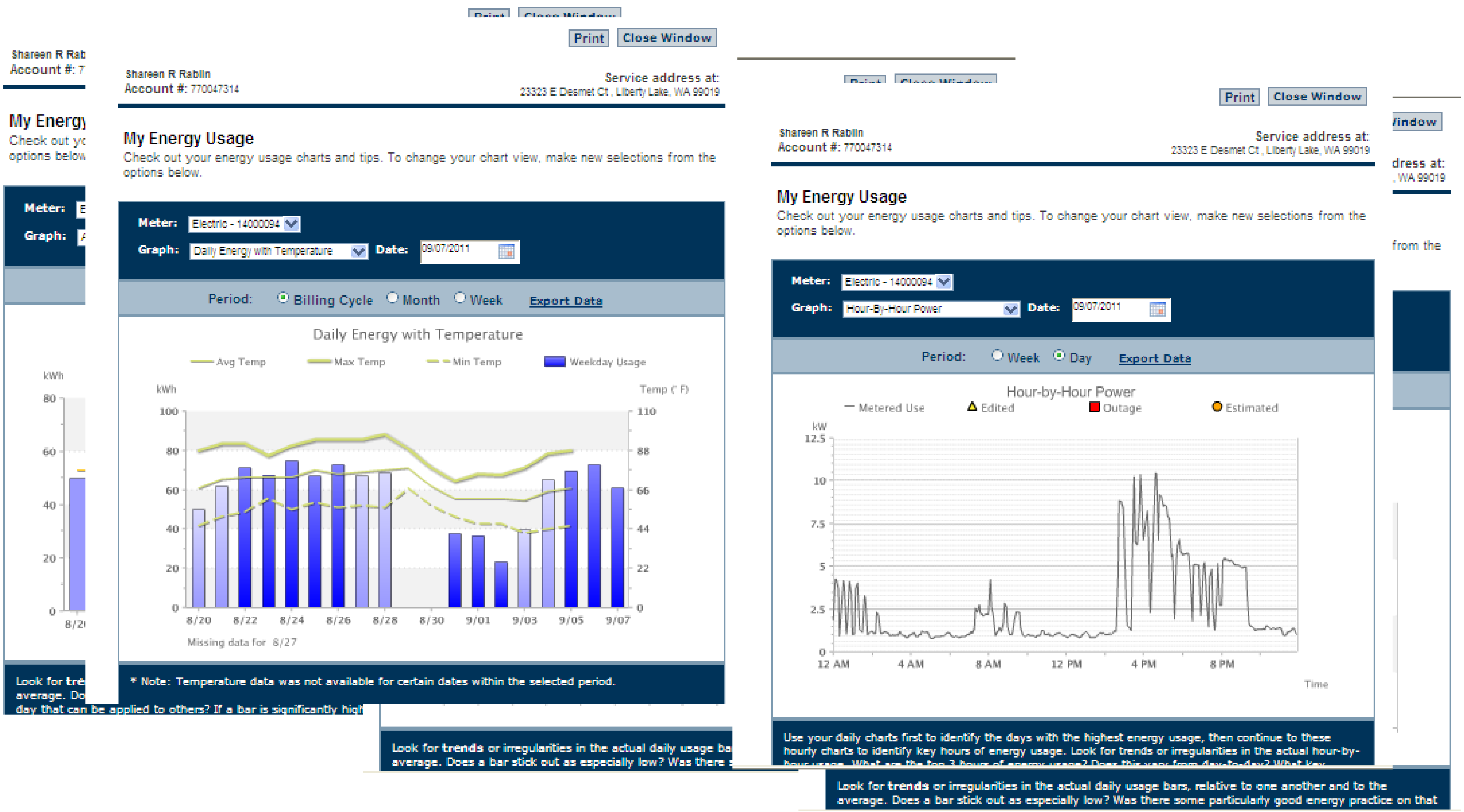
- Provide energy consumption data
- Establish and test regional signals
- Understand customer experience, satisfaction, and program participation
- Validate the need for and type of customer incentives
- 1,500 customers in Pullman

Testing, Understanding, Learning

# The Customer Experience

| Experiment | Battelle Req | Battelle ID | Enabling Technologies: Web Only | Web + Real Time | Web + Tstat | Web + DR | Web + DR + Full Analytics |
|---|---|---|---|---|---|---|---|
| This asset would provide tools to the customer to decrease their energy consumption and will also measure reduction in load due to customer behavior modification (**Behavior Conservation**) | yes | AV-05-3.1 | X | x | x | x | x |
| Transactive signal will provide automated demand response through AMI (**Automated direct demand response**) | yes | AV-05-1.2 | | | | X | X |
| Transactive signal will provide automated real time response through AMI (**Automated Real Time**) | yes | AV-05-1.4 | | | | | X |
| Avista will conduct survey for customer acceptance of the load control devices. (**Customer Acceptance**) | yes | AV-05-4.1 | | | | X | X |
| Avista will conduct survey for customer acceptance of load control devices if incentives are provided. (**Customer Incentives**) | yes | AV-05-4.2 | | | | X | X |
| Avista will conduct survey for customer acceptiance of the load control devices if incentives are provided. (recruitment practices) | yes | AV-05-4.3 | | | | X | X |
| AMI can help in customer behavior modification by providing real time info of their energy usage. This asset would provide tools to the customer to decrease their energy consumption and will also measure reduction in load due to customer behavior (**Behavior Conservation**) | yes | AV-06-3.1 | | X | X | X | X |

# Customer Web Presentment

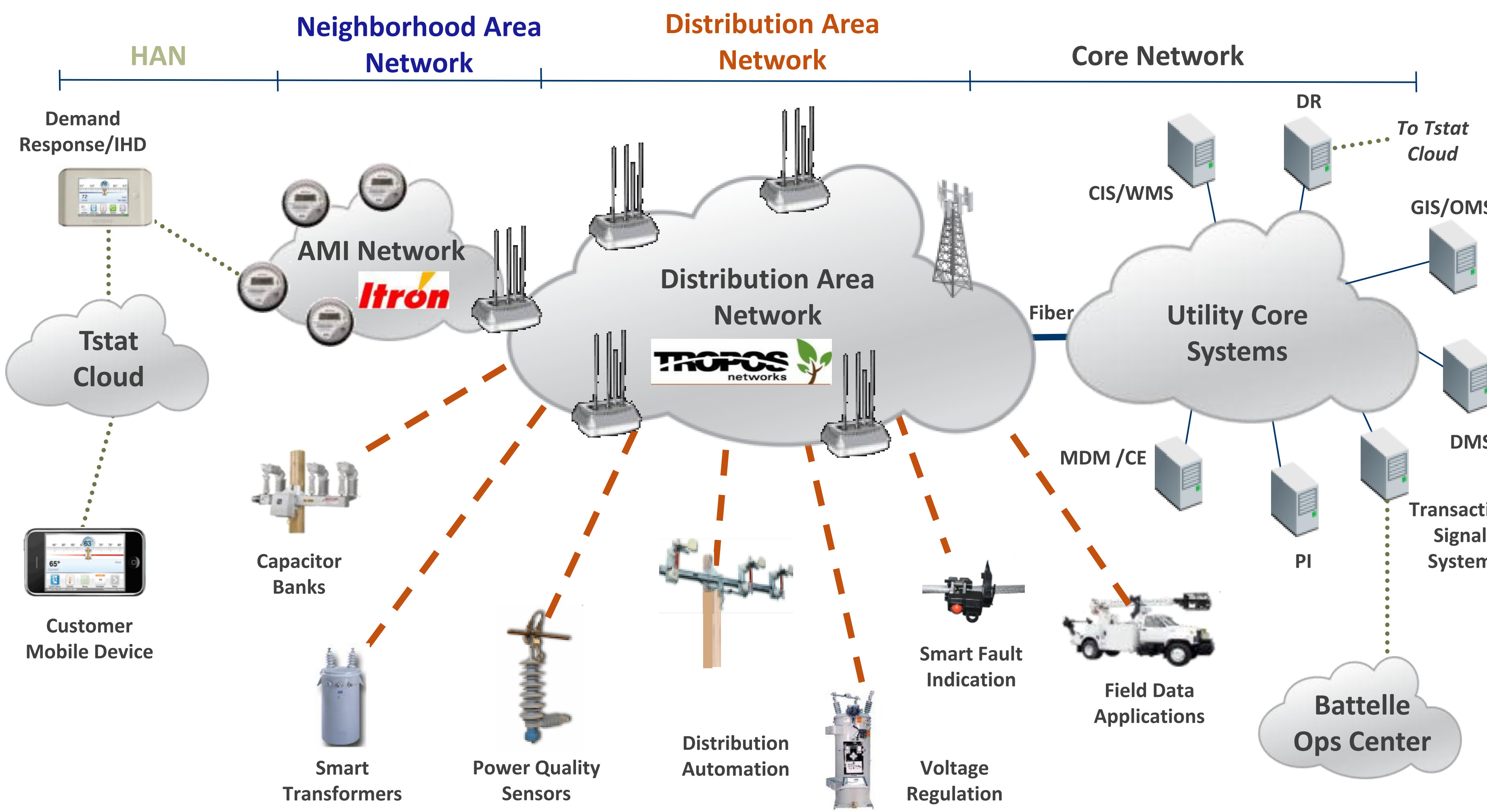


# Customer Empowerment

# The Components

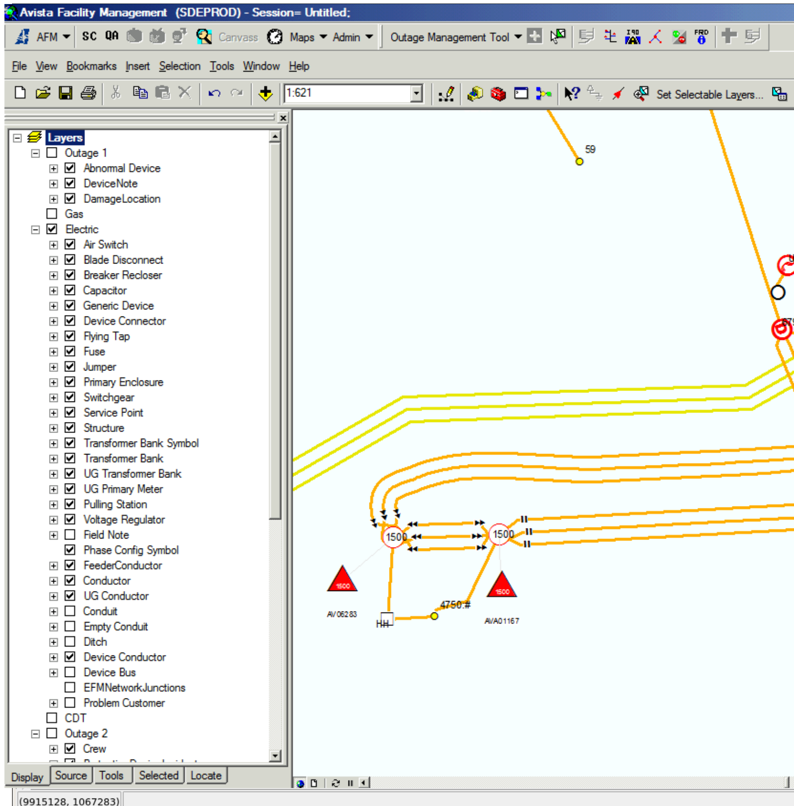
- **43** Smart Reclosers
- **31** Switched Capacitor Banks
- **39** Advanced Voltage Regulator Controls
- **400** Smart Transformers
- **300** Smart Fault Indicators
- **3** Smart Switchgear
- **13,000** Electric/**5000** Gas AMI Meters
- Advanced Demand Response System
- **1500** Advanced Programmable Thermostats
- Customer Web Portal and Mobile Tools
- WSU Chillers (**9**), Generators (**4**), and Air Handlers (**39**)
- Transactive System for Distributed Energy Resource Management
- Advanced Communications Network
- Advanced DMS
- Security Design and Risk Assessment
- Advanced Analytics Engine

# Advanced Smart Grid Infrastructure

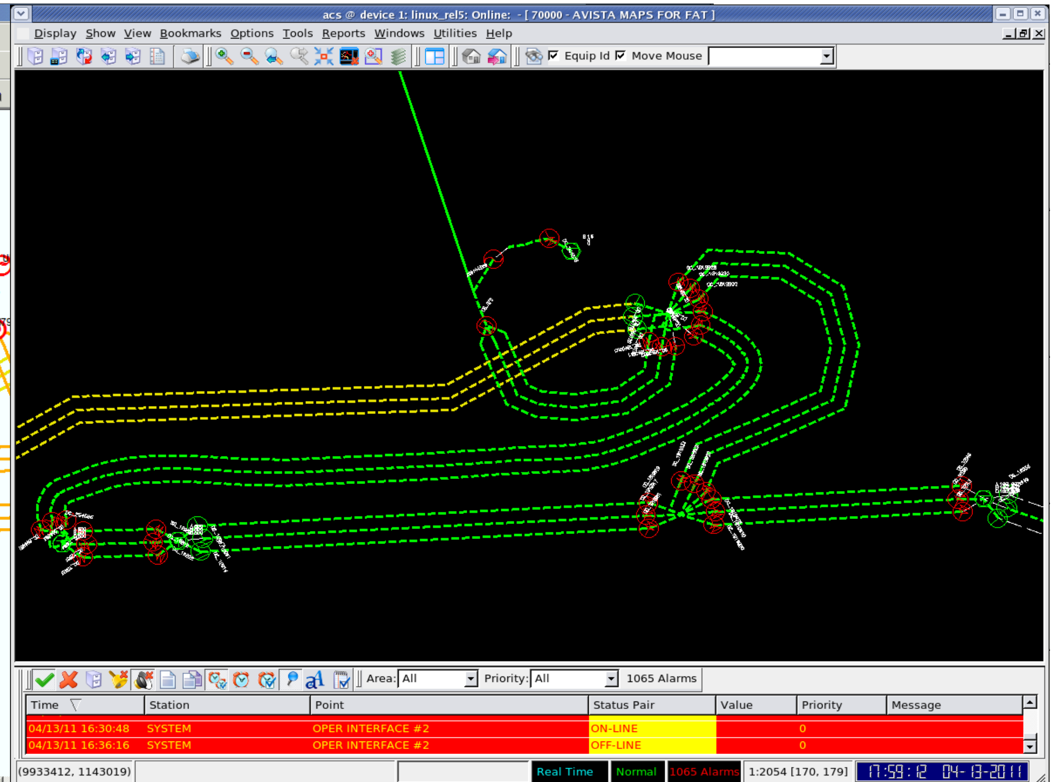


# The Smart Grid Brains

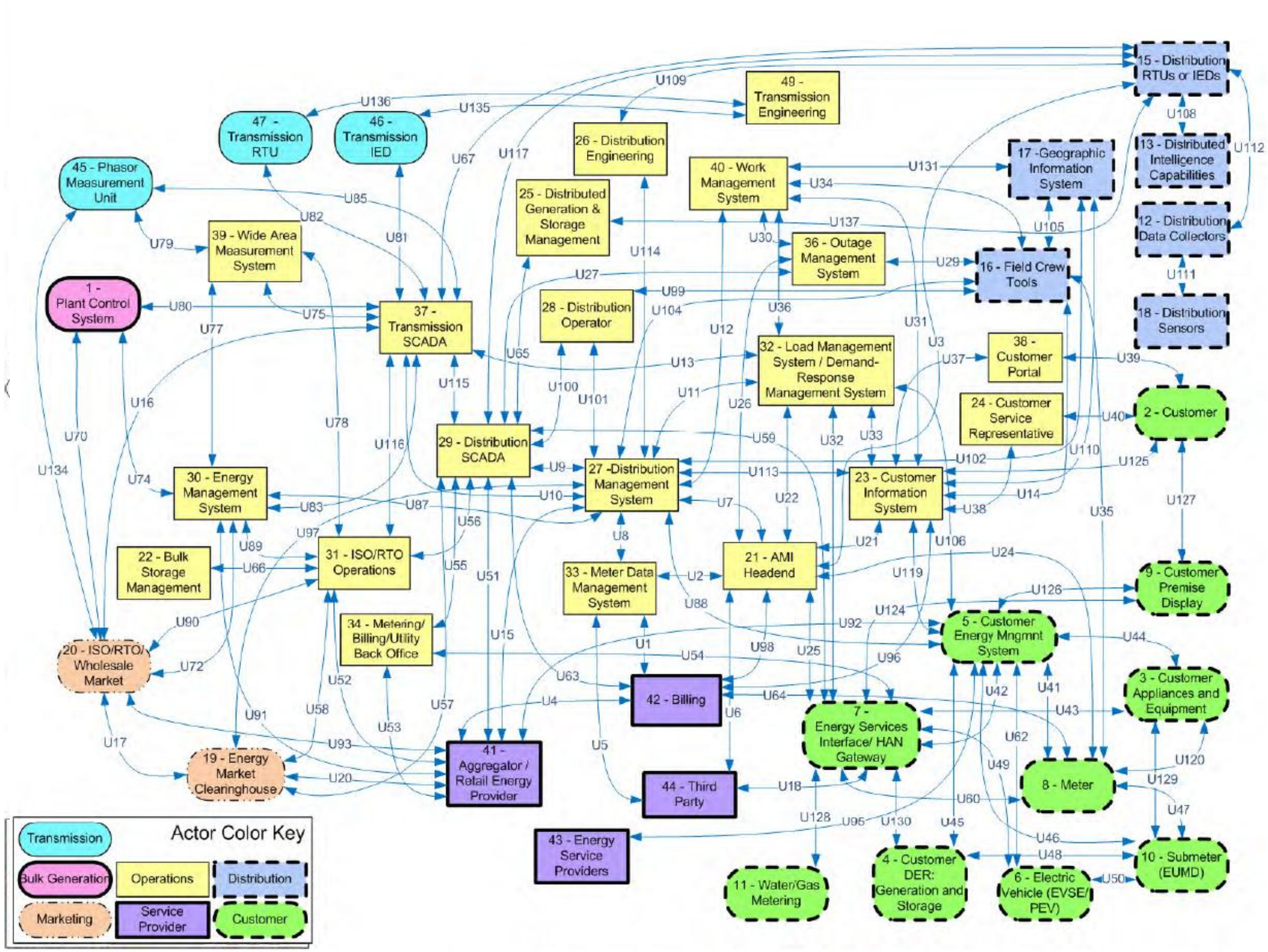
Facility Management & Outage Management Tool




Distribution Management System

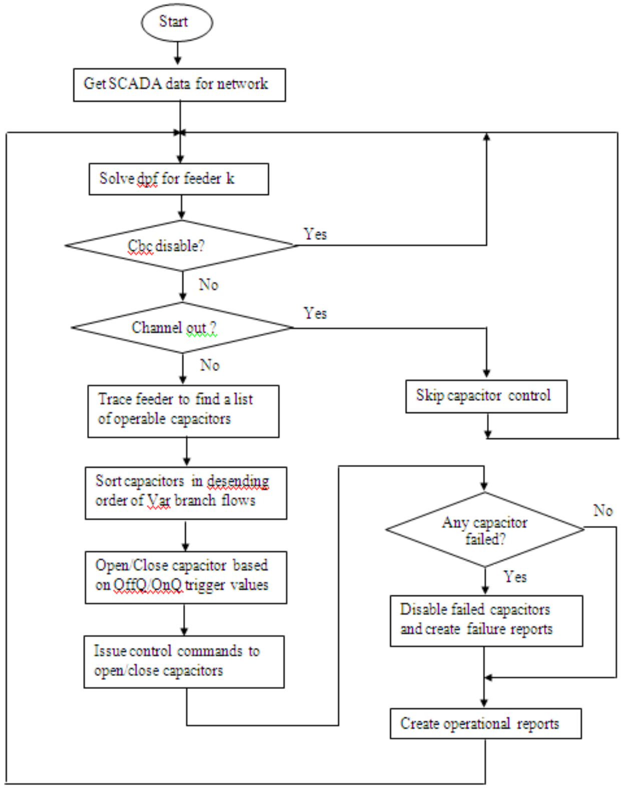


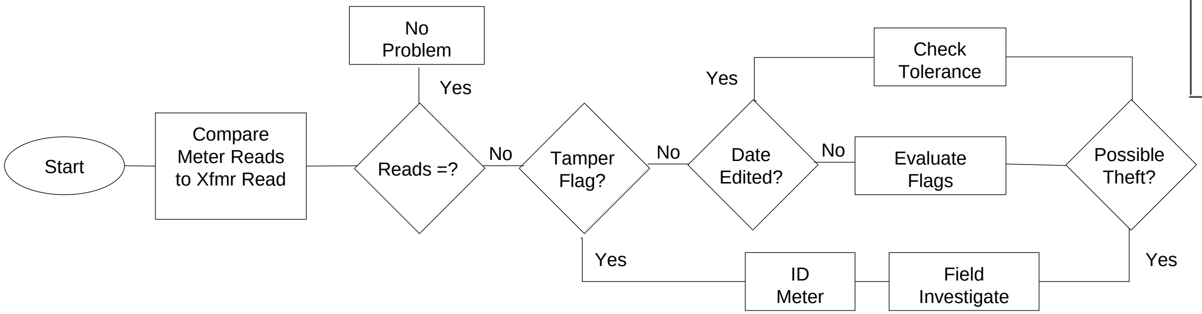
# The Matter of Security



# Analytics for Results

- Real-time Calculation of Results
- Elimination of Manual Analysis
- Automated Work Order Creation for Trouble
- Identification of Outage Scenarios
- Revenue Protection
- Loss Savings Validation
- Customer Energy Savings
- Condition Based Maintenance Program
- Grid Optimization Automation




AVISTA

# Challenges

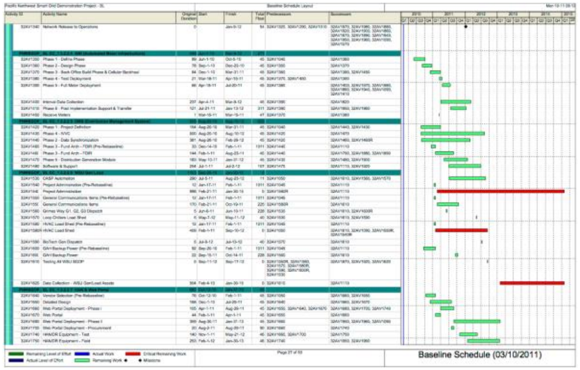
- Project Management and Hard Deadlines
- Change Management
- Documentation of Decisions, Designs and Processes
- Procedures and Organizational Structure (Roles & Responsibilities)
- Cross Functional Teamwork and Governance
- Partnership Relationship with Vendors
- Security
- Communication to Customers
- Massive Quantity of Data to Process/Analyze

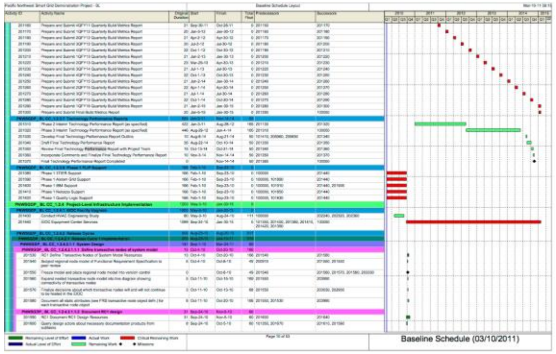
Itron Spirae Washington State University World Class. Face to Face. hp Tropos networks SEL G&W Cooper efacec Advanced Control Systems

Avista

# The Project To-Date

- AMI complete includes meters, MDM, and collection engine
- Smart  switches and switchgear installed.
- Capacitor banks installed
- Voltage regulator controls installed
- DMS in production for field measures and remote control
- Tropos Wi-Fi network complete
- Customer Community Builder Tools Deployed
- Smart transformers scheduled for delivery
- Analytics engine being installed
- Customer bill analytics web tools 2nd quarter 2012
- DR and transactive signal system in design
- Tstat recruitment to begin in April 2012
- All systems live end of August 2012



# Avista's Future

| | 2011 | 2012 | 2013 | 2014 | 2015 |
|---|---|---|---|---|---|
| Efficiency | Active Volt Var Management | Automatic Service Switch | Adaptive Fusing | | Grid Optimization |
| Reliability | Remote Operation & Control | Fault Location & Automatic Restoration | | | |
| Asset Management | Feeder Rebuild Coordination<br>Smart Transformers | Smart Grid Work& Asset Management | | | |
| Customer Participation | AMI Demonstration<br>Customer Web Portal | Home Area Network Demonstration<br>Demand Response Demonstration | Distributed Generation | Electric Vehicles<br>Trusted Energy Advisor Services | |

# Questions??

**Contact Information:**
**Curtis Kirkeby, P.E.**
**telephone: (509) 495-4763**
**email: curt.kirkeby@avistacorp.com**
**website: http://www.avistautilities.com**

# Northwest Energy Systems Symposium

## Enhancing Snohomish County PUD Grid Operations and Reliability Utilizing Smart Grid Technologies


Will Odell

John Sell

SNOHOMISH COUNTY PUD PUBLIC UTILITY DISTRICT NO. 1

ALSTOM

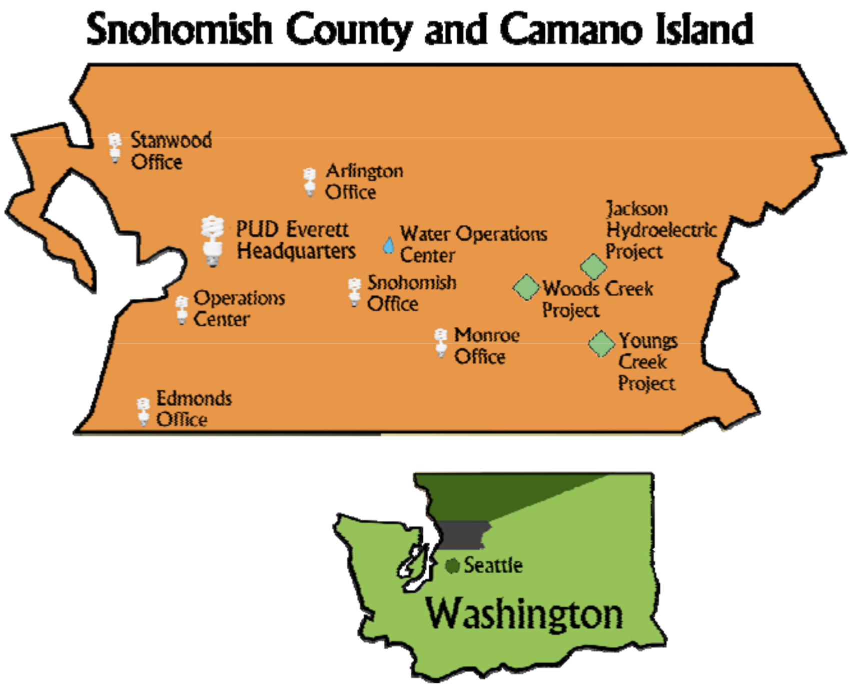

March 22, 2012

# Agenda

- Background
- Smart Grid Strategy
- Smart Grid Benefits
- Smart Grid Projects
- Systems, Domains and Process Integration
- DMS Architectural Overview
- DMS System Configuration
- DMS Situational Awareness
- DMS Expected Benefits
- Challenges

# Company Profile: Snohomish PUD

- **Total Electrical Customer:** 320,000
- **2010 Energy Sales:** 8,073,332 MWh
- **Generating Capacity:** 164 MW
- **Residential Rates:** 8.3¢ per kWh
- **# of Substations:** 86
- **# of Circuits:** 396
- **Resource Mix:** 8% Renewables



# What is a Smart Grid?

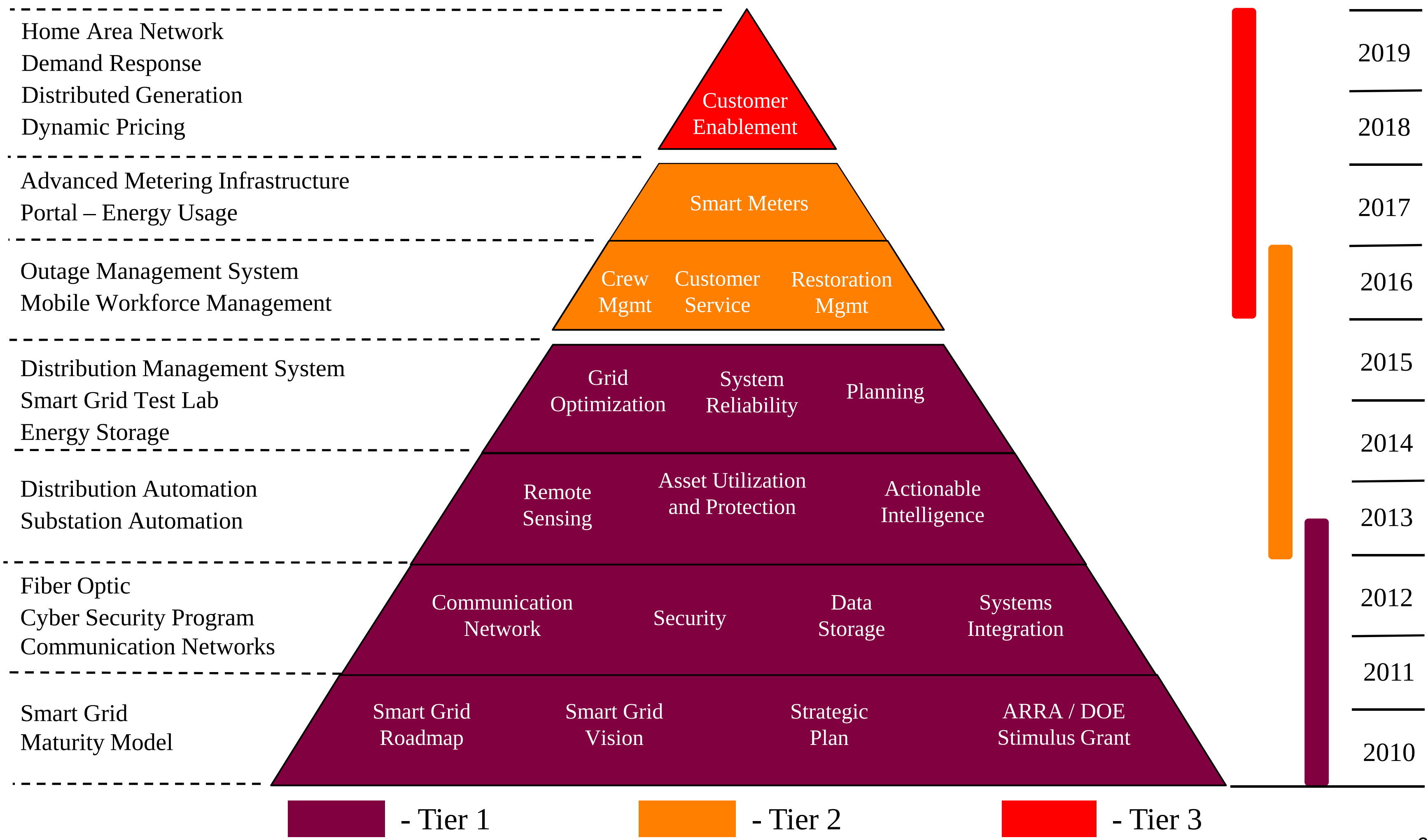
The integration and application of real-time monitoring, advanced sensing, communications, analytics, and control, enabling the dynamic flow of both energy and information to accommodate existing and new forms of supply, delivery, and use in a secure and reliable, and efficient electric power system, from generation source to end-user.

North American Electric Reliability Corporation (NERC)

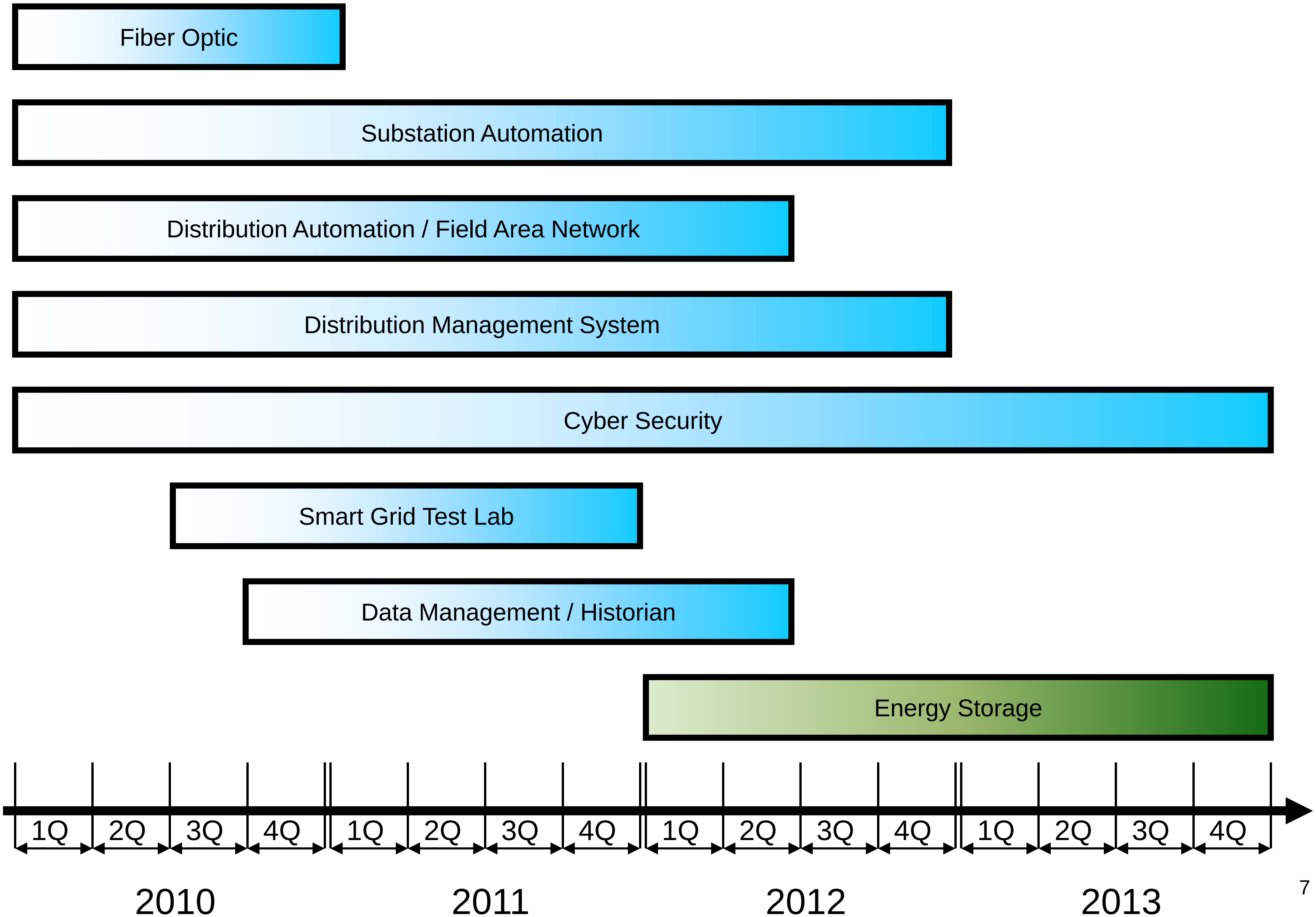
# Smart Grid Benefits

- Improved power reliability and power quality
- Improved safety and cyber security
- Improved energy efficiencies
- Reduced environmental impact
- Increased energy conservation
- Customer choices
- Direct financial

# Smart Grid Pyramid

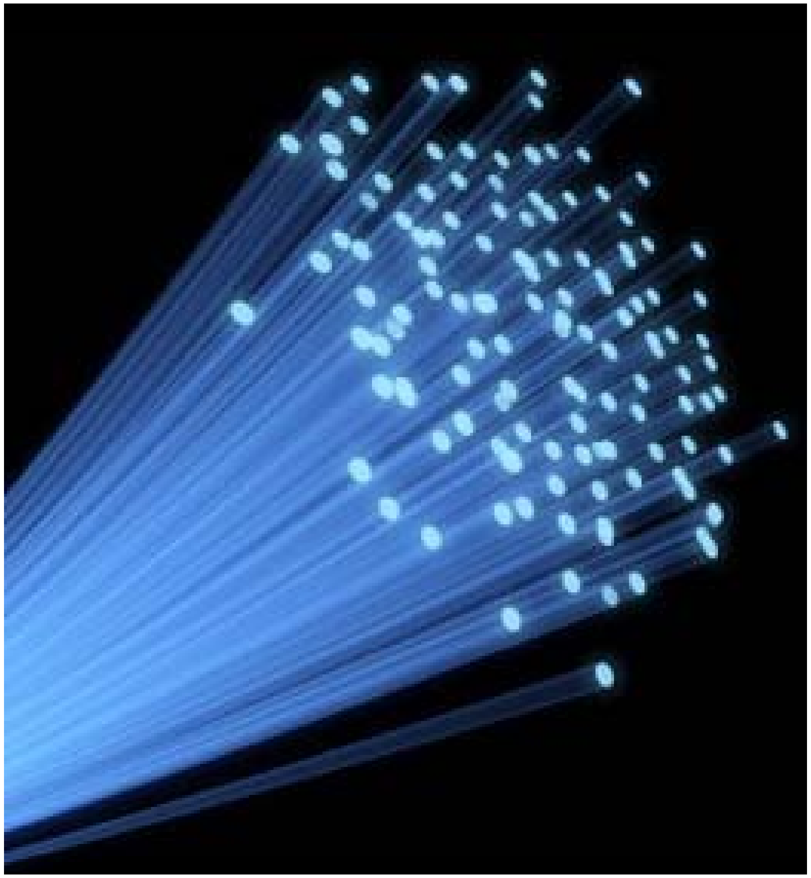


# Smart Grid Projects



# Fiber Optic

- Provides two-way high speed data communications to substations
- 163 miles installed
- Completed 12/2010
- Project Budget - $7M



# Substation Automation

- Replace analog equipment with digital technologies
- Enhanced communication equipment and systems
- Real time access to non operational information
- 42 of 86 Substations
- Project Budget - $12.2M

# Substation Automation Benefits

- Reduce Operating Expenses
- Reduce Capital Expenses
- Meet Emerging Regulatory Requirements
- Improve Grid Security

# Distribution Automation (DA) and Field Area Network (FAN)

- DA is a family of technologies including sensors, processors, and automated field devices that can perform a number of distribution system functions depending on how they are implemented.
- FAN is a communication network that wirelessly connects field devices with the District Operations Center

# Network Requirements by Application

| Application | Bandwidth | Latency | Reliability | Security | Backup Power |
|---|---|---|---|---|---|
| AMI | 10-100 kbps/node, 500 kbps for backhaul | 2-15 sec | 99-99.99% | High | Not Necessary |
| Demand Response | 14kbps-100kbps per node /device | 500 ms- several minutes | 99-99.99% | High | Not Necessary |
| Wide Area Situational Awareness | 600-1500 kbps | 20 ms – 200 ms | 99.999-99.9999% | High | 24 hour supply |
| Distribution Energy Resources and Storage | 9.6-56 kbps | 20 ms – 15 sec | 99-99.99% | High | 1 hour |
| Electric Transportation | 9.6-56 kbps, 100 kbps is a good target | 2 sec – 5 min | 99-99.99% | Relatively High | Not Necessary |
| Distribution Grid Management | 9.6-100 kbps | 100 ms – 2 sec | 99-99.99% | High | 24-72 hours |

Department of Energy analysis - Oct. 5, 2010

# Network Performance Requirements for DA

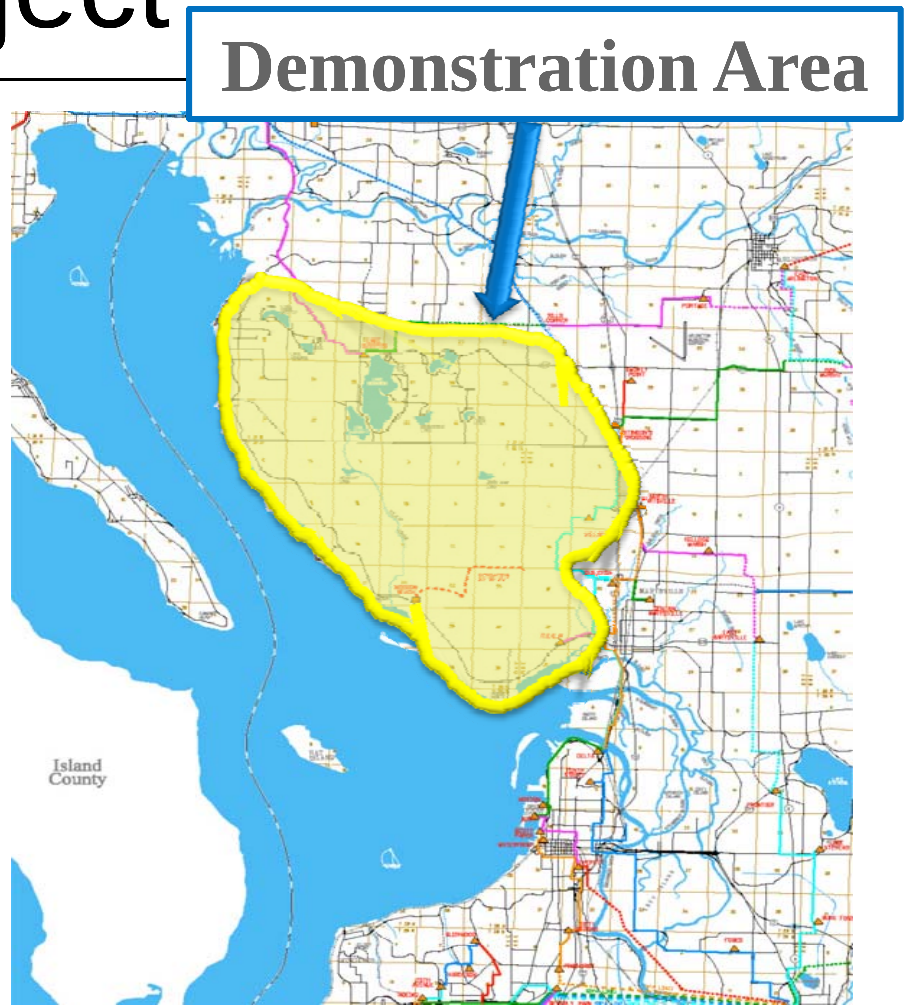
| | Monitoring and Sensing | Conditioning and Control | Switching and Protection |
|---|---|---|---|
| Applications | •Asset monitoring<br>•Power quality monitoring<br>•Predictive maintenance | •Volt/Var optimization | •Fault detection, isolation and recovery<br>•Feeder reconfiguration<br>•Outage management |
| Grid Devices | •Transformers<br>•Cap - bank neutral current monitors<br>•Voltage and current sensors | •Voltage regulators<br>•Capacitor - bank controllers<br>•Fault Current Indicators | •Switches<br>•Reclosers<br>•Sectionalizers<br>•Breakers |
| Bandwidth | •Low | •Low | •Medium |
| Latency | •High (minutes) | •Medium (seconds) | •Low (tens of milliseconds) |

# Comparison of Wireless Technologies for DA

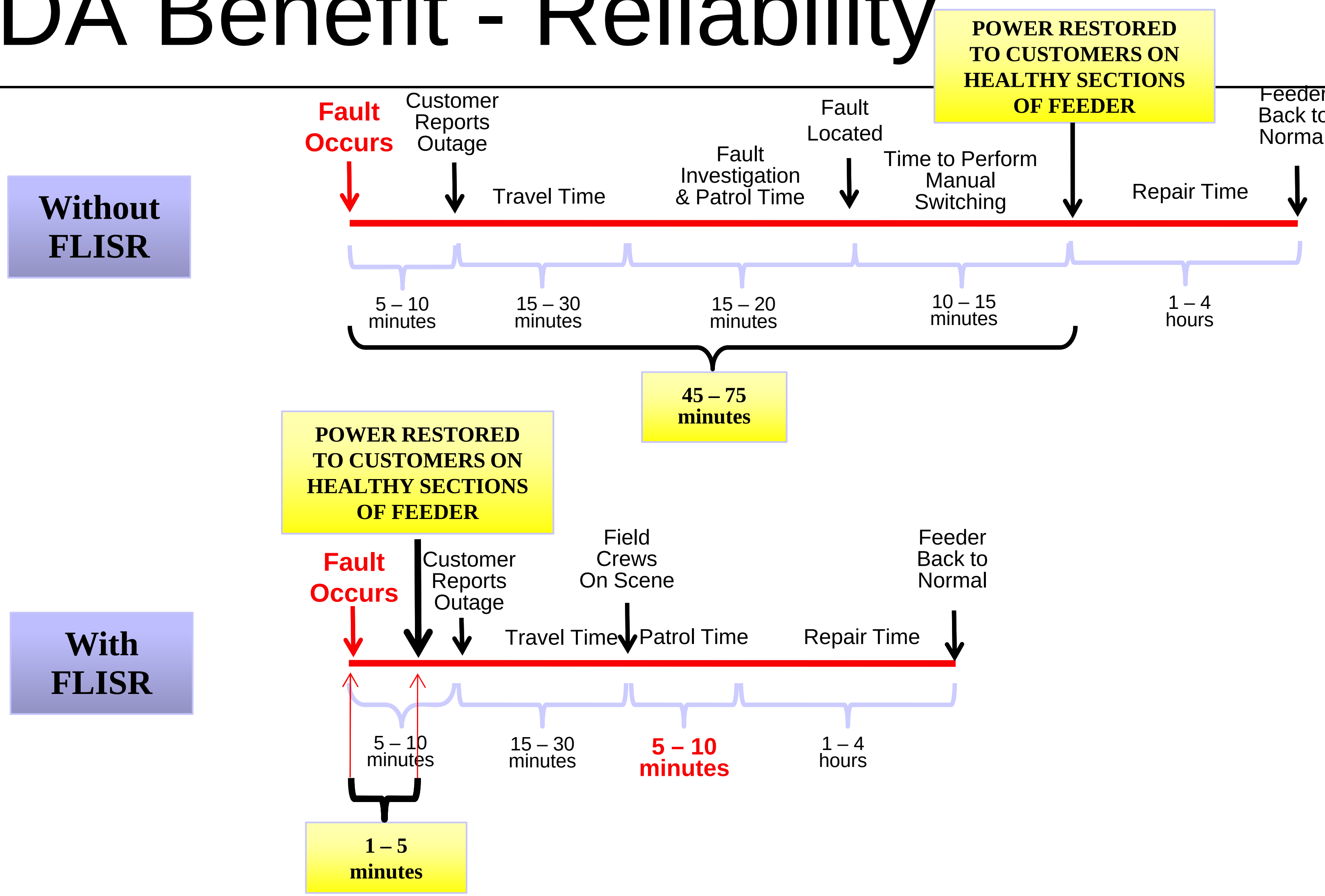
| | Private Narrowband Radio Systems | Public-Carrier Cellular Networks | Private Mesh Systems |
|---|---|---|---|
| Latency | 100s-1000s of ms | 100s-1000s of ms | 10-100 ms |
| Capacity | 0.01-0.1 Mbps | 0.1-10 Mbps | 1-100 Mbps |
| Security | Medium | Medium-High | High |
| Reliability | Medium | Medium | High |
| QoS | Limited | Limited | Yes |
| Standards – Based Interoperability | Proprietary | Yes (GPRS,GMS, EDGE,1xRTT, EVDO,HSPA, LTE) | Yes (802.11/802.16 and IP) |
| Manageability | Limited | Very Limited | Enterprise Class |
| Control | Utility owns and operates | Carrier owns and operates | Utility owns and operates |

# DA and FAN Project

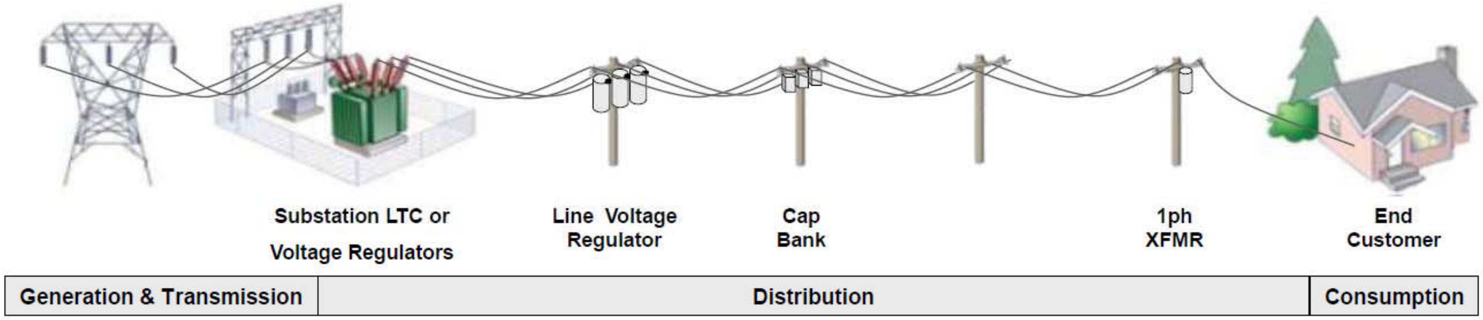
- DA Demonstration Area
  - 5 Substations & 10 Circuits
  - 9,100 Customers
- Automated Equipment
  - Switches (8)
  - Reclosers (26)
  - Regulators (39)
- Improve Reliability
  - SAIDI 4-Yr Avg 90 min/yr
- Project Budget - $3.8M



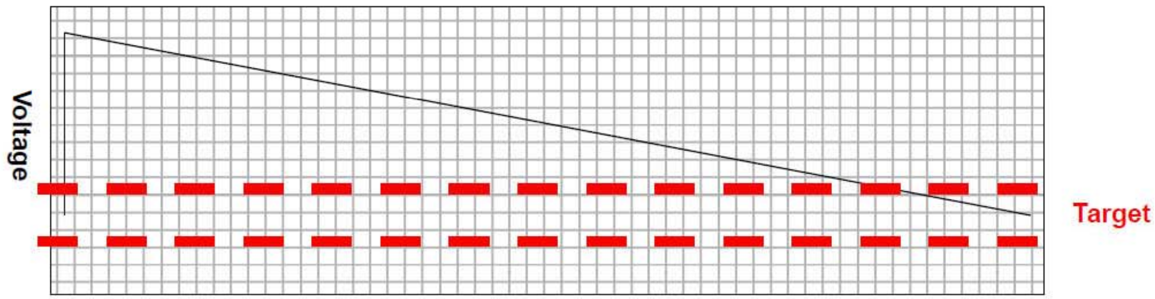
# DA Benefit - Reliability



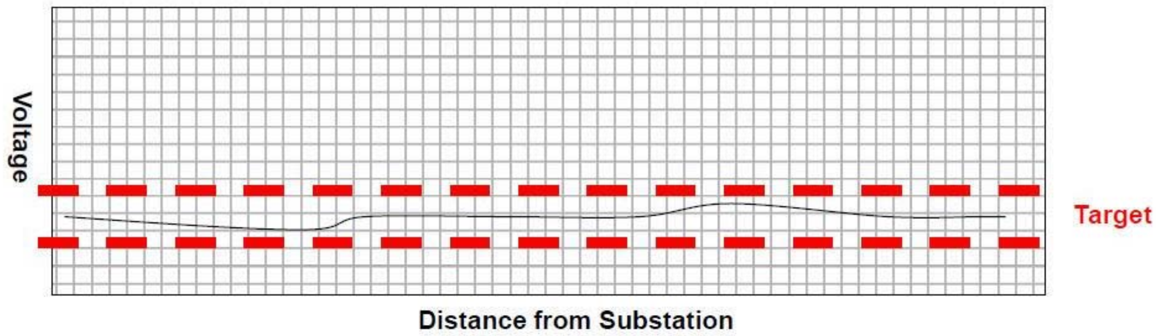
# DA Benefit – Grid Optimization




No Voltage Control

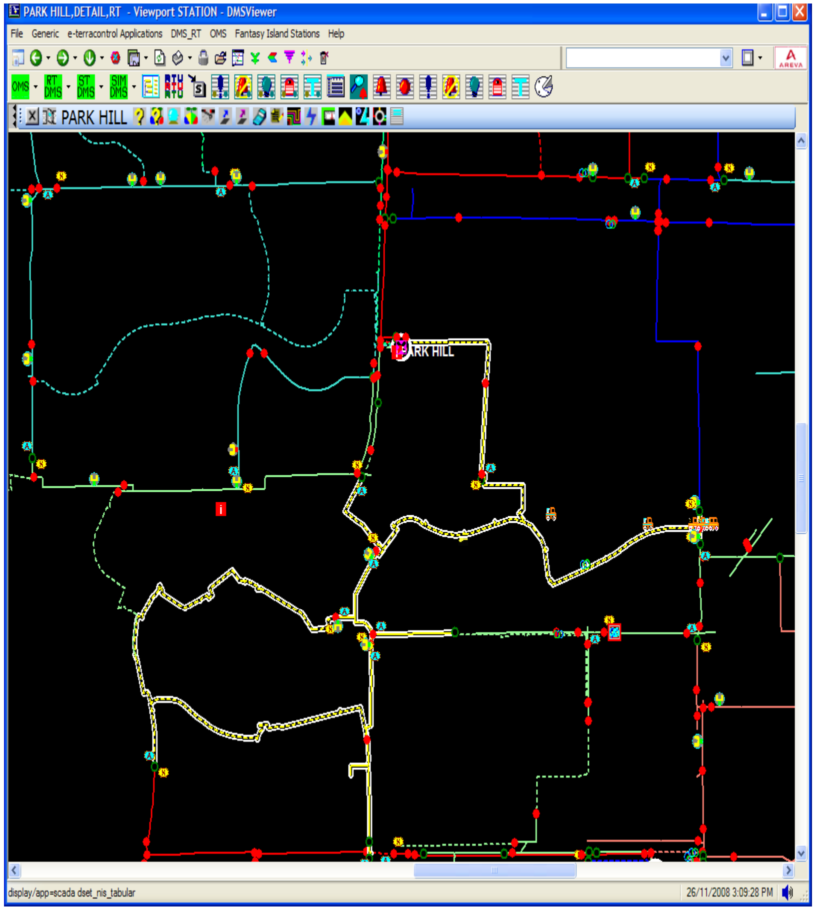



Integrated Volt/Var



# Distribution Management System (DMS)

- IT system capable of collecting, organizing, displaying and analyzing real-time or near real-time electric distribution system information.
- Interfaces with other operations applications such as geographic information systems (GIS), outage management systems (OMS), and customer information systems (CIS) to create an integrated view of distribution operations.
- Project Budget - $6.1M

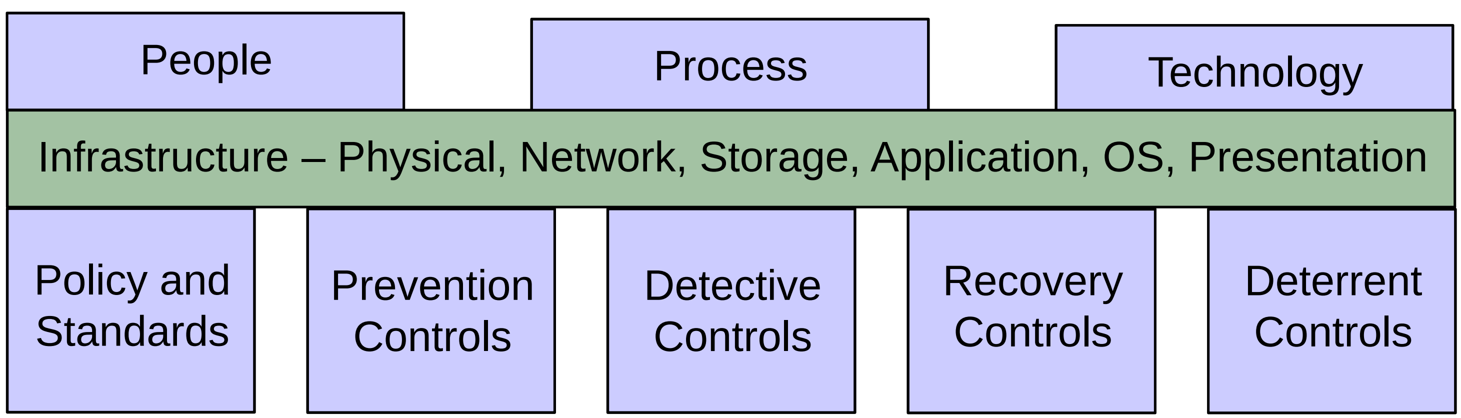


# DMS Benefits

- **Powerflow**
  - Near real time calculation of voltage and flow for the electric grid
- **Switching**
  - Planned and Emergency, Tagging
  - Automatically generated Switch Plans based on Operator request
- **FLISR** (Fault Location, Isolation and Service Restoration)
  - Automatic fault location and switching of field devices
- **Feeder Load Management**
  - Predictive Powerflow
- **Voltage Optimization**
  - Set of action plans based on loss minimization

# Cyber Security

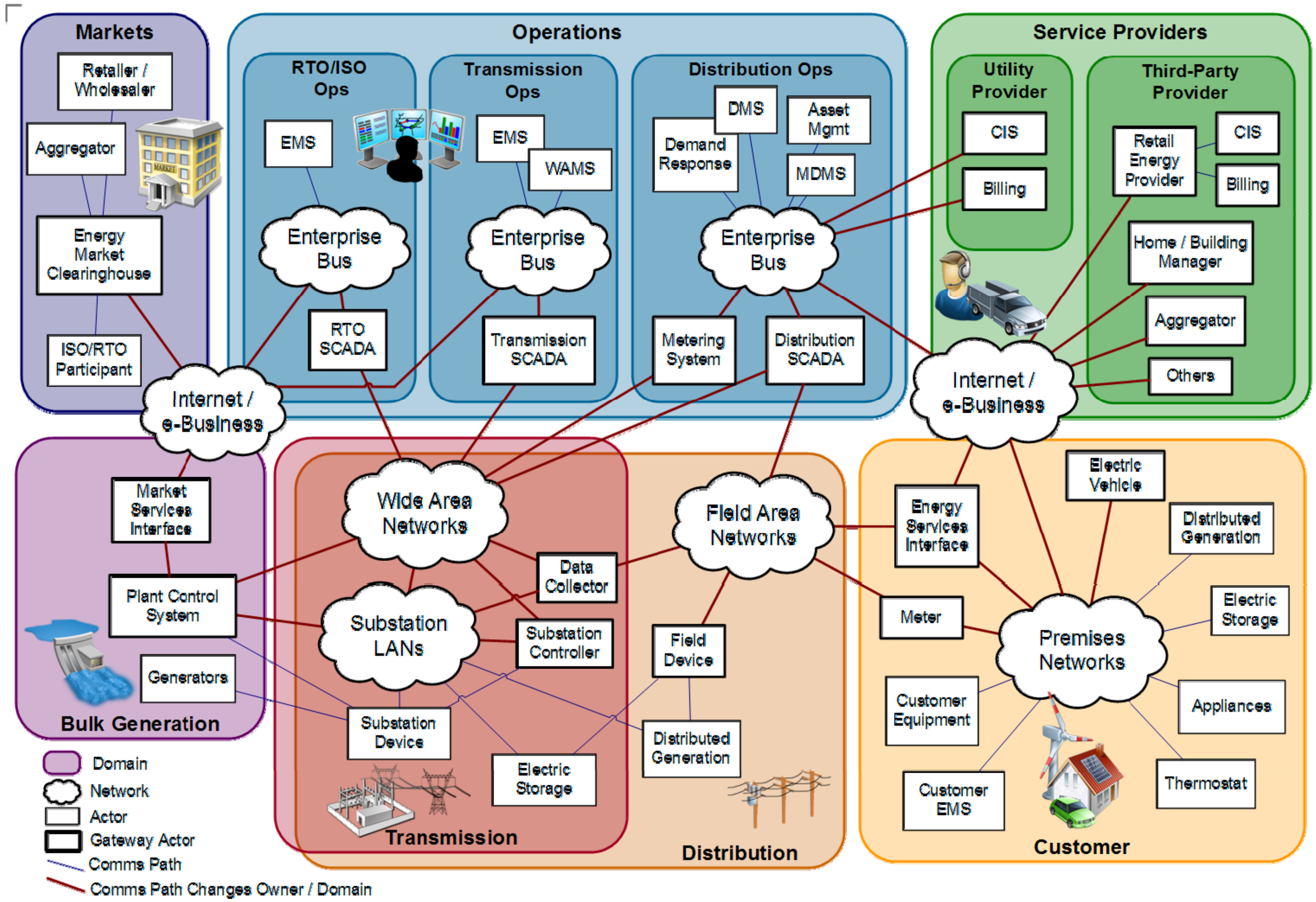
The cyber security program provides assurance that the confidentiality, integrity and availability of systems are maintained at an acceptable risk level.



# Smart Grid Test Lab

- Safe environment to test compliance of products and services with existing and new standards
- End to end testing of new products and services for compliance and interoperability with other systems prior to field deployment
- Training platform for smart grid system installations, operations and diagnostics
- Project Budget $450k

# Smart Grid System Integration






Source: NIST Smart Grid Framework

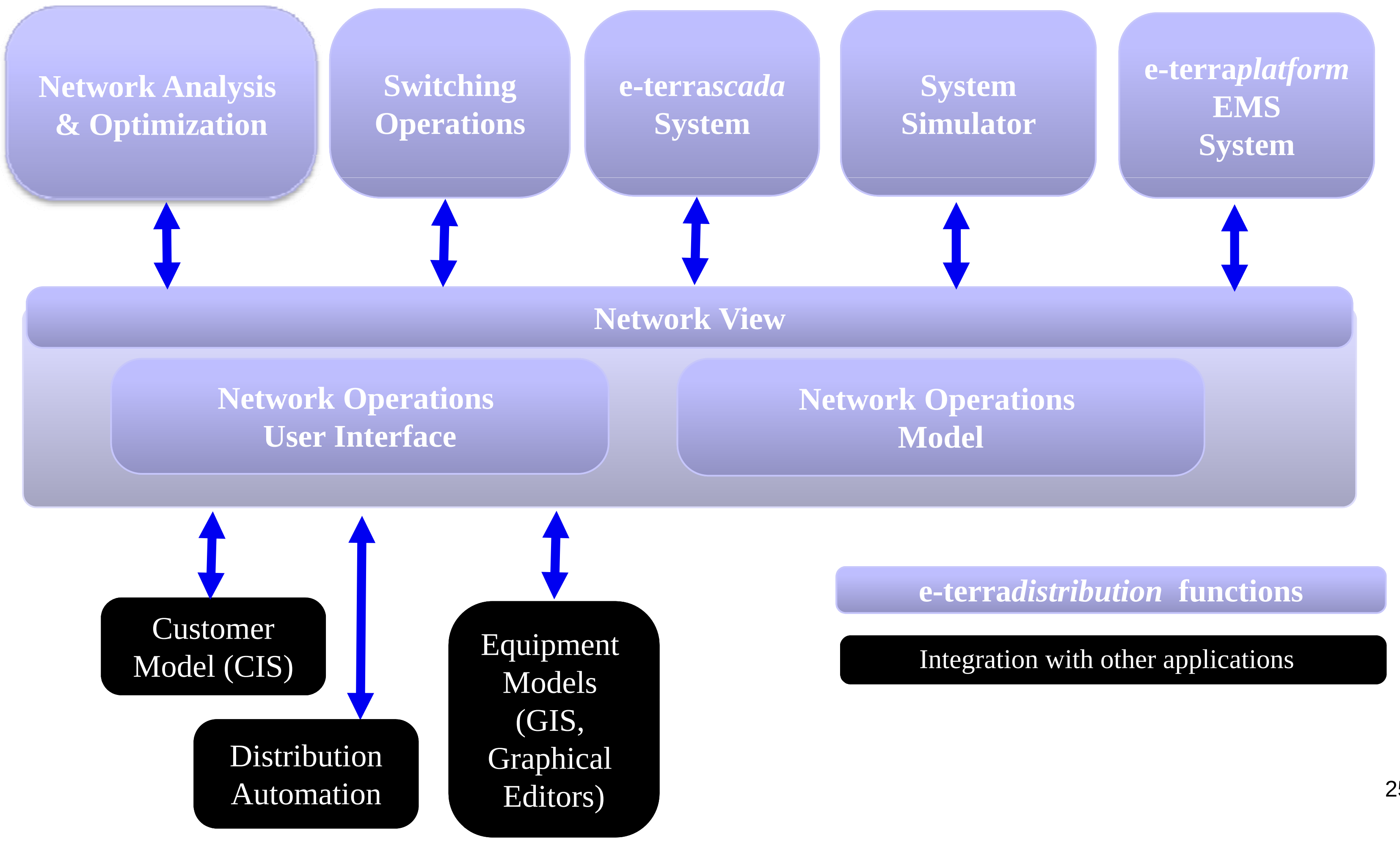
# Smart Grid Domains

| | | | |
|---|---|---|---|
| SMR | **Strategy, Mgmt & Regulatory**<br>*Vision, planning, governance, stakeholder collaboration* | TECH | **Technology**<br>*IT architecture, standards, infrastructure, integration, tools* |
| OS | **Organization and Structure**<br>*Culture, structure, training, communications, knowledge mgmt* | CUST | **Customer**<br>*Pricing, customer participation & experience, advanced services* |
| GO | **Grid Operations**<br>*Reliability, efficiency, security, safety, observability, control* | VCI | **Value Chain Integration**<br>*Demand & supply management, leveraging market opportunities* |
| WAM | **Work & Asset Management**<br>*Asset monitoring, tracking & maintenance, mobile workforce* | SE | **Societal & Environmental**<br>*Responsibility, sustainability, critical infrastructure, efficiency* |

# System and Process Changes

- Processes that will be Replaced with DMS
  - Use of the tool Switch Order Request
  - Use of the paper Hot Log
- Processes that will be Duplicated in DMS until Replaced
  - As Operating Model on Wall Board and Underground Drawing Updates
- Processes that will be New or Changed
  - Near real time updating of GIS (GIS, Crews, Engineers)
  - Daily GIS updates to DMS including QC check (New)
  - Real Time Distribution Optimization (New)
  - Planning and Protection Processes
  - Switch Operation Processes
  - Closed Loop Switching Operations (New)
  - Reporting and tracking of outages for SAIFI and CADI
- OT vs IT
  - Past and future support roles between IT and OT need consideration

# IDMS Functional Components at the PUD



# DMS Applications

| Network Analysis | Network Optimization | Switching Operations |
|---|---|---|

**Network Analysis**

- State Estimation
- Power Flow
- Load Allocation
- Limit Monitor
- Power Quality
- Short Circuit
- Loss Analysis
- Load Model & Forecast
- Fault Location
- Protection Validation

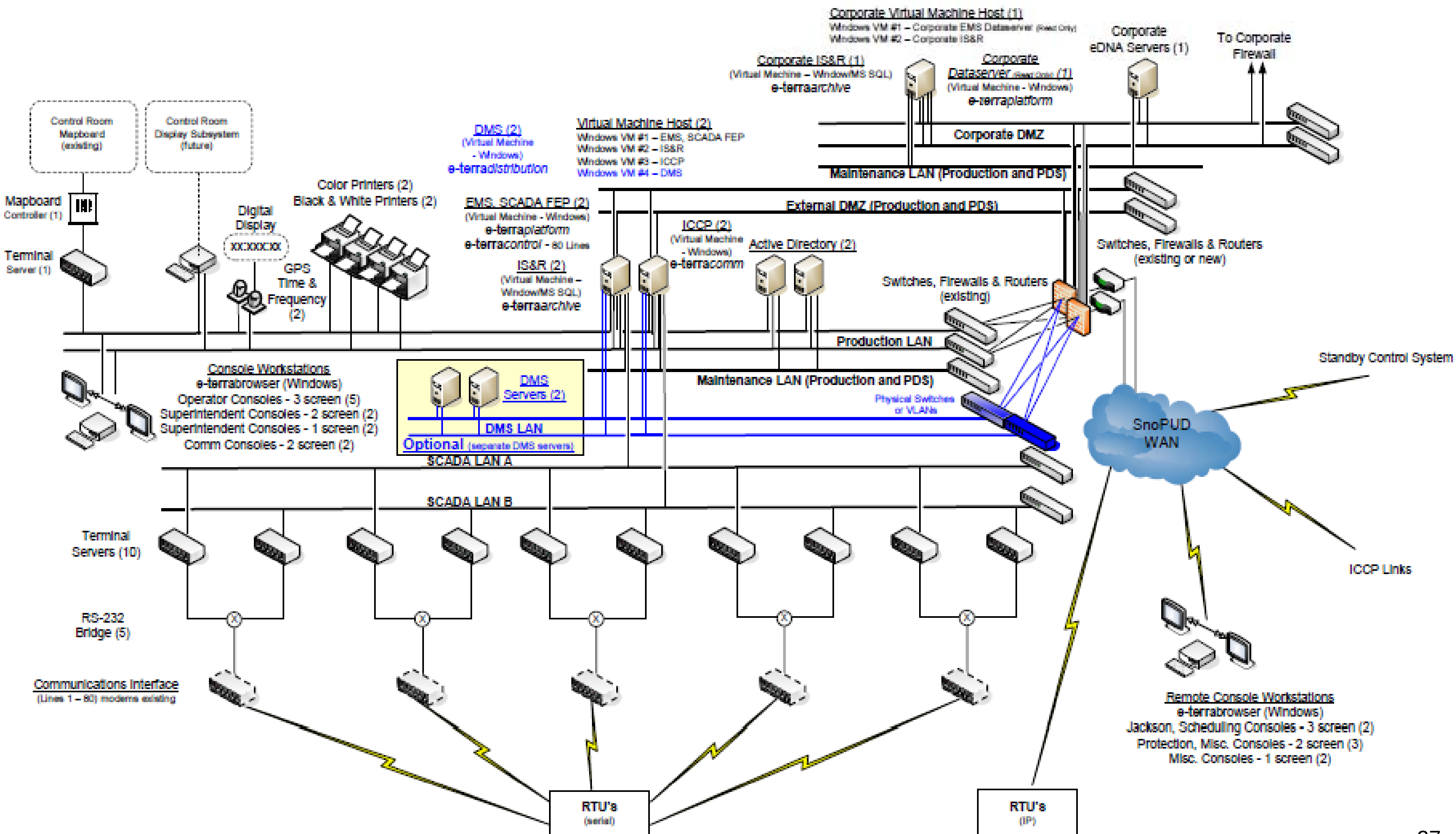
**Network Optimization**

- FISR
- Feeder Reconfiguration
- Planned Outage Study
- VVC
  - Loss Minimization (also includes CVR, VAr support)

**Switching Operations**

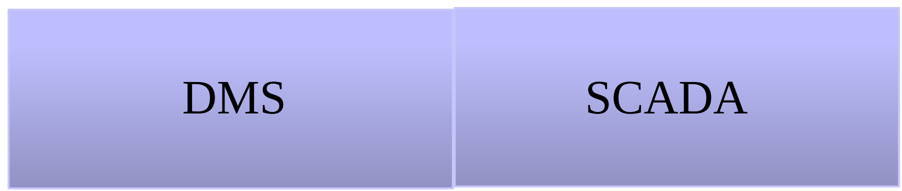
- Creation, Validation & Execution of Switching Orders
- Creation and Management of Safety Documents

# DMS Production System




*Not Shown: Backup, Planning, QA Systems*

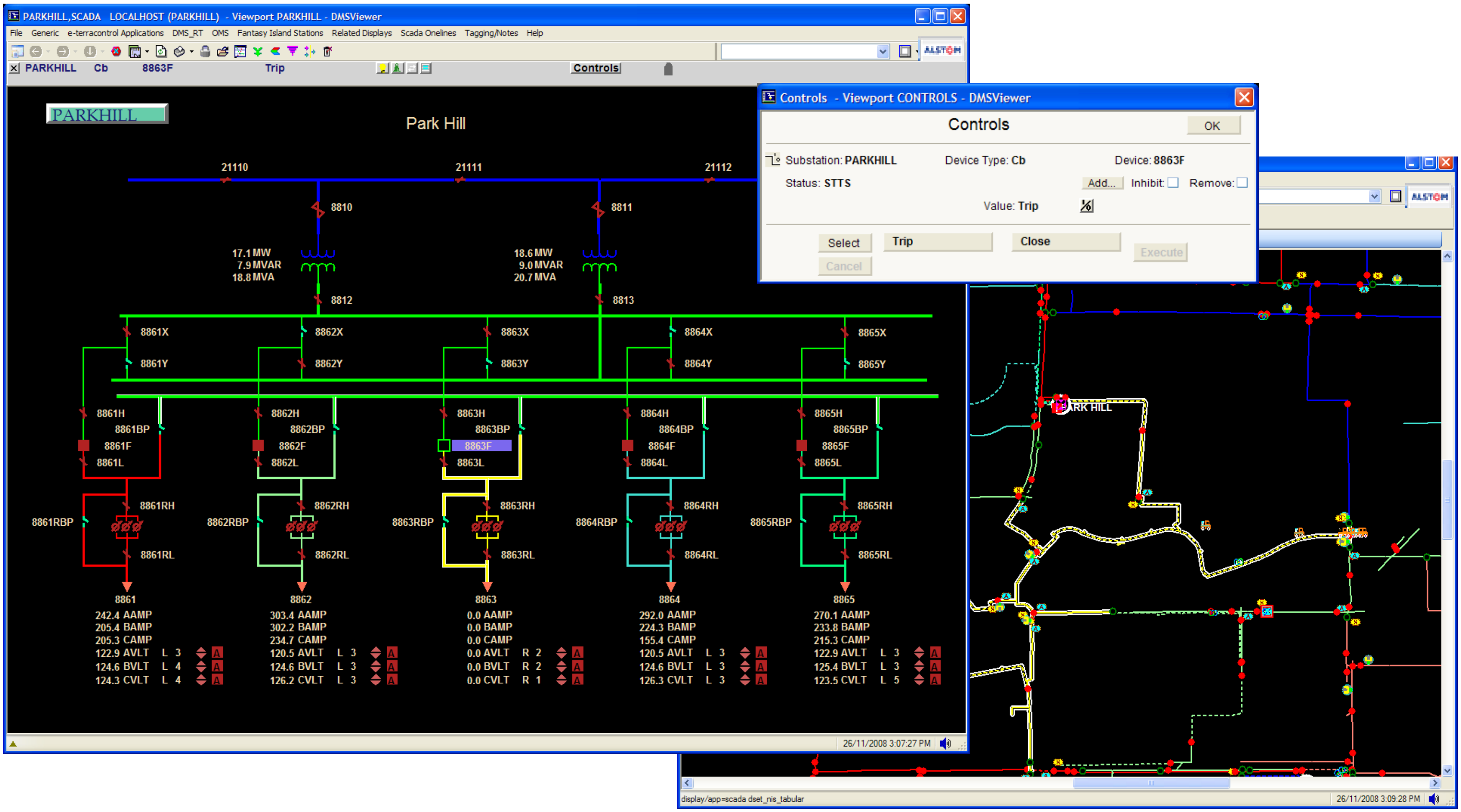
# DMS & SCADA Integration




*Operation is Consistent and Persistent Across Applications:*

- Device control from SCADA or GIS display or both
- Common Model/Consistent Model
- Single User Interface
- Permissions (Log-in)
- Training Simulator
- Switch Orders
- Logging
- Tagging

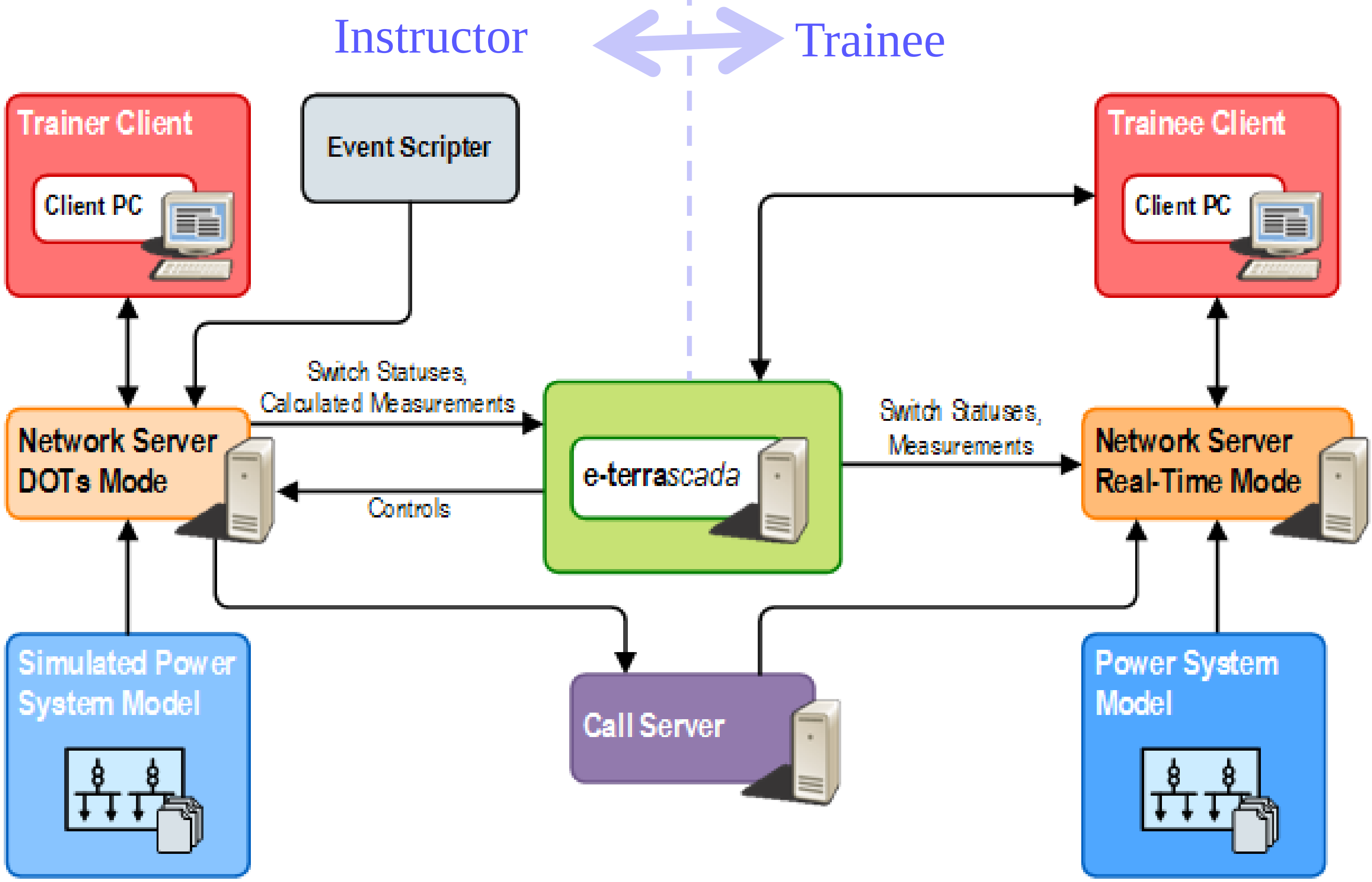
# Integrated User Interface



# Benefits of an Integrated Product

- **Reduced Cost of Ownership** – installation, training, maintenance
- **Increased Operator Efficiency** – higher awareness, more visibility
- **Improved Crew Safety** – completeness, consistency and persistence of data across multiple operator and crew-facing applications (e.g., tagging)
- **System Easily Scaled in Real-time** – reduce or increase the number of operators and control rooms quickly for different conditions: peak load, low load, storm/outage
- **SOA Architecture** – reduces complexity and maintenance of 3rd party interfaces

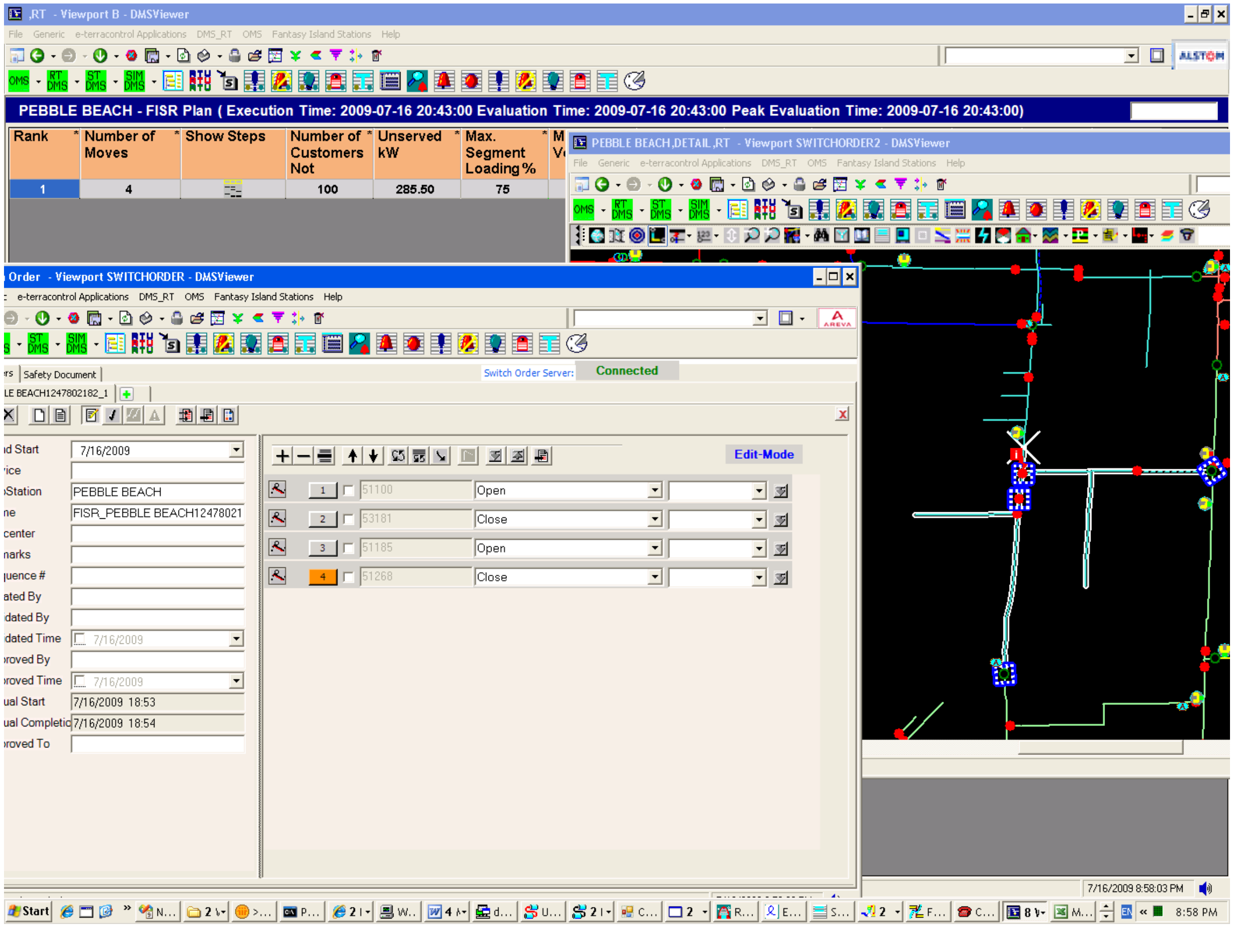
# Integration Includes
# Distribution Operations Training Simulator



# Fault Isolation and Service Restoration

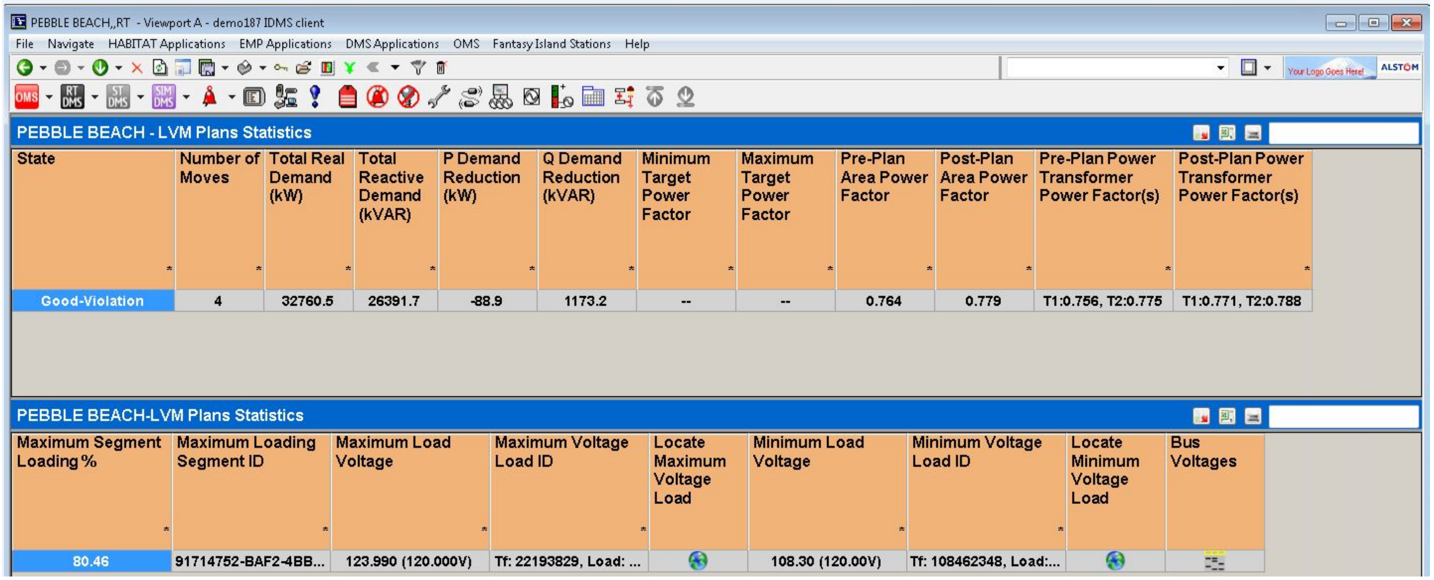
- Generates Switching Plans to Isolate Faulted Circuits, Restore Non-faulted Circuits
- Plans can be executed in Study Mode prior to implementation in Real-Time
- Can be triggered by event or on demand
- Runs in Closed-loop or Advisory Modes
- Several Problem Formulations:
  - Minimize un-served kW
  - Minimize minutes of interruption
  - Minimize number of switching actions
  - Minimize voltage drop

# Switching Order Steps from FLISR Results



# Optimization – Volt/VAr Control

- Distribution System Optimization *without customer involvement or impact*
  - Loss minimization (Also CVR, VAr Support)




| State | Number of Moves | Total Real Demand (kW) | Total Reactive Demand (kVAR) | P Demand Reduction (kW) | Q Demand Reduction (kVAR) | Minimum Target Power Factor | Maximum Target Power Factor | Pre-Plan Area Power Factor | Post-Plan Area Power Factor | Pre-Plan Power Transformer Power Factor(s) | Post-Plan Power Transformer Power Factor(s) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Good-Violation | 4 | 32760.5 | 26391.7 | -88.9 | 1173.2 | -- | -- | 0.764 | 0.779 | T1:0.756, T2:0.775 | T1:0.771, T2:0.788 |

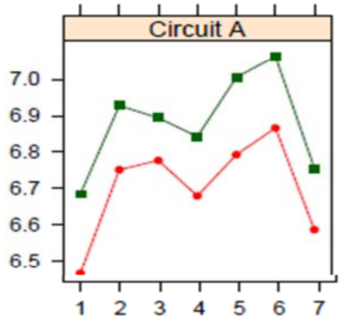
| Maximum Segment Loading % | Maximum Loading Segment ID | Maximum Load Voltage | Maximum Voltage Load ID | Locate Maximum Voltage Load | Minimum Load Voltage | Minimum Voltage Load ID | Locate Minimum Voltage Load | Bus Voltages |
|---|---|---|---|---|---|---|---|---|
| 80.46 | 91714752-BAF2-4BB... | 123.990 (120.000V) | Tf: 22193829, Load: ... | | 108.30 (120.00V) | Tf: 108462348, Load:... | | |

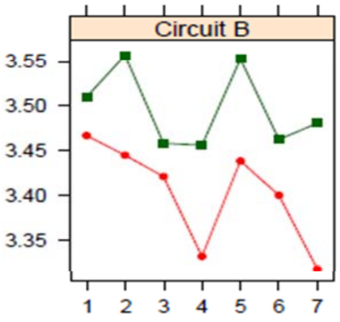
Study Mode Loss Minimization Results

# Model/Optimization-Based Volt-VAr Control

**Model-based**, Powerflow Analysis with Optimization Algorithms

- Preferred Method
- Achieves Maximum VVC Benefit
- Works for Nominal & Backup Switching Configurations



# DMS Implementation Challenges

- Data
  - All data required by DMS may not be readily available in GIS
  - Required to locate data from other sources (paper & electronic)
- Systems Integration
- Security Architecture

# Required Disclaimer for DOE Funded Project

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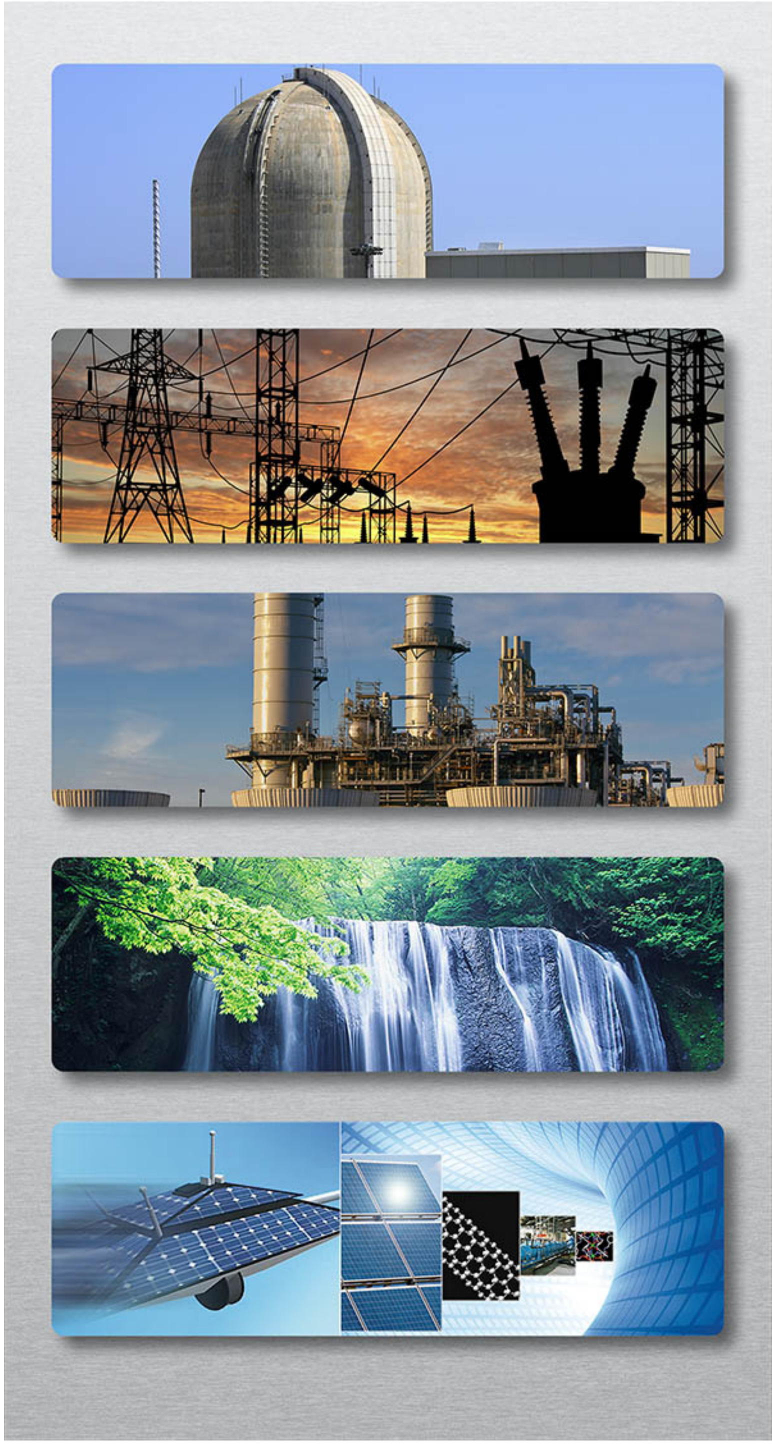
# Q & A

**Will Odell**
Smart Grid Program Manager
Snohomish County PUD
whodell@snopud.com

SNOHOMISH COUNTY PUD PUBLIC UTILITY DISTRICT NO. 1

**John Sell**
IDMS Product Marketing Manager
Alstom Grid, Inc.
john.sell@alstom.com

ALSTOM



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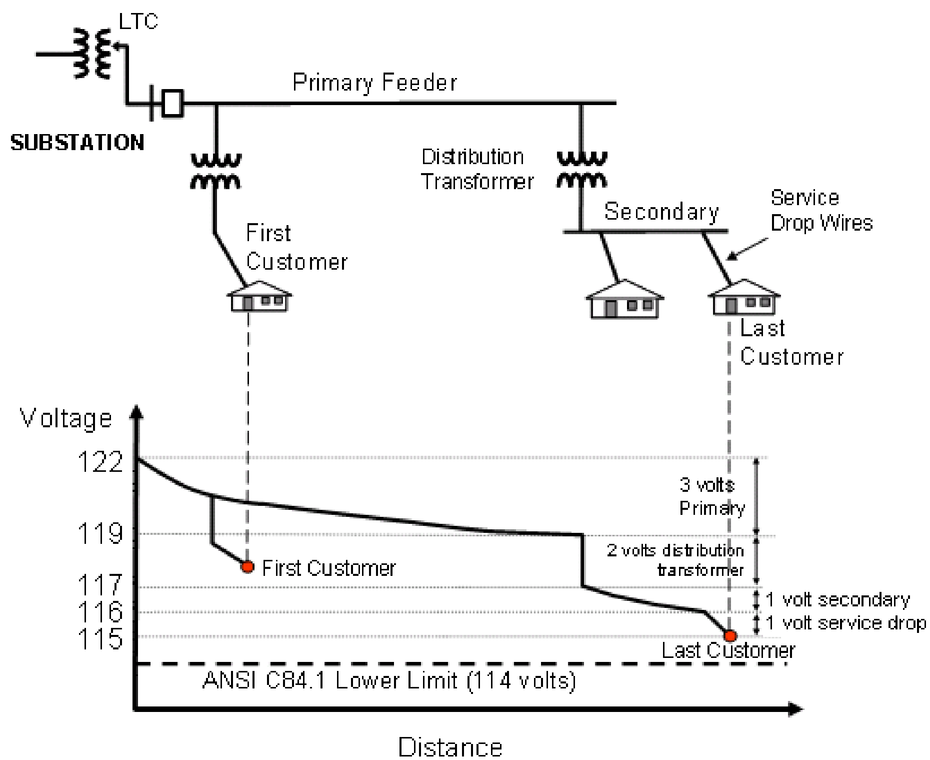
# Volt/VAR Control and Optimization Concepts and Issues

**Bob Uluski, EPRI**
Technical Executive


- **Basic concepts of Volt-VAR Control and Optimization**
- **How these technologies should be assessed ("Proof of Concept")**

# *What is Volt-VAR control?*

- Volt-VAR control (VVC) is a fundamental operating requirement of all electric distribution systems
- The prime purpose of VVC is to maintain acceptable voltage at all points along the distribution feeder under all loading conditions



# Volt-VAR Control in a Smart Grid World

- **Expanded** objectives for Volt-VAR control include
  - **Basic requirement – maintain acceptable voltage**
  - **Support major "Smart Grid" objectives:**
    - Improve efficiency (reduce technical losses) through voltage optimization
    - Reduce electrical demand and/or Accomplish energy conservation through voltage reduction
    - Promote a "self healing" grid (VVC plays a role in maintaining voltage after "self healing" has occurred)
    - Enable widespread deployment of Distributed generation, Renewables, Energy storage, and other distributed energy resources (dynamic volt-VAR control)



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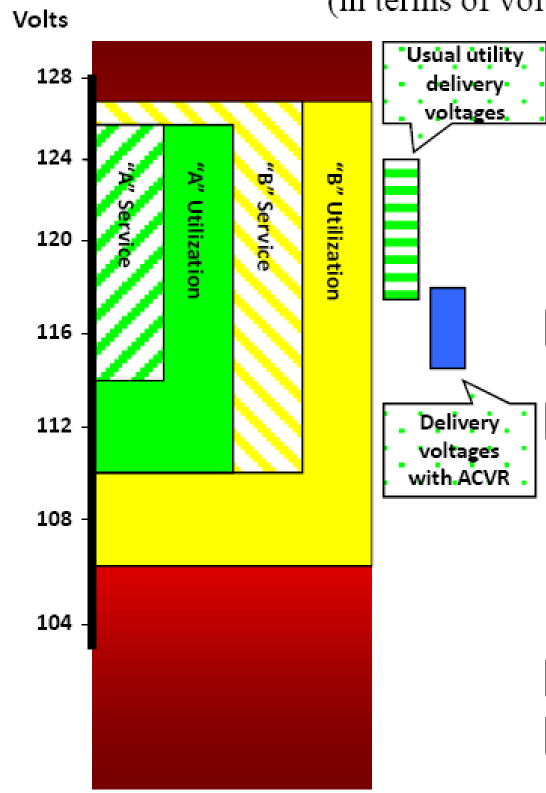
# Concept of Conservation Voltage Reduction

- ANSI standards have some flexibility in the allowable delivery voltage
- Distribution utilities typically have delivery voltage in upper portion of the range
- **<u>Concept of CVR:</u> Maintain voltage delivered to the customer in the lower portion of the acceptable range**

## Allowable Voltage Range

(in terms of voltages used in homes)




ANSI Standard C 84.1 – 1995 "Electrical Power Systems and Equipment – Voltage Ratings"
[similar to CAN3-C235-83 (R2000)]

Nominal 120 VAC – Range A (Normal Operation

- **Service Voltage 114 v – 126 v**
  - Voltage at which utility delivers power to home
- **Utilization Voltage 110v – 126 v**
  - Voltage at which equipment uses power
  - Most Motors rated at 115 v
  - Incandescent Lamps rated at 120 v

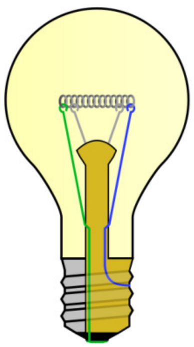
Nominal 120 VAC – Range B (Out of Normal Operation)

- **Service Voltage 110 v – 127 v**
- **Utilization Voltage 106v – 127 v**

Source*: **PCS Utilidata***

# Conservation Voltage Reduction – Why Do It?

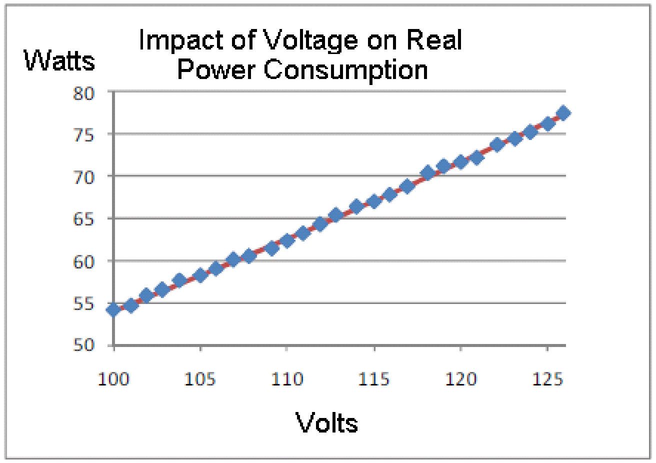
- Many electrical devices operate more efficiently (use less power) with reduced voltage



$$P = V^2 \div R$$

***"Constant Impedance" Load***

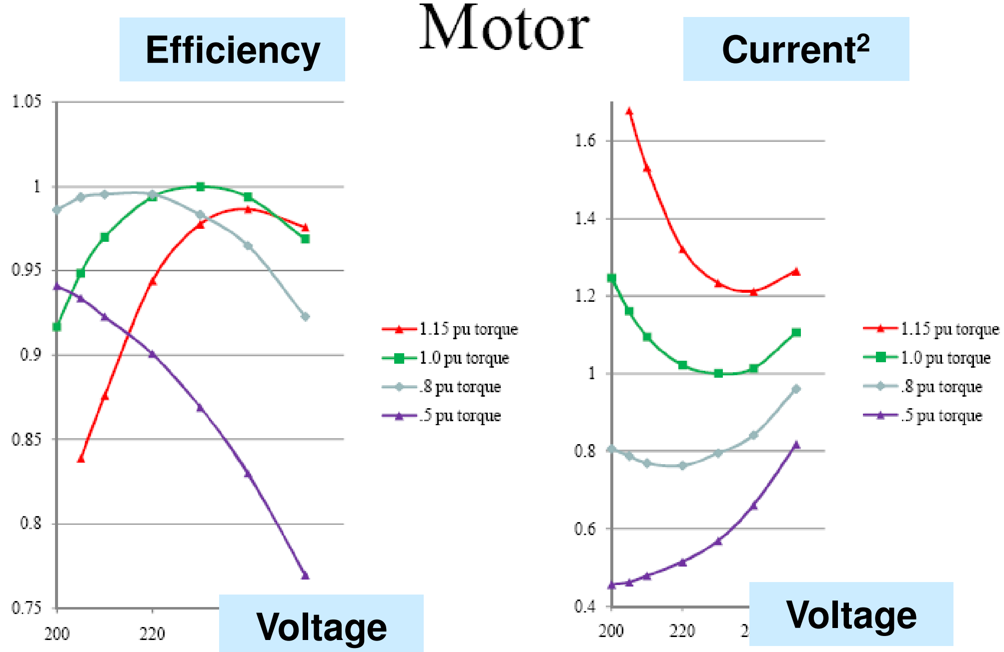
Incandescent Light Bulb (70W)




"Evaluation of Conservation Voltage Reduction (CVR) on a National Level"; PNNL; July 2010

# Impact of Voltage Reduction on Electric motors Conservation Voltage Reduction

## Voltage effects on ½ Hp, 230 Vac, 1Ø Motor




M.S. Chen, R.R. Shoults and J. Fitzer, *Effects of Reduced Voltage on the Operation and Efficiency of Electric Loads, Volumes 1 & 2*, EPRI, Arlington: University of Texas, 1981, Motor Number 3

**Efficiency improve for small voltage reduction**

**Incremental change in efficiency drops off and then turns negative as voltage is reduced**

**Negative effect occurs sooner for heavily loaded motors**

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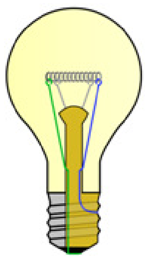
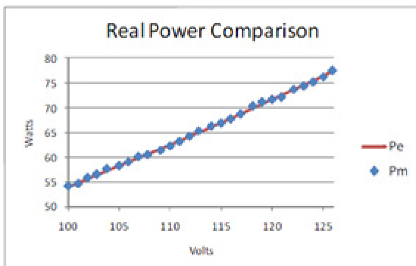
# Conservation Voltage Reduction – Why Do It?

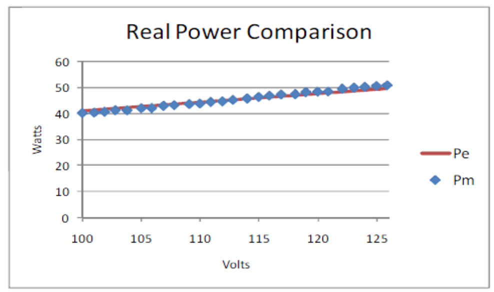
- Some newer devices have exhibit “constant power” behavior to some extent

Incandescent Light Bulb (70W)

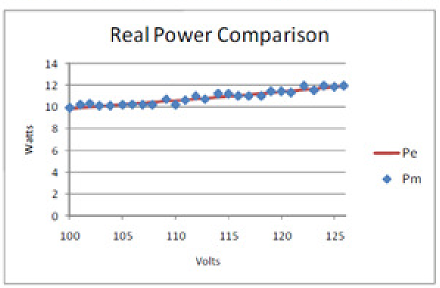




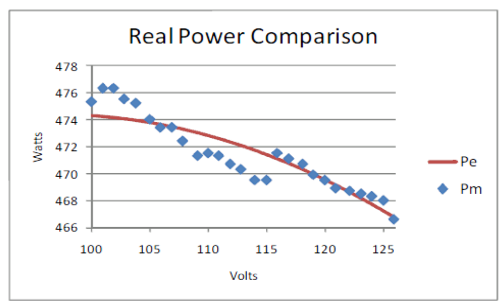

Television (Cathode Ray Tube)




Compact Fluorescent Light (CFL) 13W




Plasma TV





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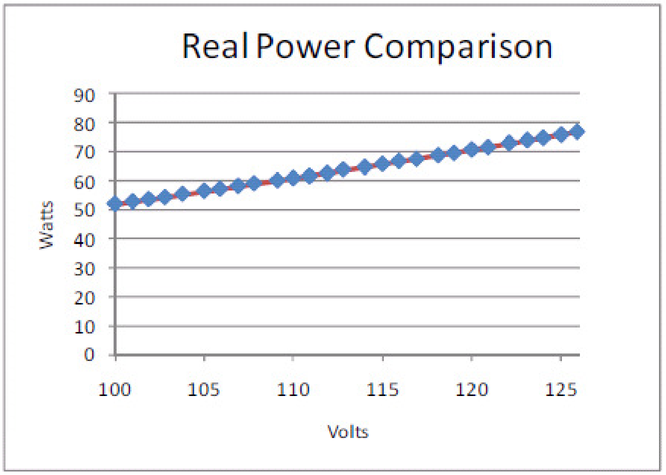
# Recent results

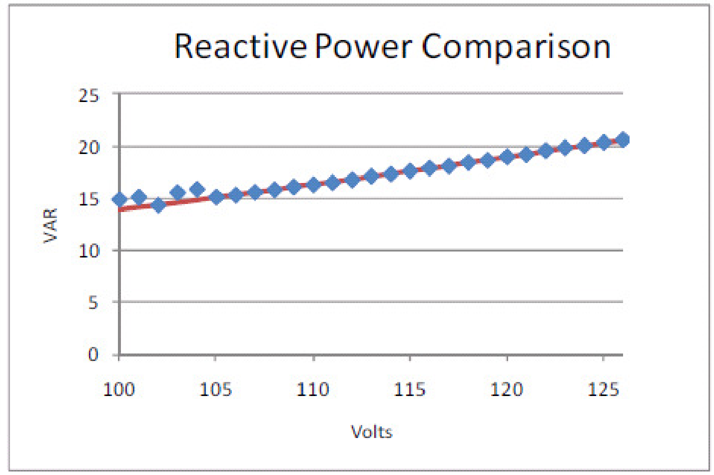
- Despite trend to constant power, reported results are still pretty favorable

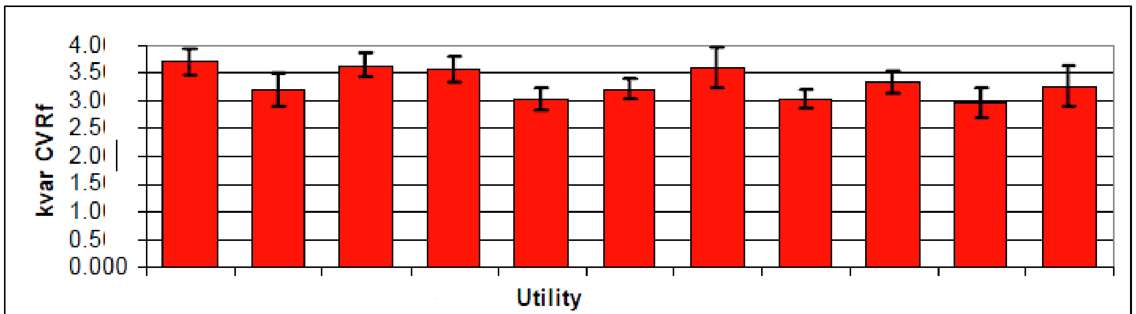
| CVRf | Mean Voltage Reduction | | Mean Energy Reduction |
|---|---|---|---|
| pu | % | V | % |
| 0.1 | 3.29% | | 0.2% |
| 0.2 | 2.33% | 2.86 | 0.5% |
| 0.3 | 2.83% | 3.47 | 0.8% |
| 0.7-0.9 | 1.5% - 2.5% | | 1.1%-2.2% |
| 0.6 | 2.00% | | 1.2% |
| 0.5 | 2.96% | 3.66 | 1.4% |
| 0.8 | 2.00% | | 1.5% |
| 0.6 | 2.98% | | 1.7% |
| 0.2-0.7 | | | 1.8% |
| 0.6 | 3.28% | | 2.0% |
| 0.7 | 2.98% | | 2.1% |
| 0.6 | 3.42% | 4.22 | 2.1% |
| 0.9 | 2.50% | | 2.1% |
| 0.7 | 2.94% | 3.61 | 2.2% |
| 0.7 | 3.57% | | 2.4% |
| 0.6 | 3.95% | | 2.4% |
| 1.1 | 2.38% | 2.9 | 2.6% |
| 2.5 | 1.05% | 1.3 | 2.6% |
| 1.0 | 2.87% | 3.54 | 2.7% |
| 1.6 | 1.71% | 2.08 | 2.8% |
| 1.1 | 2.64% | 3.25 | 3.0% |
| | | | 3.4% |
| 3.0 | 1.18% | 1.4 | 3.5% |
| 1.2 | 3.21% | 3.9 | 3.9% |
| 0.9 | 4.44% | 5.3 | 4.0% |
| | | | 4.0% |
| 1.0 | 4.23% | 5.1 | 4.2% |
| 1.6 | 2.90% | 3.5 | 4.6% |
| 2.7 | 1.84% | 2.26 | 4.9% |
| 1.5 | 3.77% | 4.69 | 5.6% |
| 1.9 | 3.17% | 3.8 | 6.0% |
| 4.7 | 1.72% | 2.09 | 8.1% |

# CVR Also Impacts Reactive Power

Oscillating Fan




| OVERALL kvar CVRf | *CVRf* 3.284 |
|---|---|

kvar CVR factor Results by Utility

**Effect of CVR on kVAR is more significant than on kW**

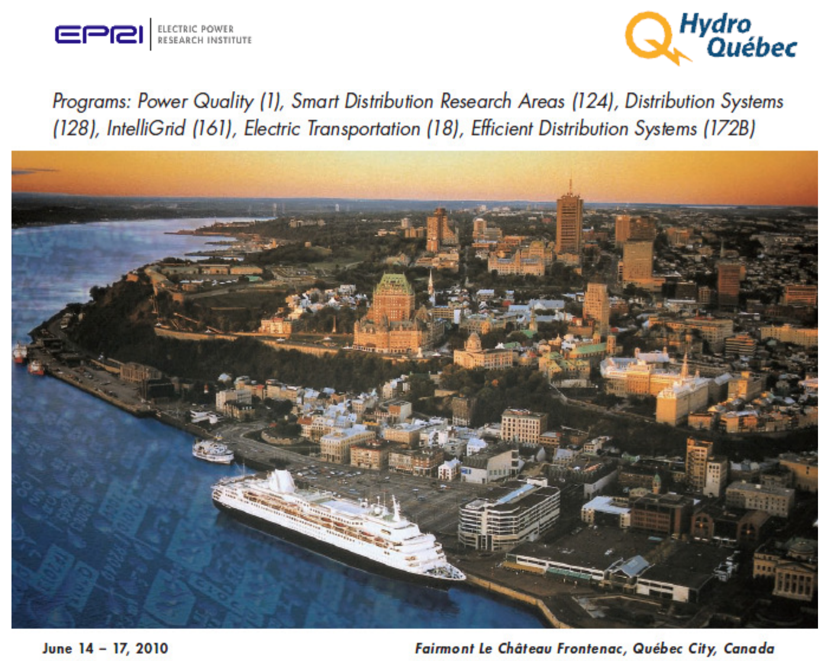
**kW CVRf ≈ 0.7**

**kVAR CVRf ≈ 3.0**

Distribution Efficiency Initiative
Northwest Energy Efficiency Alliance

# Summary of Voltage Optimization Benefits

- **Voltage optimization is a very effective energy efficiency measure**
  - Demand Reduction - 1.5% to 2.1%; Energy Reduction - 1.3% - 2%
  - “Painless” efficiency measure for utilities and customers
  - Cost effective – Leverage existing equipment
  - Short implementation schedule
- **Reduce number of tap changer operations**
- **Improved voltage profile**
- **Early detection of:**
  - Voltage quality problems
  - Voltage regulator problems



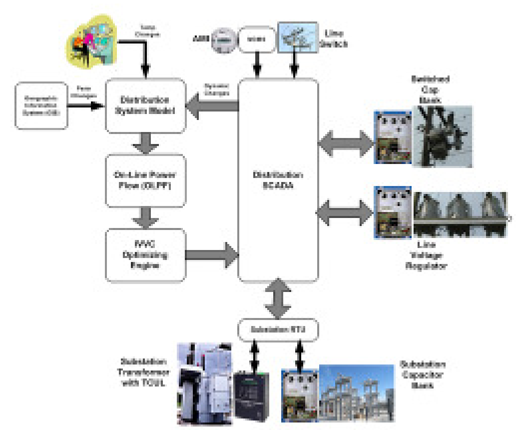

EPRI PQ/Smart Distribution Conference & Expo June 2010

# Approaches to Volt VAR Control

- Standalone Voltage regulator and LTC controls with line drop compensation set to "end-of-line" voltage for CVR

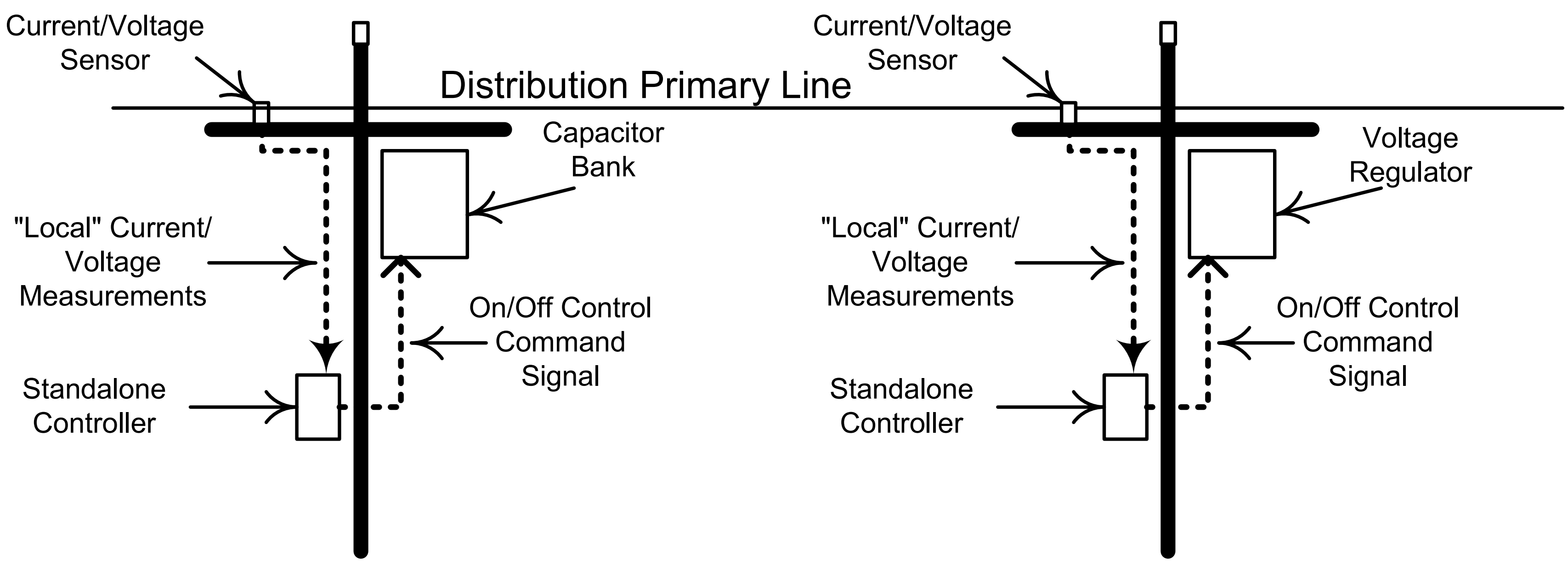

- On-Site Voltage Regulator (OVR) for single location voltage regulation

- "Rule-based" DA control of capacitor banks and voltage regulators for CVR with/without voltage measurement feedback from end of line
- "Heuristic" voltage regulation (e.g. PCS Utilidata "AdaptiVolt", Cooper Power Systems IVVC)
- "Distribution model based" Volt-VAR Optimization



# Standalone Controller Approach

- ***VV Control managed by individual, independent, standalone volt-VAR regulating devices:***
  - Substation transformer load tap changers (LTCs) with voltage regulators
  - Line voltage regulators
  - Fixed and switched capacitor banks



# Reactive Power Compensation Using Fixed and Switched Capacitor Banks

- Switch single capacitor bank on or off based on “local” conditions (voltage, load, reactive power, etc.)
- **Control parameters**
  - Power Factor
  - Load Current
  - Voltage
  - Var Flow
  - Temperature
  - Time of day and day of week



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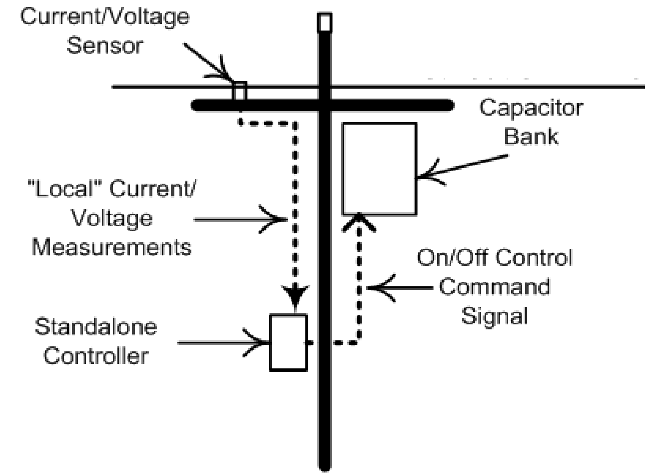
# Standalone Volt VAR Controllers - Strengths and Weakness




- **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

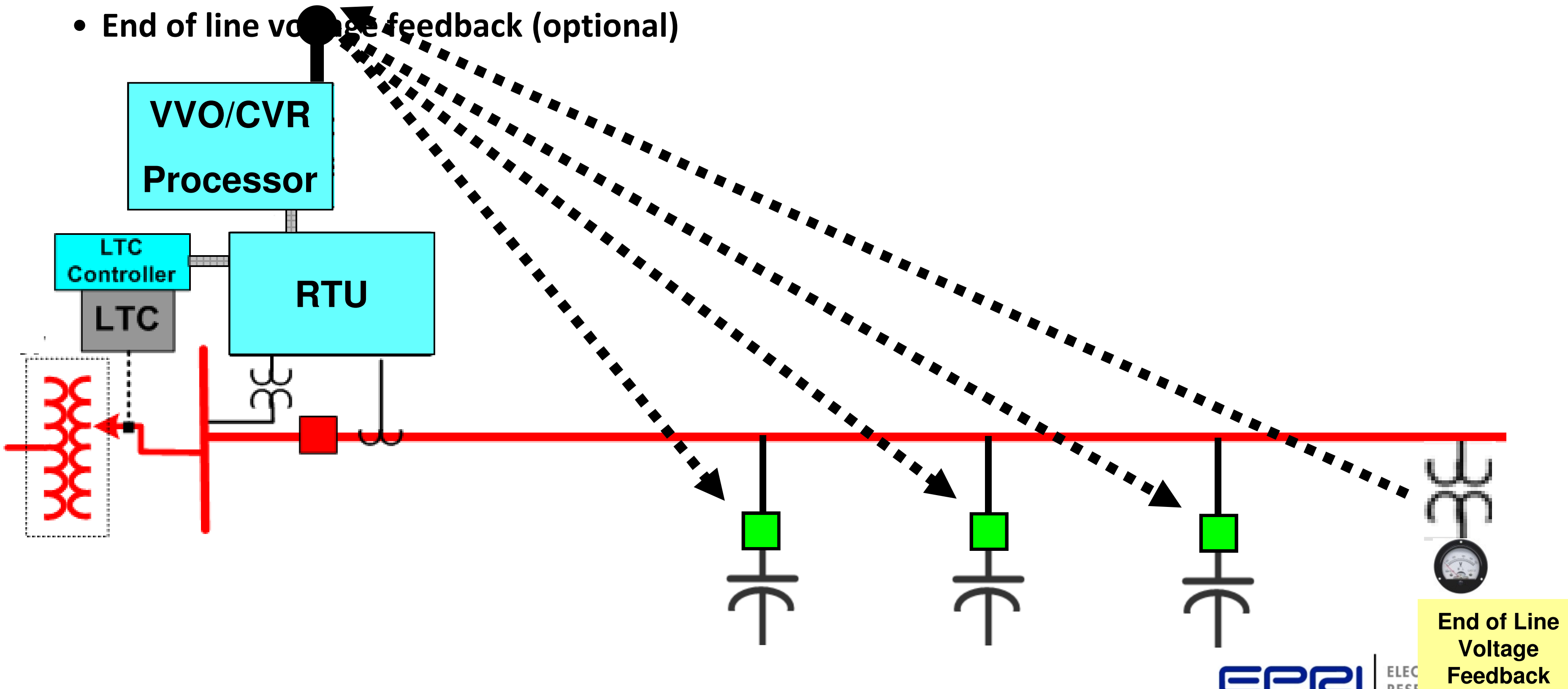
- **Weaknesses**
  - No self monitoring features
  - Lacks coordination between volt and VAR controls – not able to block counter-acting control actions
  - System operation may not be "optimal" under all conditions – need to build in bigger safety margin due to lack of "visibility" of remote conditions
  - Lacks flexibility to respond to changing conditions out on the distribution feeders – can misoperate following automatic reconfiguration
  - May not handle high penetration of DG very effectively
  - Cannot override traditional operation during power system emergencies

# "SCADA" Controlled Volt-VAR

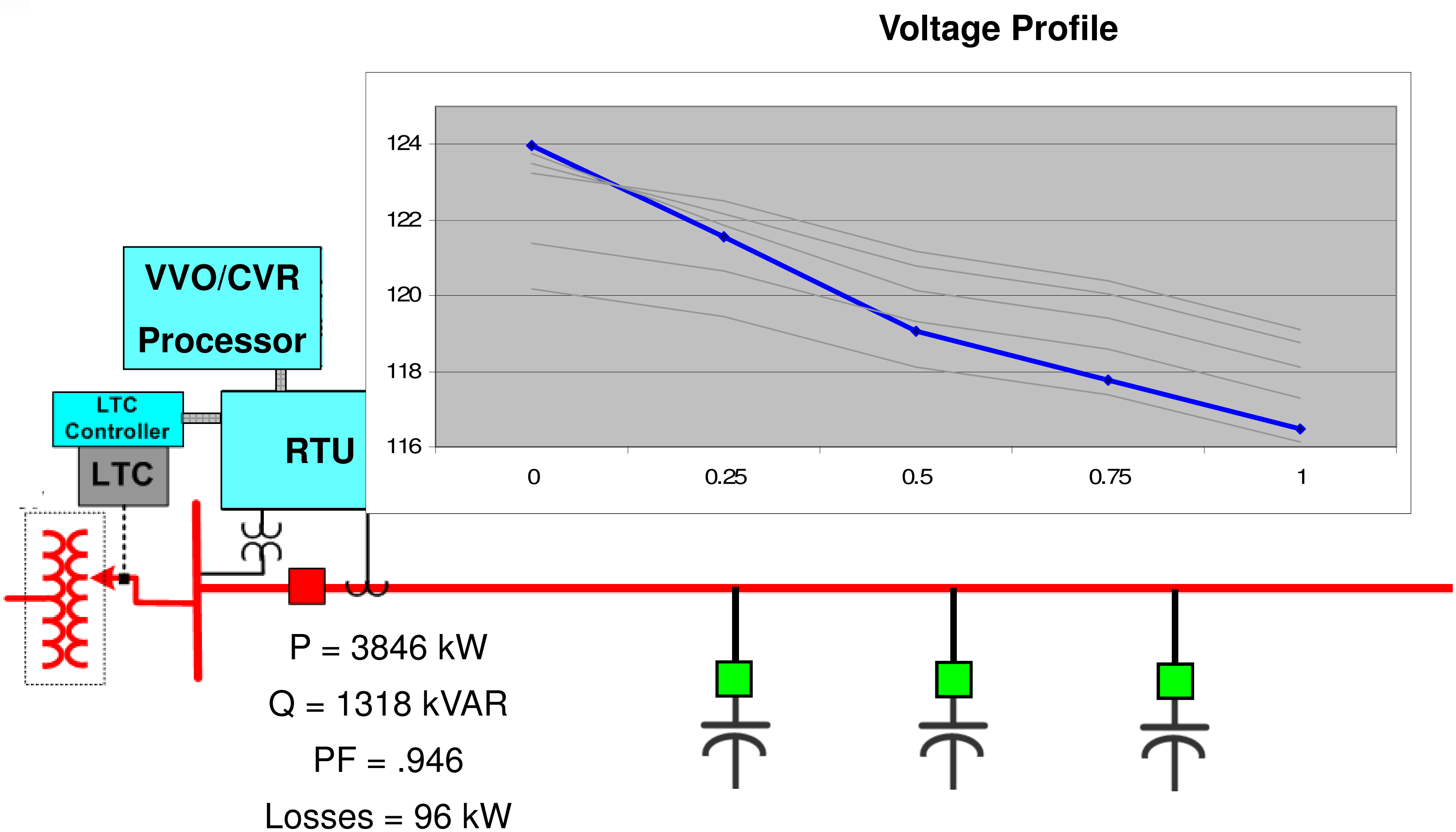
- Volt-VAR power apparatus monitored and controlled by Supervisory Control and Data Acquisition (SCADA)
- Volt-VAR Control typically handled by two separate (independent) systems:
  - **VAR Dispatch** – controls capacitor banks to improve power factor, reduce electrical losses, etc
  - **Voltage Control** – controls LTCs and/or voltage regulators to reduce demand and/or energy consumption (aka, **Conservation Voltage Reduction**)
- Operation of these systems is primarily based on a **stored set of predetermined rules** (e.g., *"if power factor is less than 0.95, then switch capacitor bank #1 off"*)

# SCADA (Rule Based) Volt-VAR Control System Components

- 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
- Voltage regulators (LTCs) & local measurement facilities
- Communication facilities
- End of line voltage feedback (optional)



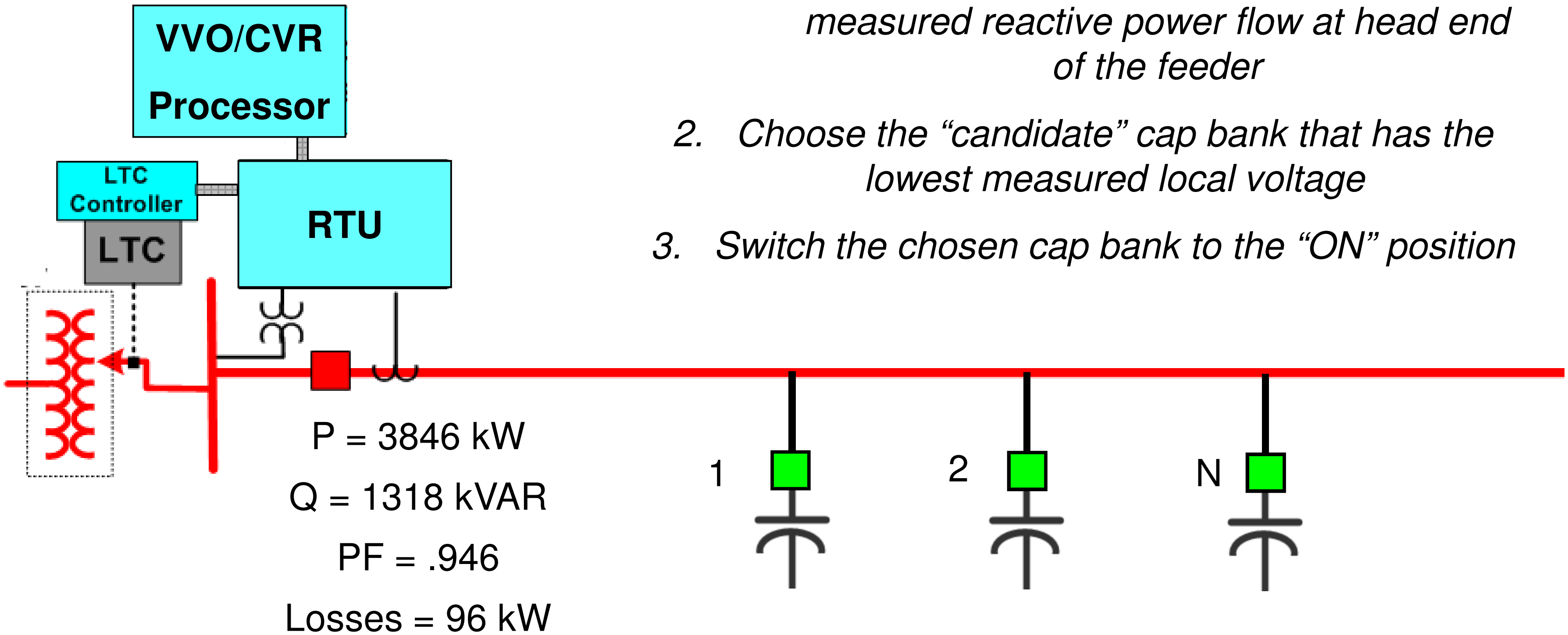
# SCADA (Rule Based) Volt-VAR Control
# Part 1: VAR Control (Power Factor Correction)



# SCADA (Rule Based) Volt-VAR Control
# Part 1: VAR Control (Power Factor Correction)

**Sample Rules:**

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





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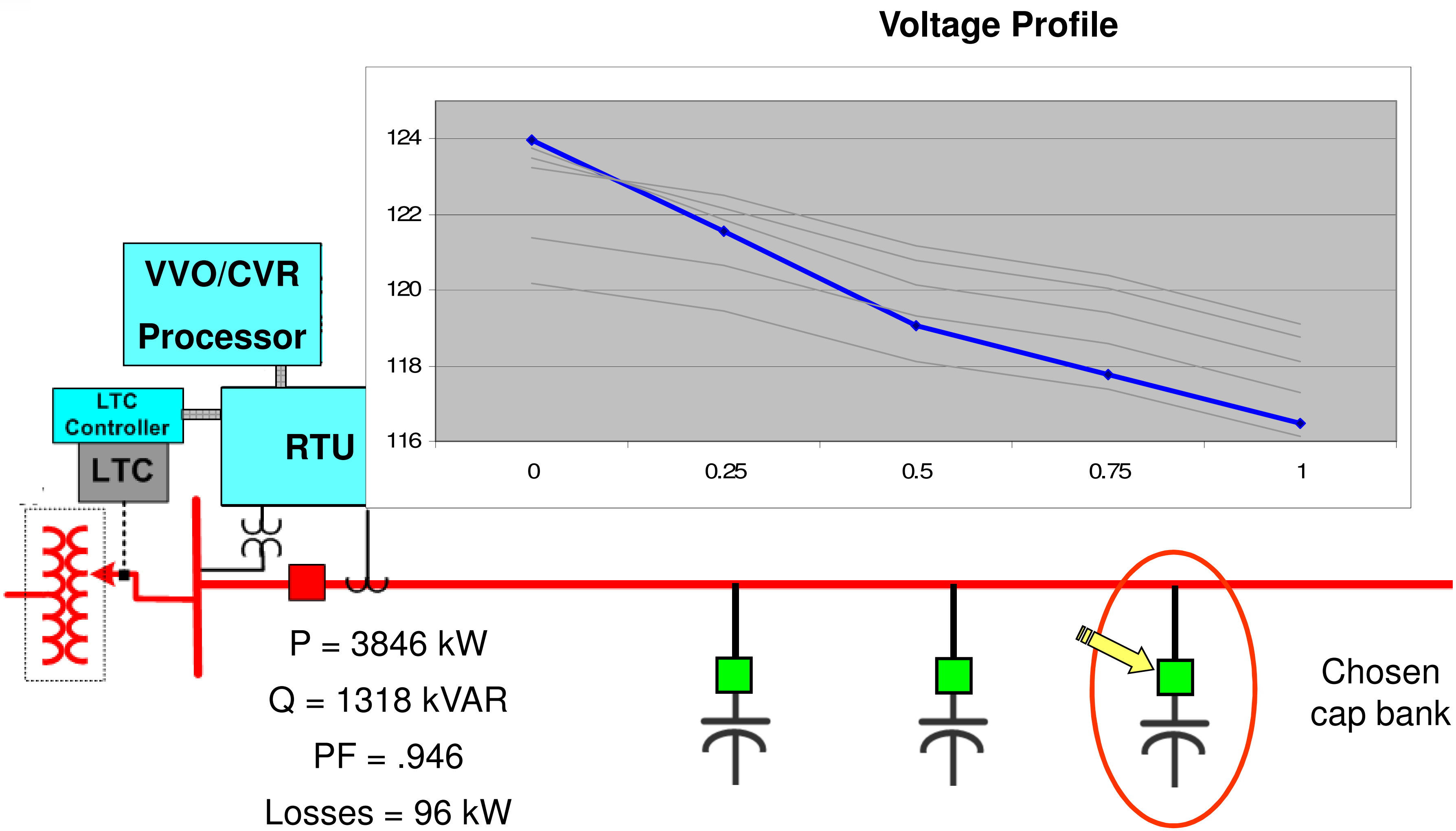

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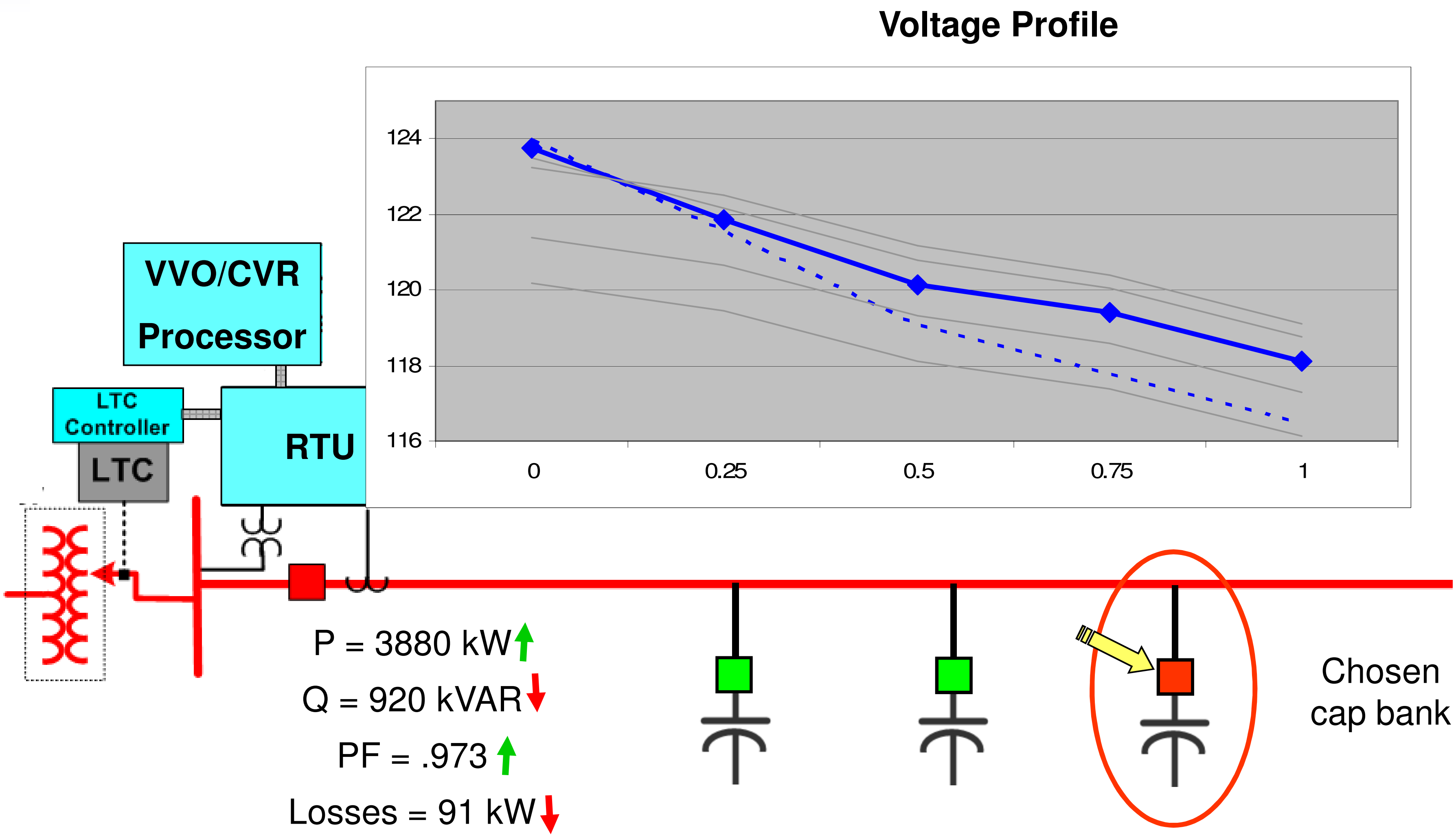






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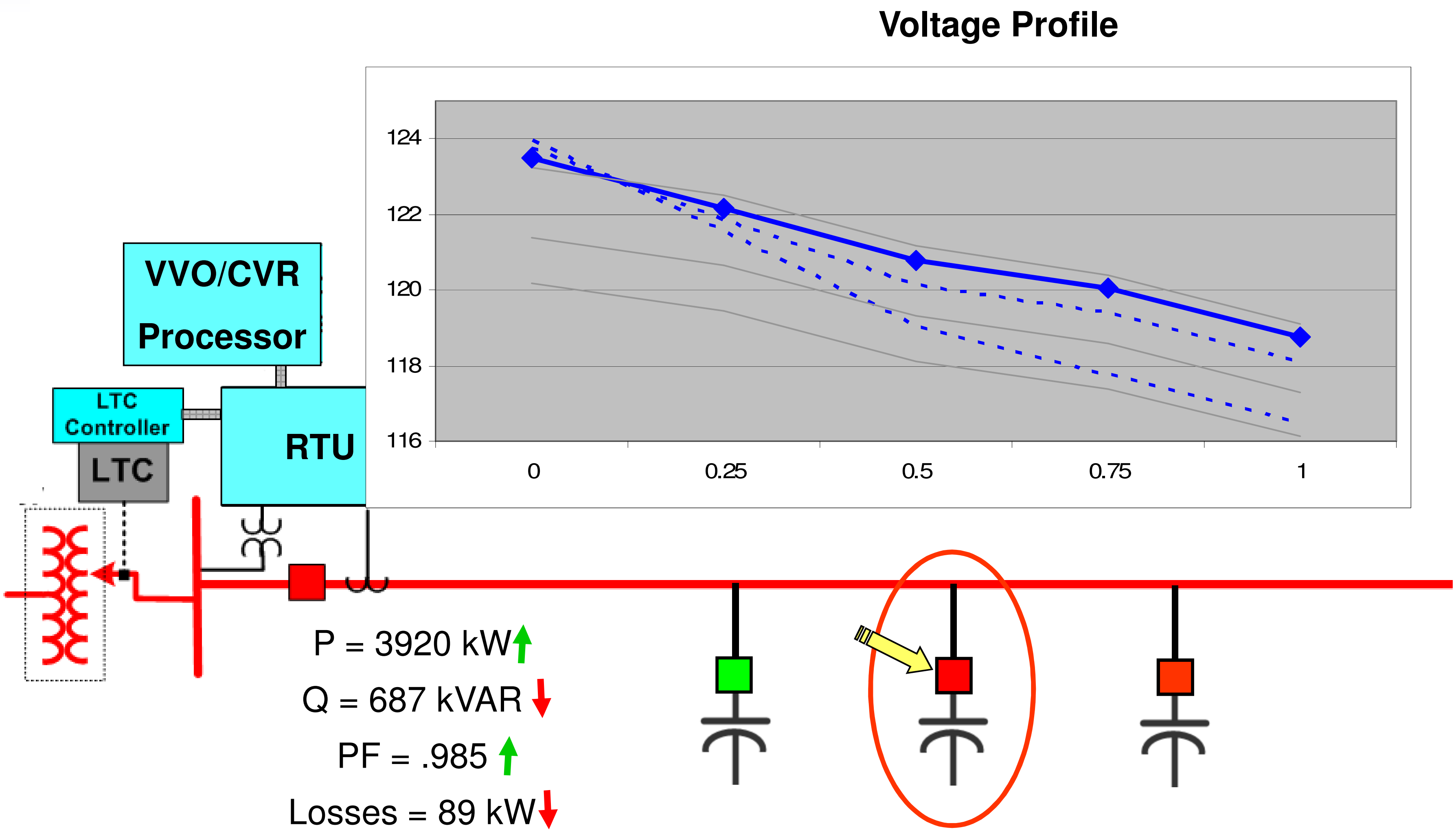

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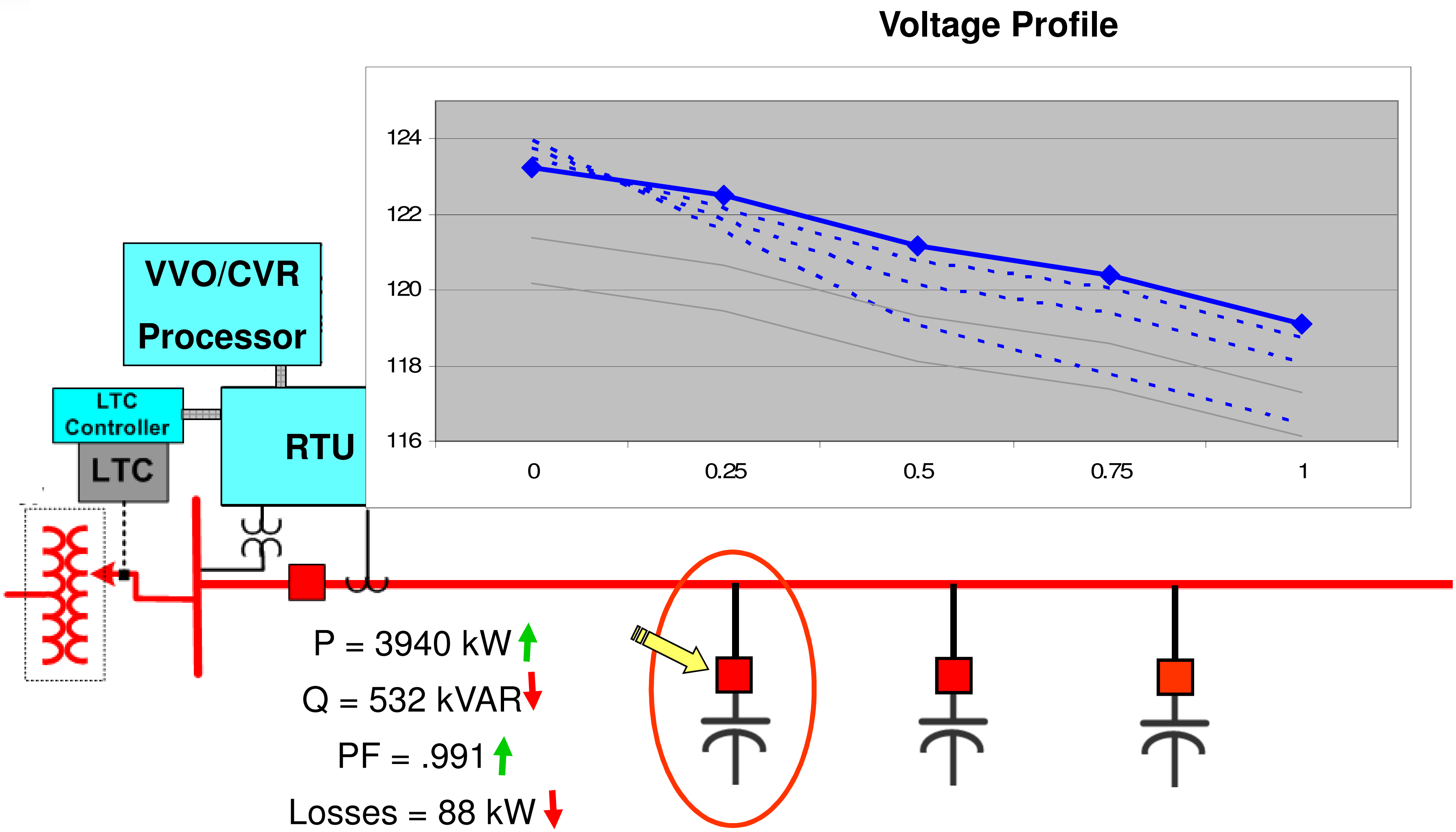

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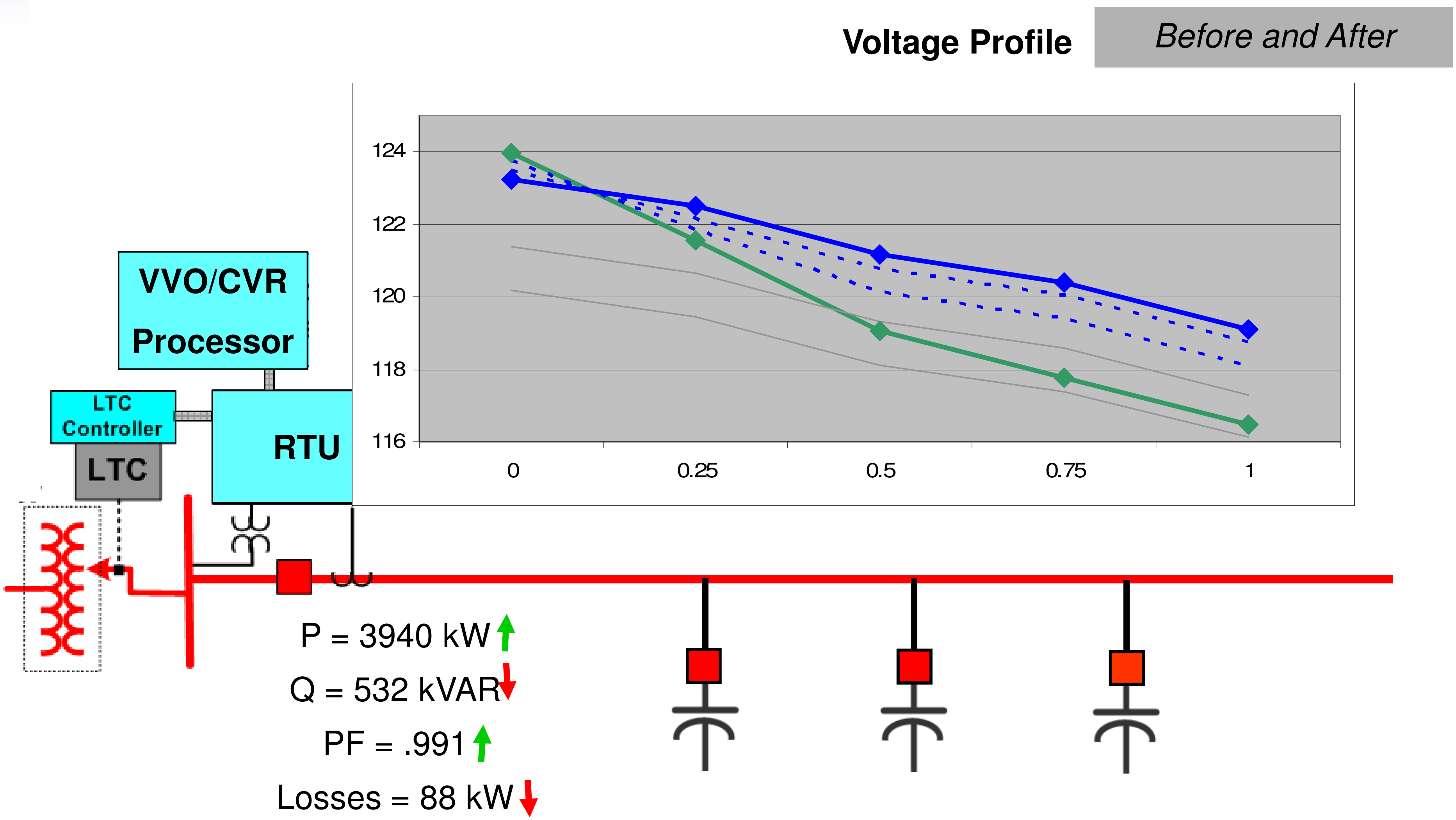






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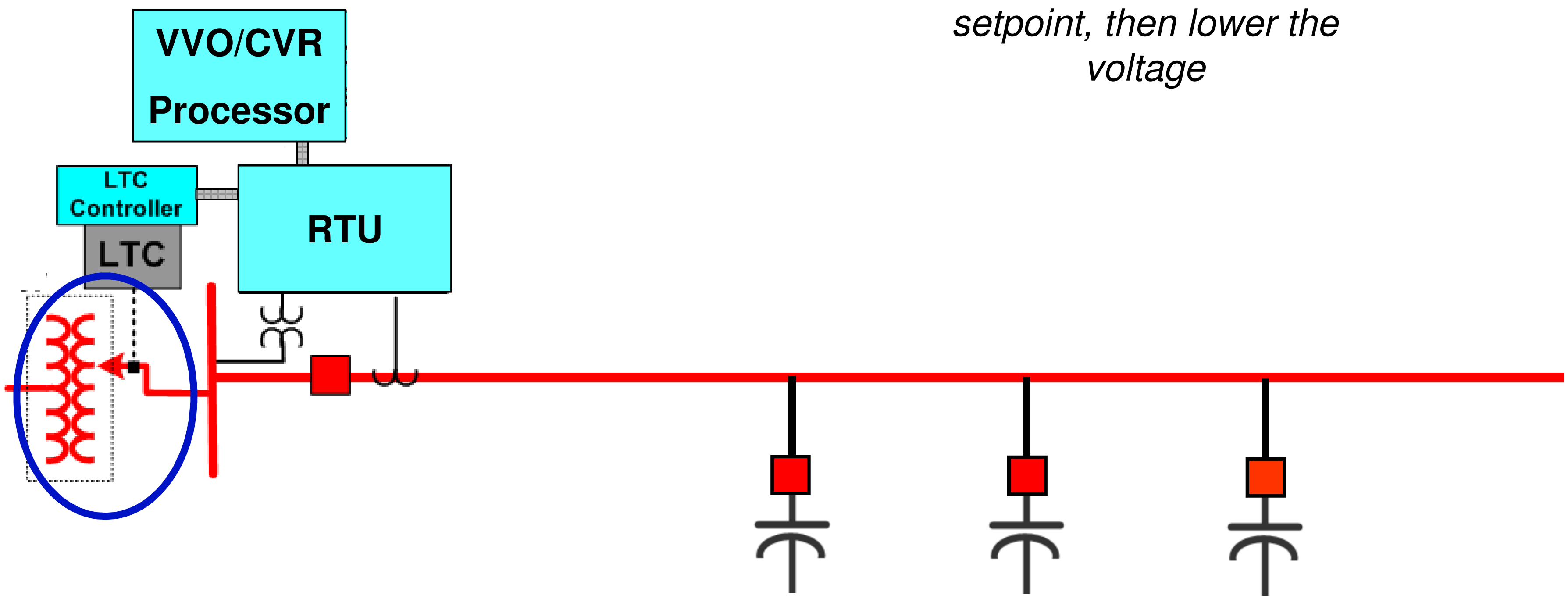
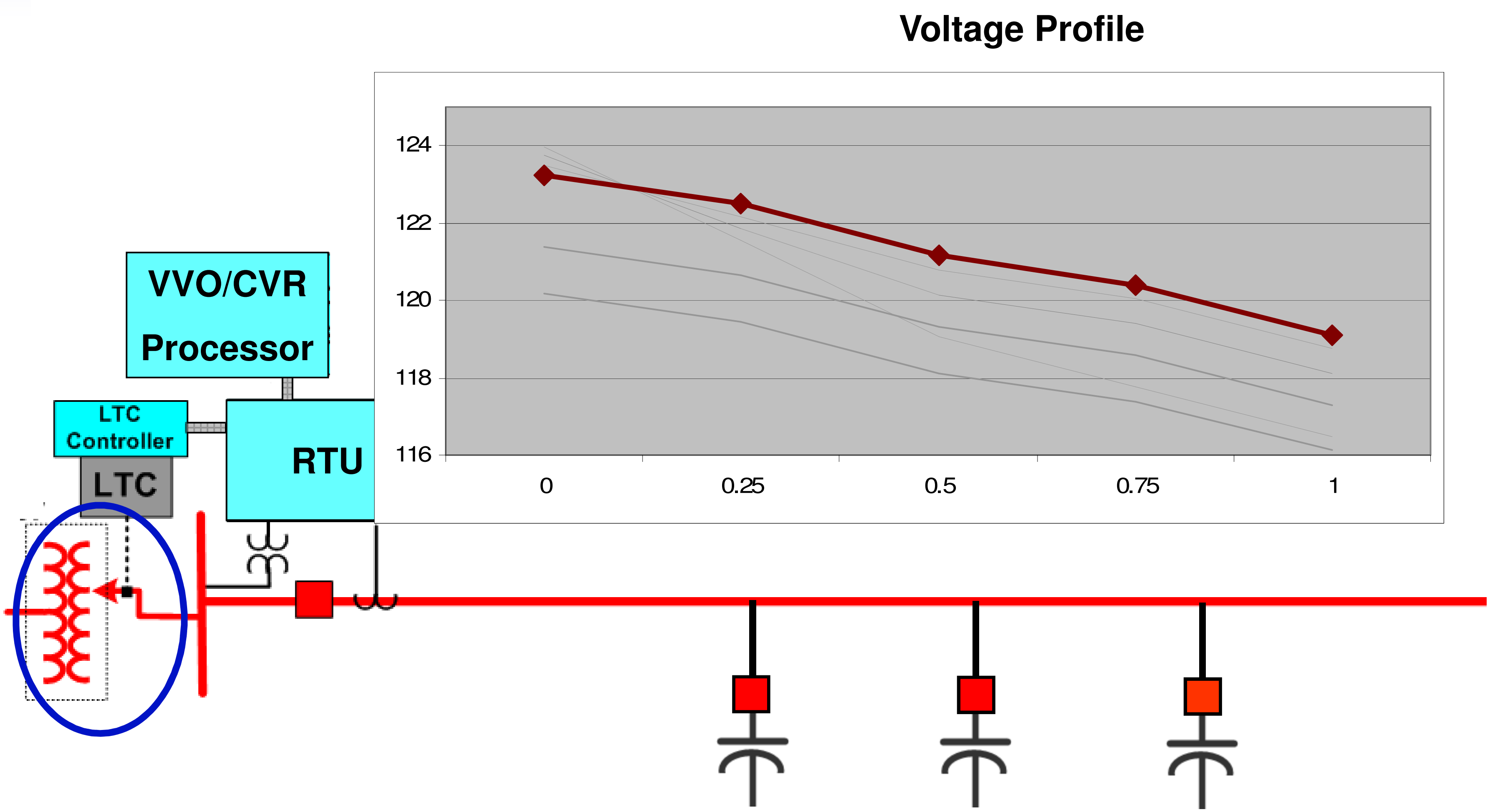
# SCADA (Rule Based) Volt-VAR Control
# Part 2: Voltage Control (CVR)




**Sample rule for voltage reduction:**

1. *If voltage at head end of the feeder exceeds LTC setpoint, then lower the voltage*

# SCADA (Rule Based) Volt-VAR Control
# Part 2: Voltage Control (CVR)



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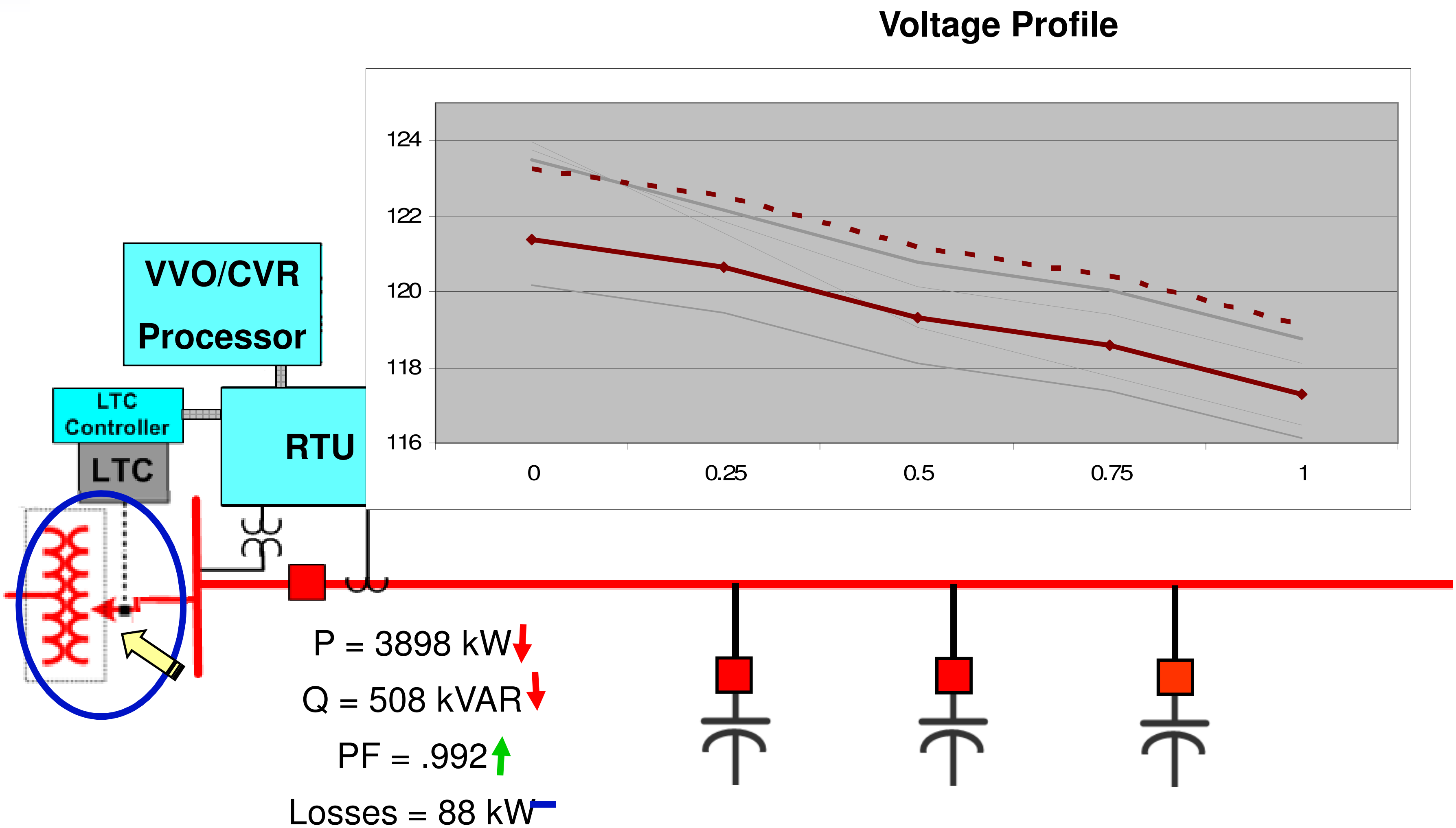






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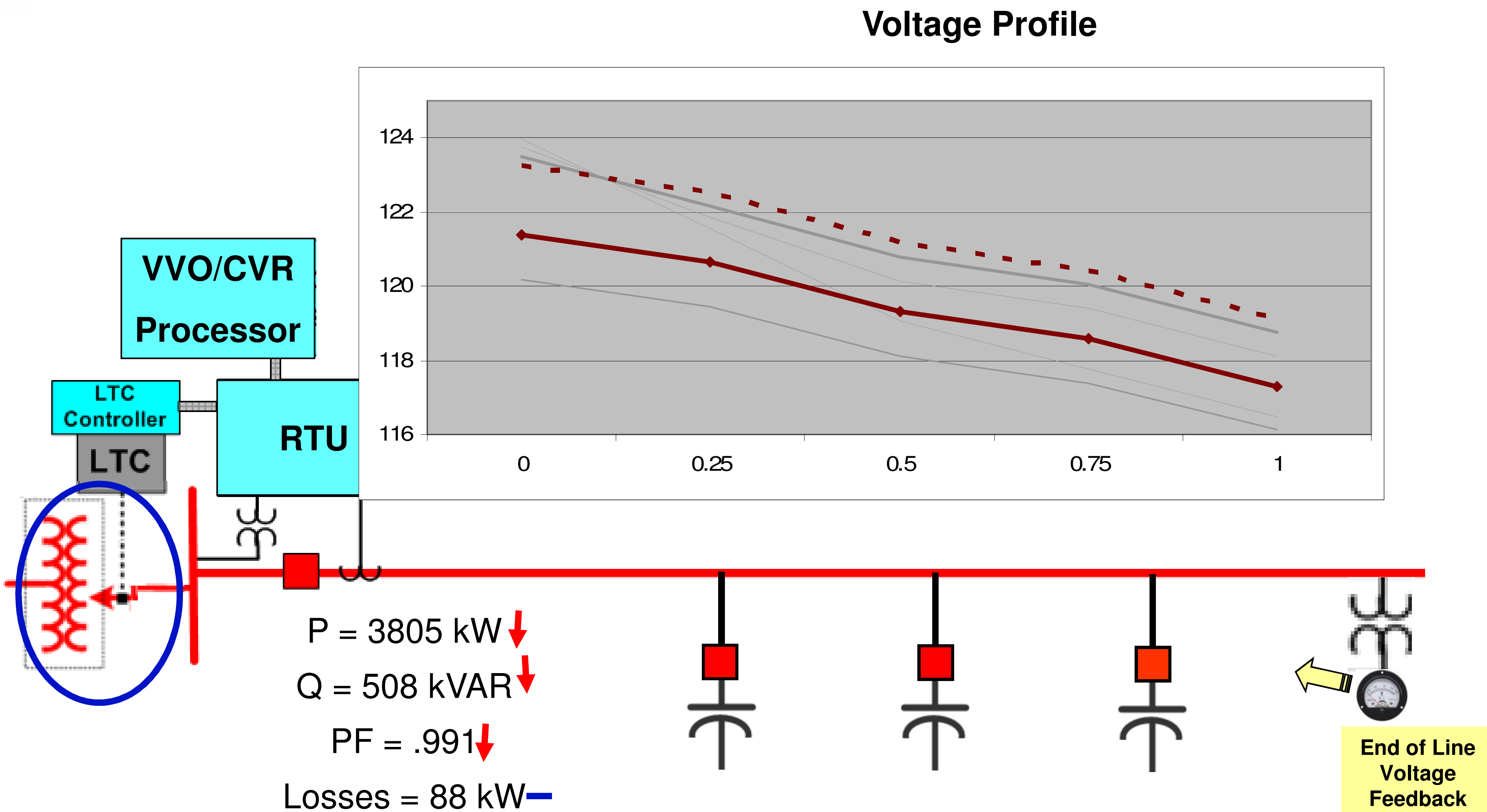






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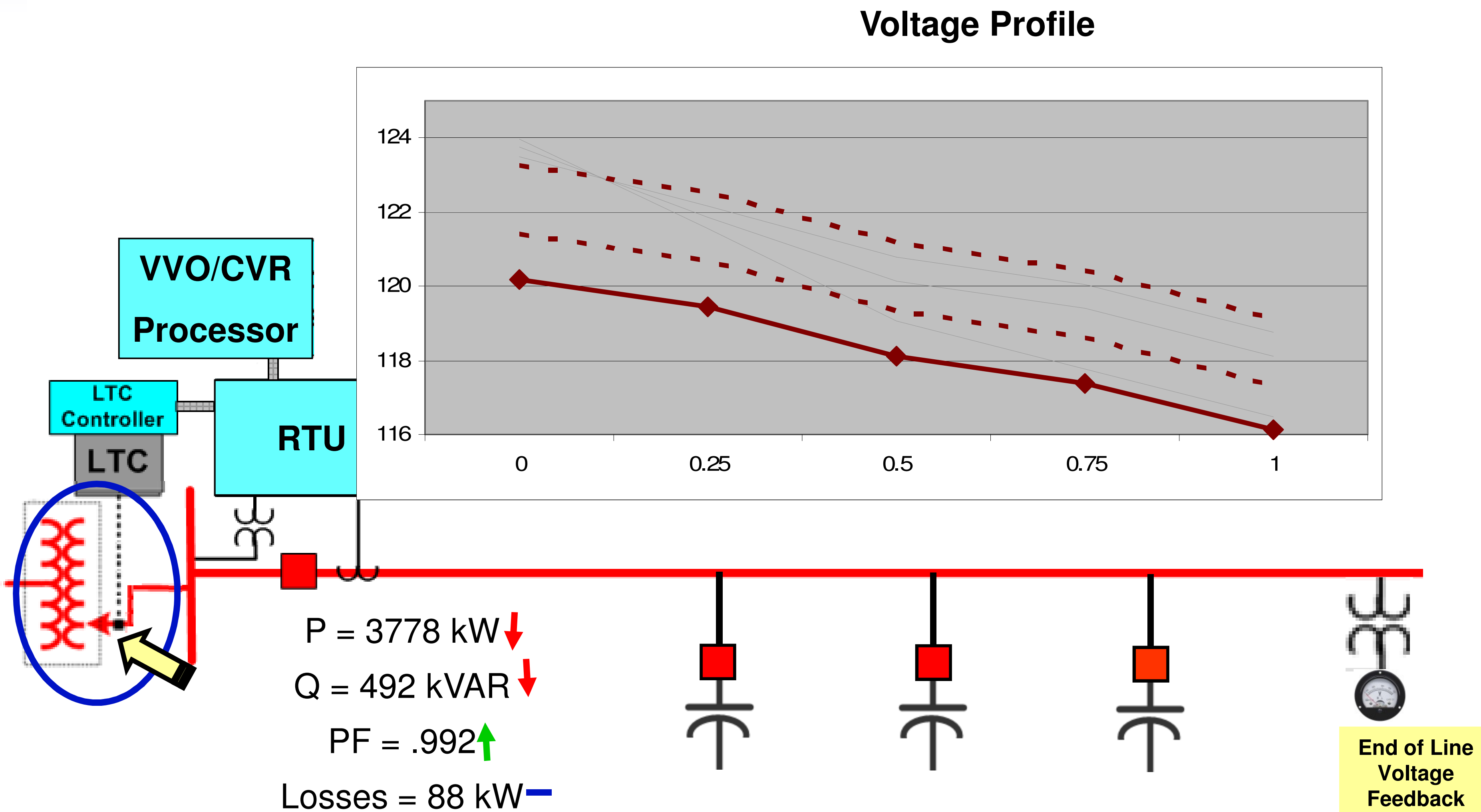

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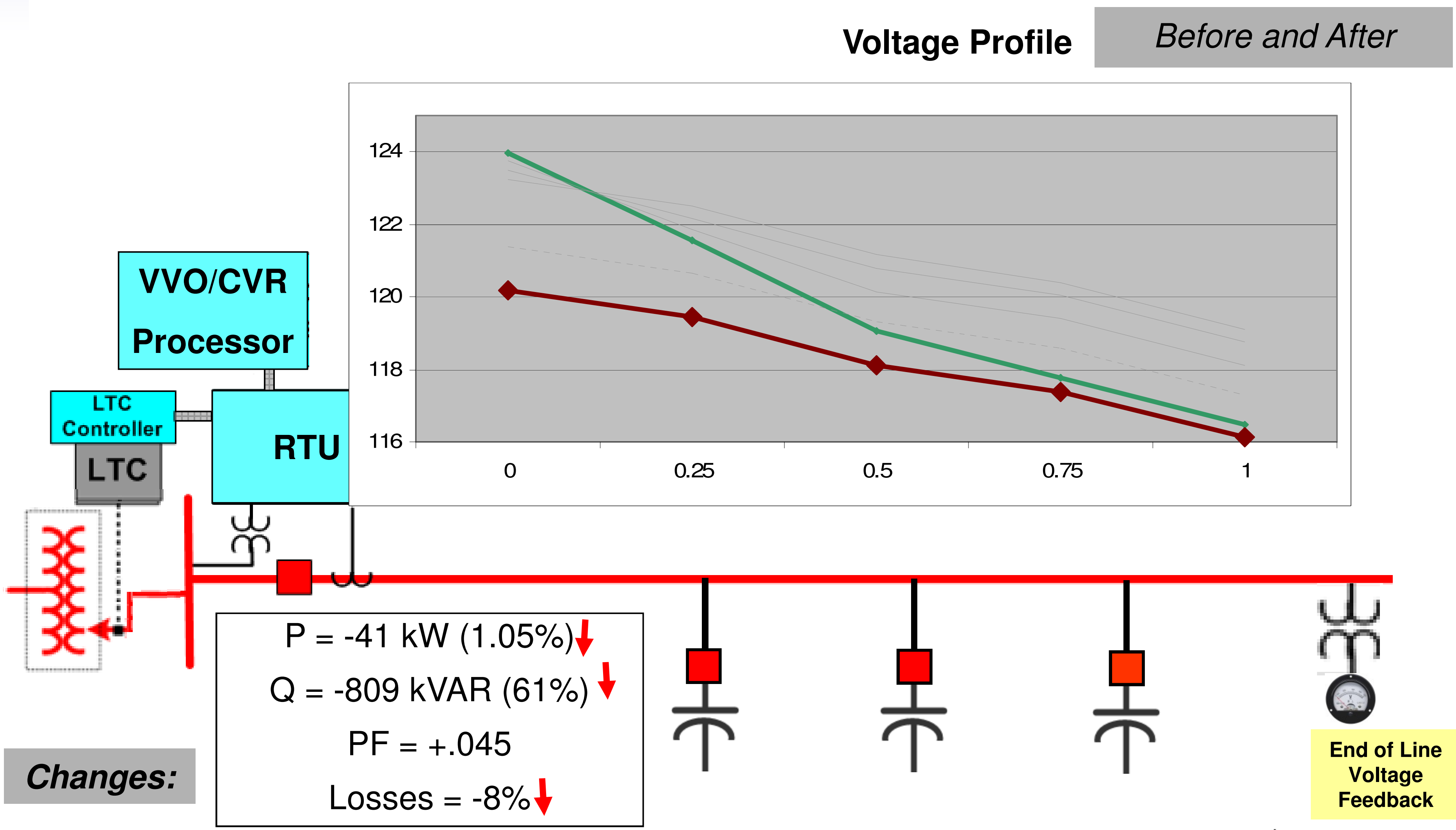






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# SCADA Controlled Volt VAR Summary

## •Strengths:

- Usually **some efficiency improvement** versus standalone controllers
- **Self monitoring**
- **Can override operation** during system emergencies
- Can include remote measurements in the "rules" – smaller margin of safety needed

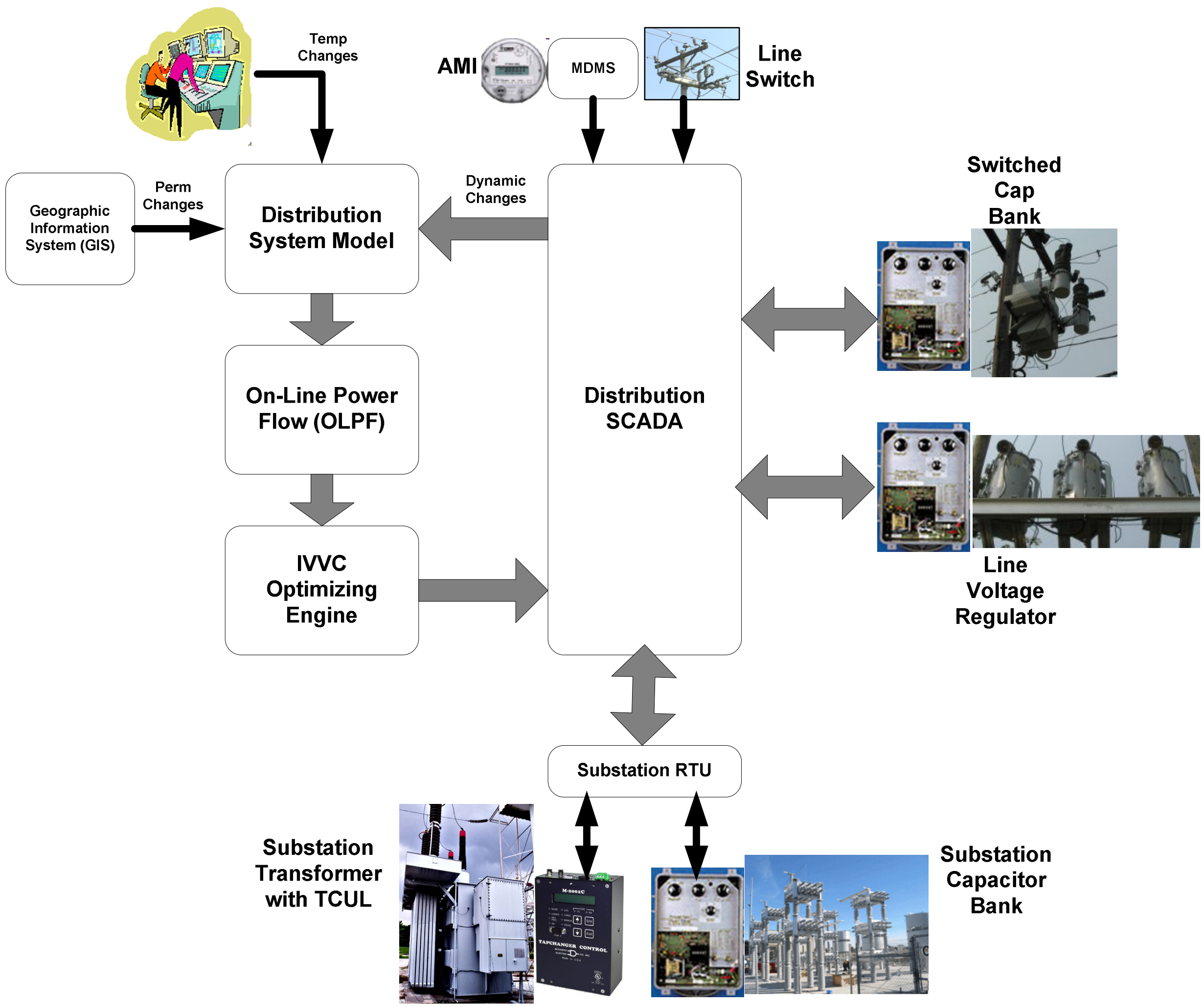
## •Weaknesses:

- **Somewhat less scalable** that standalone controllers (minimum deployment is one substation)
- More complicated – requires extensive communication facilities
- Does **not** adapt to **changing feeder configuration** (rules are fixed in advance)
- Does **not** adapt well to **varying operating needs** (rules are fixed in advance)
- Overall efficiency is improved versus traditional approach, but is **not necessarily optimal under all conditions**
- Operation of VAR and Volt devices usually not **coordinated (separate rules for cap banks & Vregs)**
- Does **not** adapt well to **presence of high DG penetration**

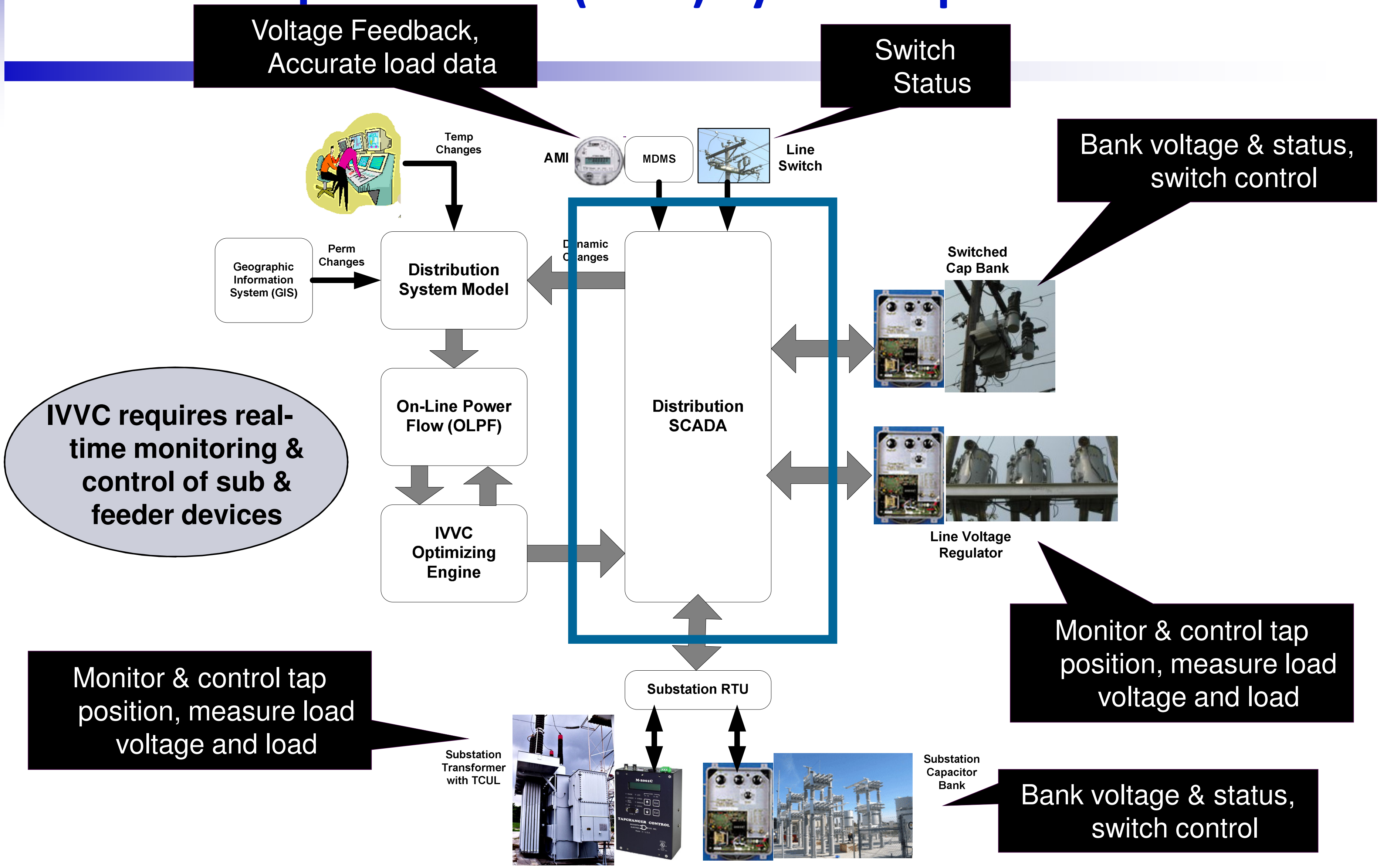
# Distribution Model Driven Volt-VAR Control and Optimization

- Develops and executes a coordinated "optimal" switching plan for all voltage control devices to achieve utility-specified objective functions:
  - Minimize energy consumption
  - Minimize losses
  - Minimize power demand
  - Combination of the above
- Can bias the results to minimize tap changer movement and other equipment control actions that put additional "wear and tear" on the physical equipment

# DMS Volt-VAR Optimization



# Volt VAR Optimization (VVO) System Operation



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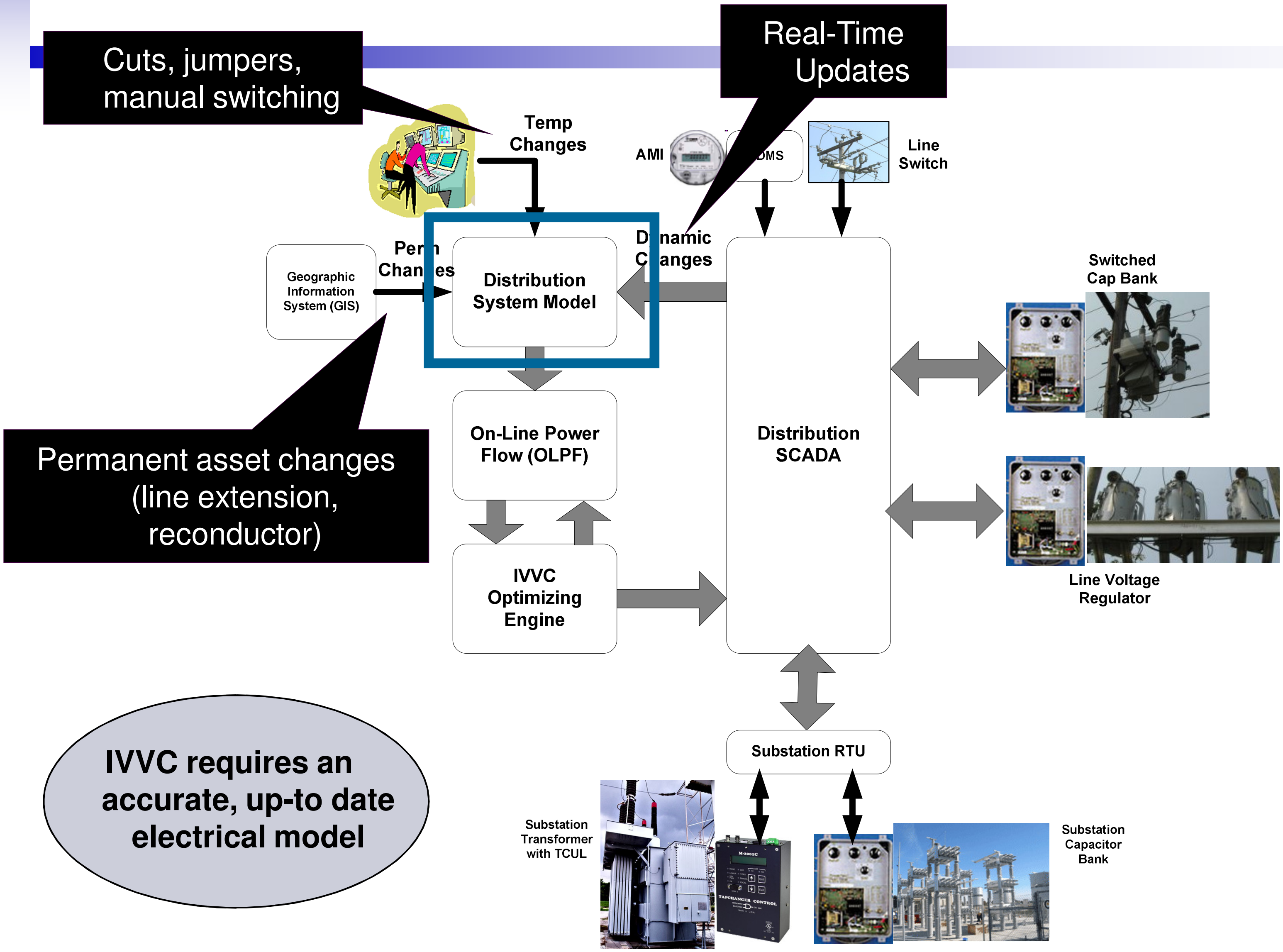

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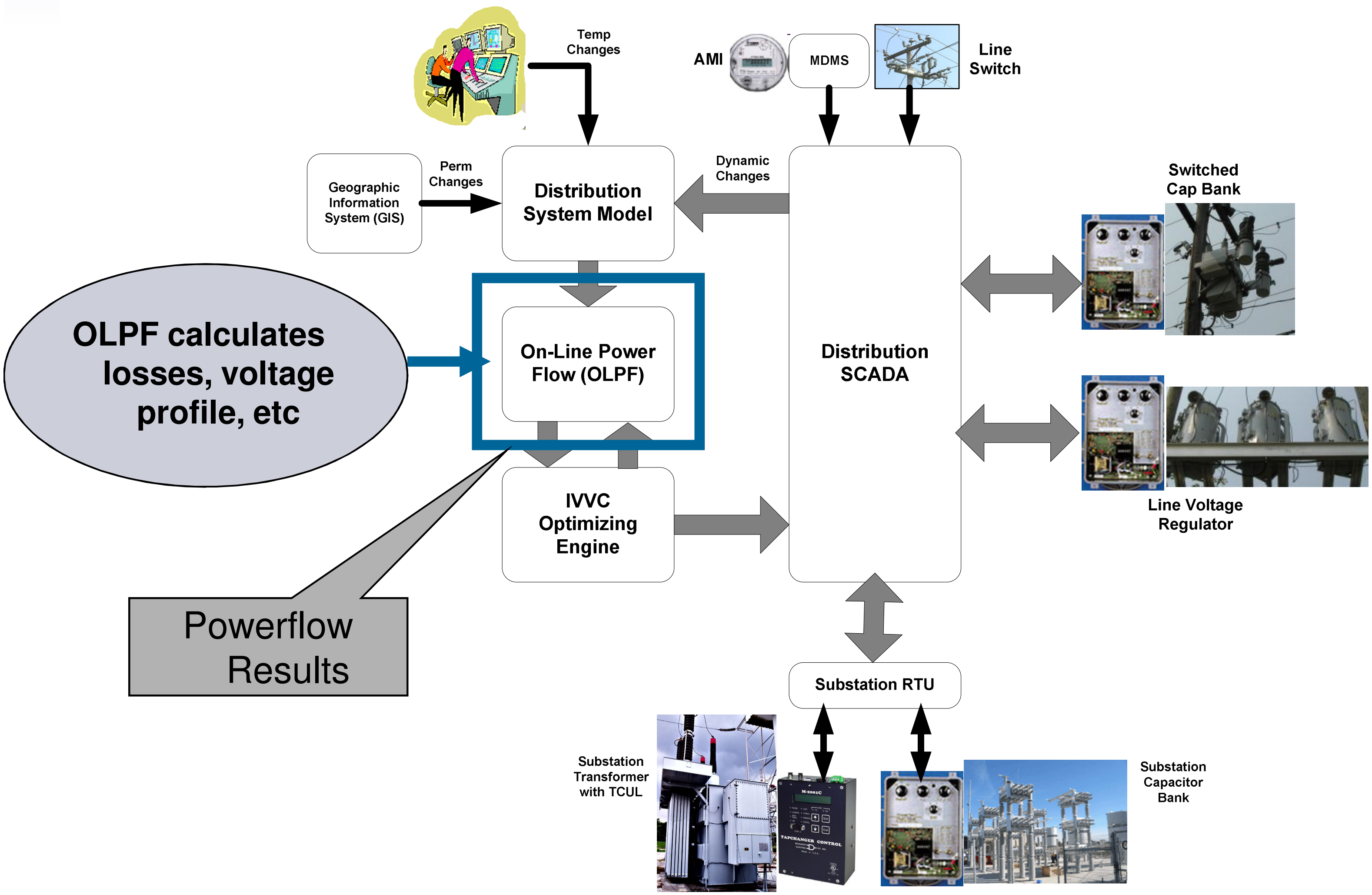






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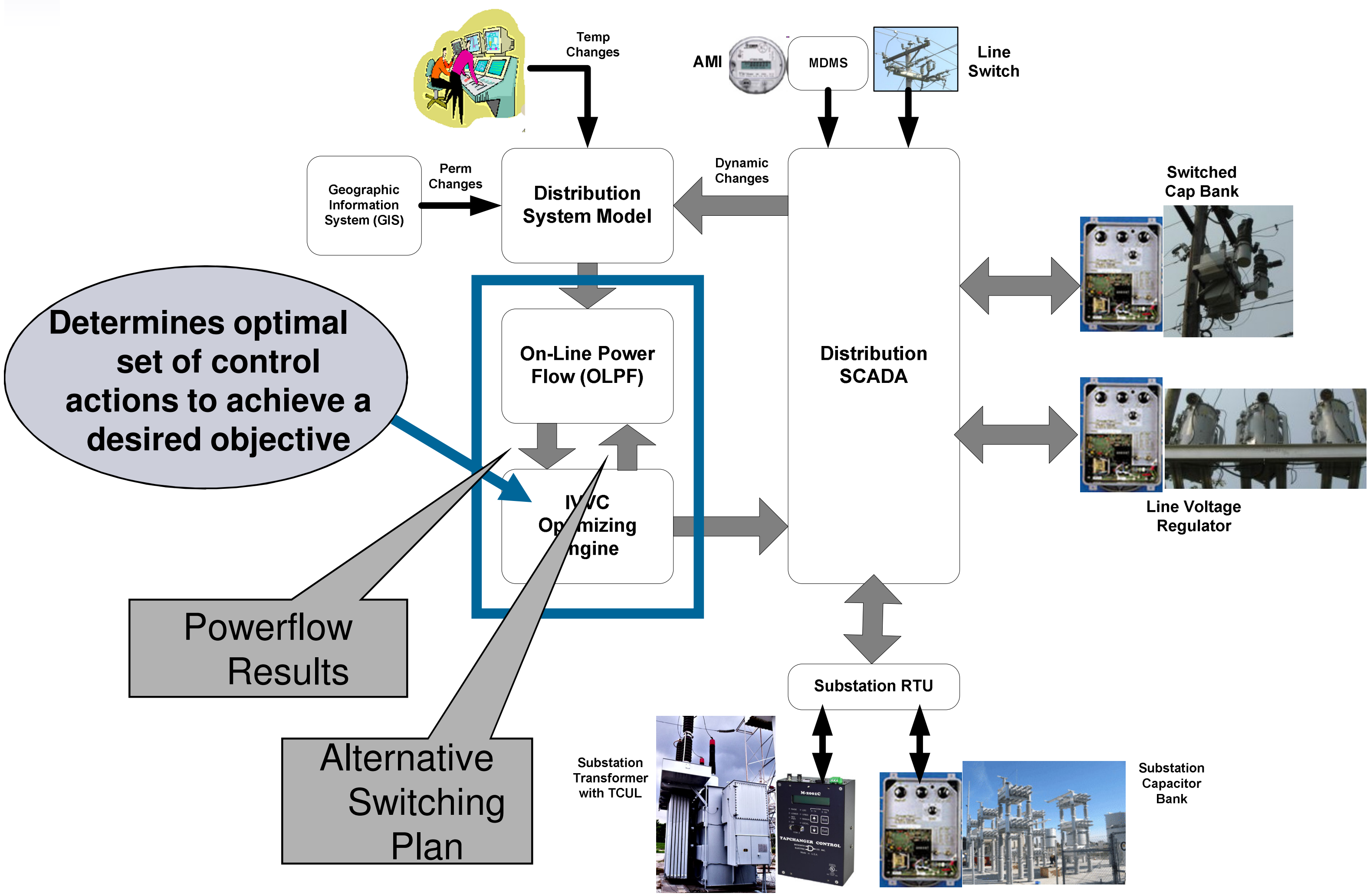

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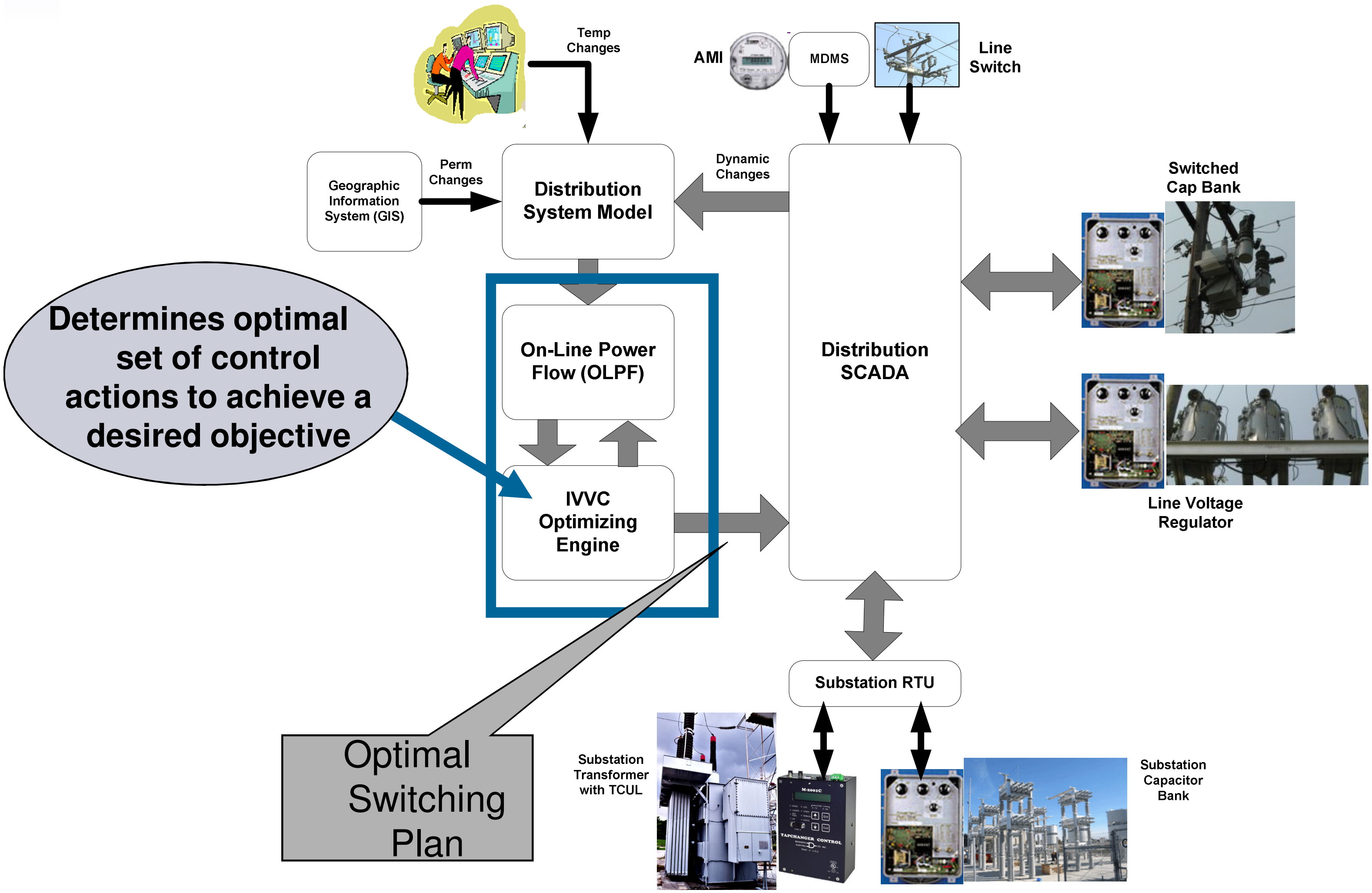

# DMS-Based Volt VAR Optimization Strengths and Weaknesses

- **Strengths**
  - Fully coordinated, optimal solution
  - Flexible operating objectives - Accommodates varying operating objectives depending on present need
  - Able to handle complex feeder arrangements - Dynamic model updates automatically when reconfiguration occurs
  - Works correctly following feeder reconfiguration
  - System can model the effects of Distributed Generation and other modern grid elements - Handles high penetration of DER properly, including proper handling of reverse power flows
- **Weaknesses**
  - Not very scalable – would not use this approach for one feeder or substation due to high control center
  - High cost to implement, operate and sustain
  - Learning curve for control room personnel
  - Lack of field proven products



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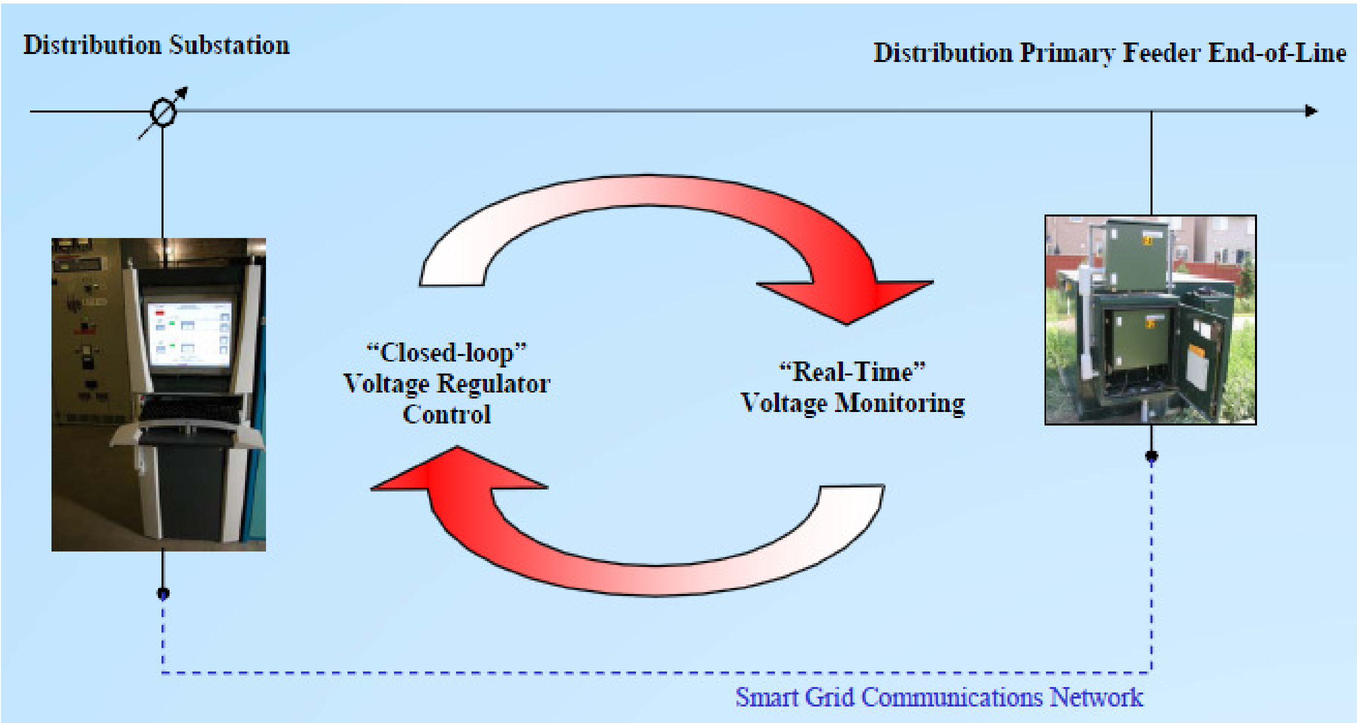
# Auto-Adaptive Volt VAR Optimization

- processes real-time distribution system information to determine appropriate volt-VAR control actions and provide closed-loop feedback to accomplish electric utility specified objectives
- uses advanced signal processing techniques to determine what control actions are needed




**Courtesy of PCS Utilidata**

# Auto-Adaptive Approach

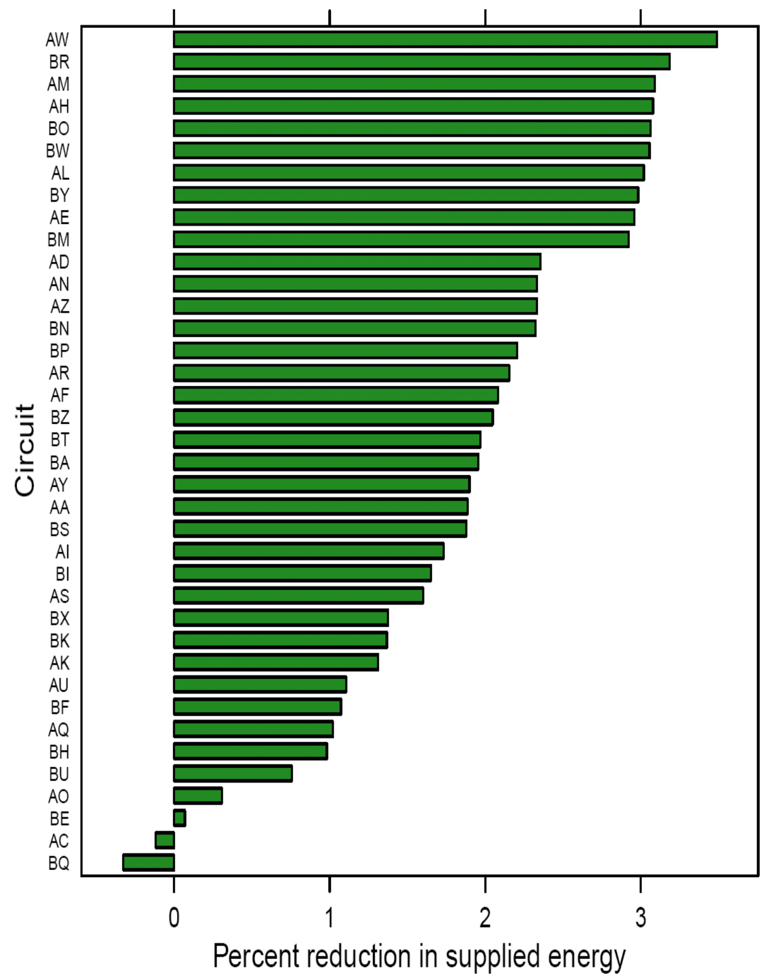
- Strengths
  - Does not require models or predetermined rules
  - Highly scalable (one substation or many)
- Weaknesses
  - (Presenter's opinion) → How it works is a bit of a mystery

# *Proving the Concept*

# Proof of Concept: What is it? and Why Do it?

- What is it?:
  - Typically a small-scale CVR demonstration on a few representative substations
    - Live operation on real feeders
    - Close observation of the results that are achieved
- Why Do It?
  - Not all feeders are created equal
  - Will CVR work as well on my distribution system?

From EPRI "Green Circuits"



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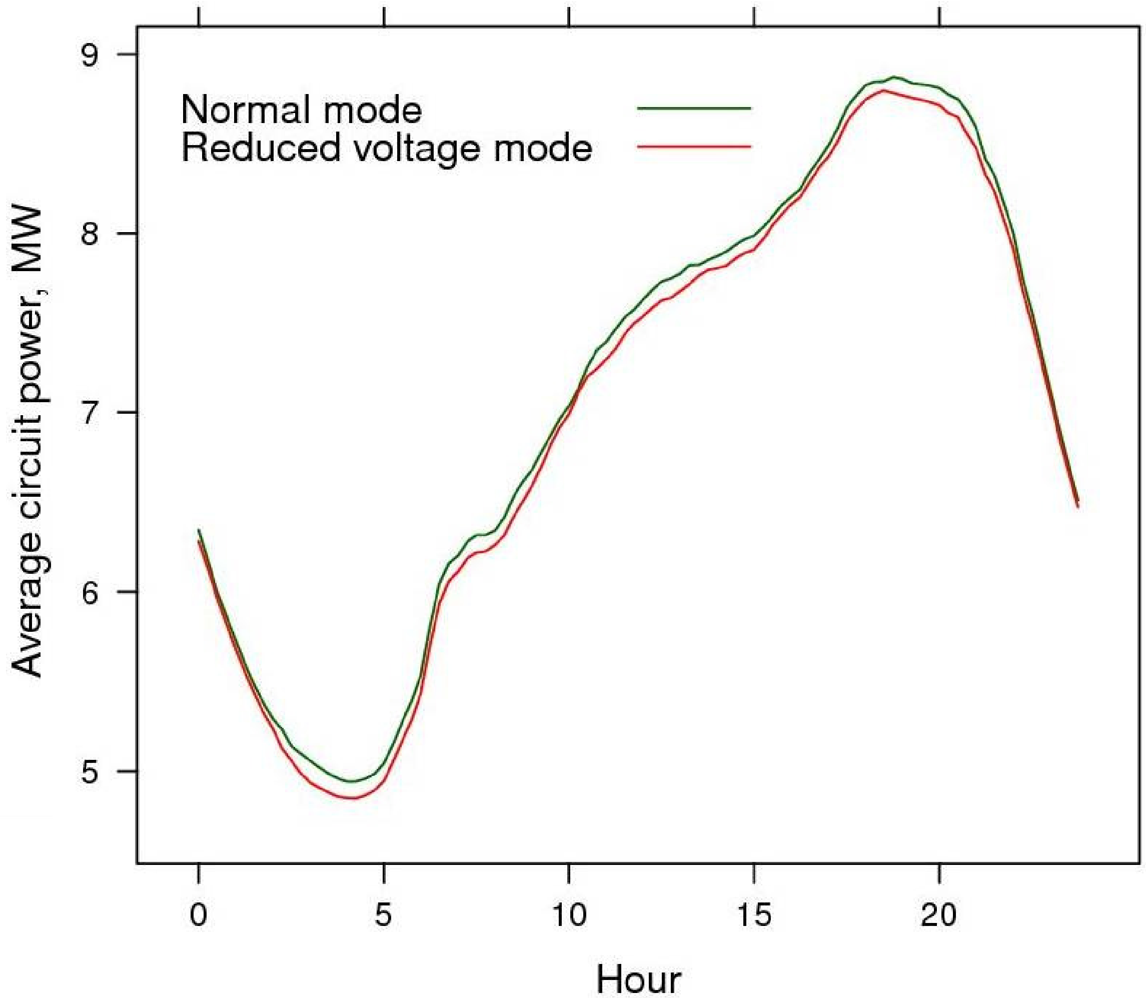
# Objectives for Proof of Concept

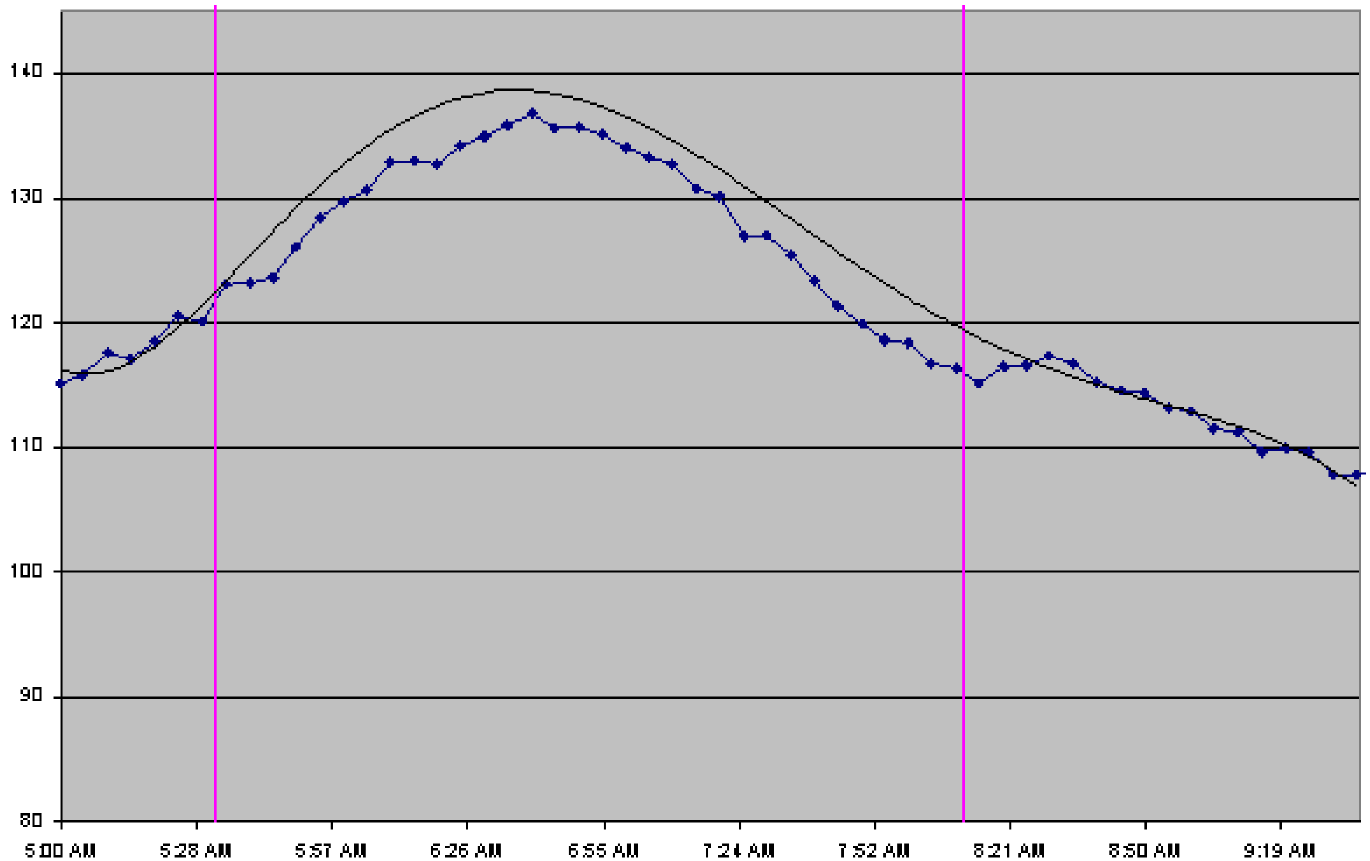
- **Primary Objectives:**
  - Show that CVR produces benefits without customer complaints
  - Show that it works before “making the plunge”

- **Secondary Objectives:**
  - gain valuable implementation and operating experience
  - compare vendor solutions

# Measurement and Verification
# CVR Impact on Energy

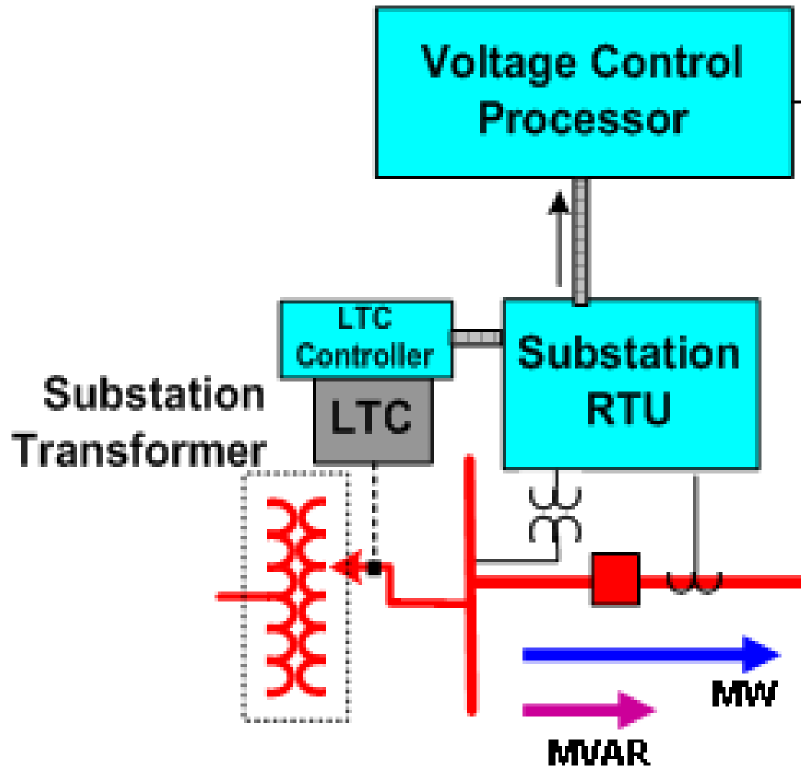


# Measurement and Verification
# CVR Impact on Demand



# A simple approach – “flip the switch”, measure “instantaneous” response

- **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
    - Devices that run off a thermostat just run longer
    - Loss of load diversity



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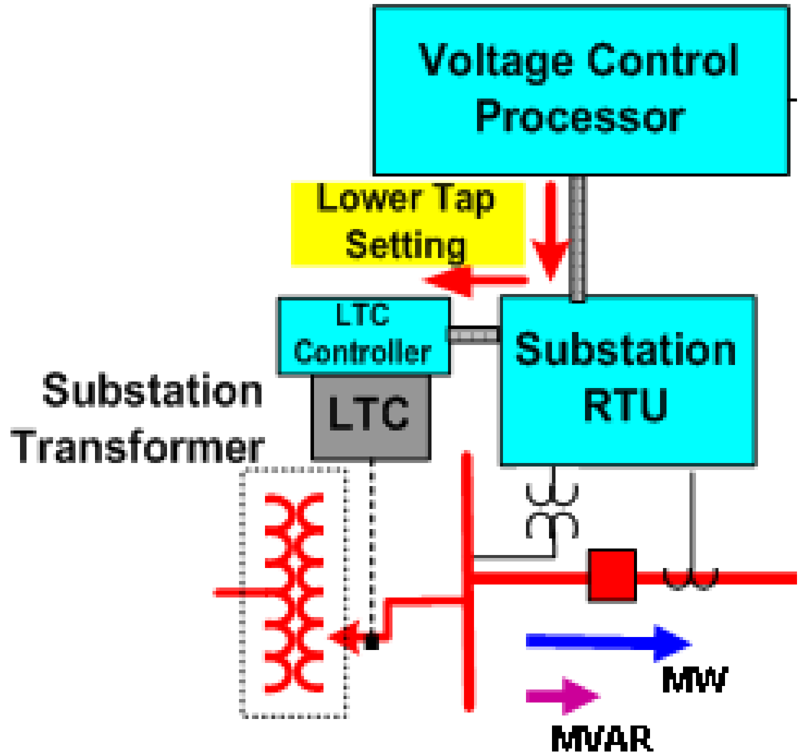
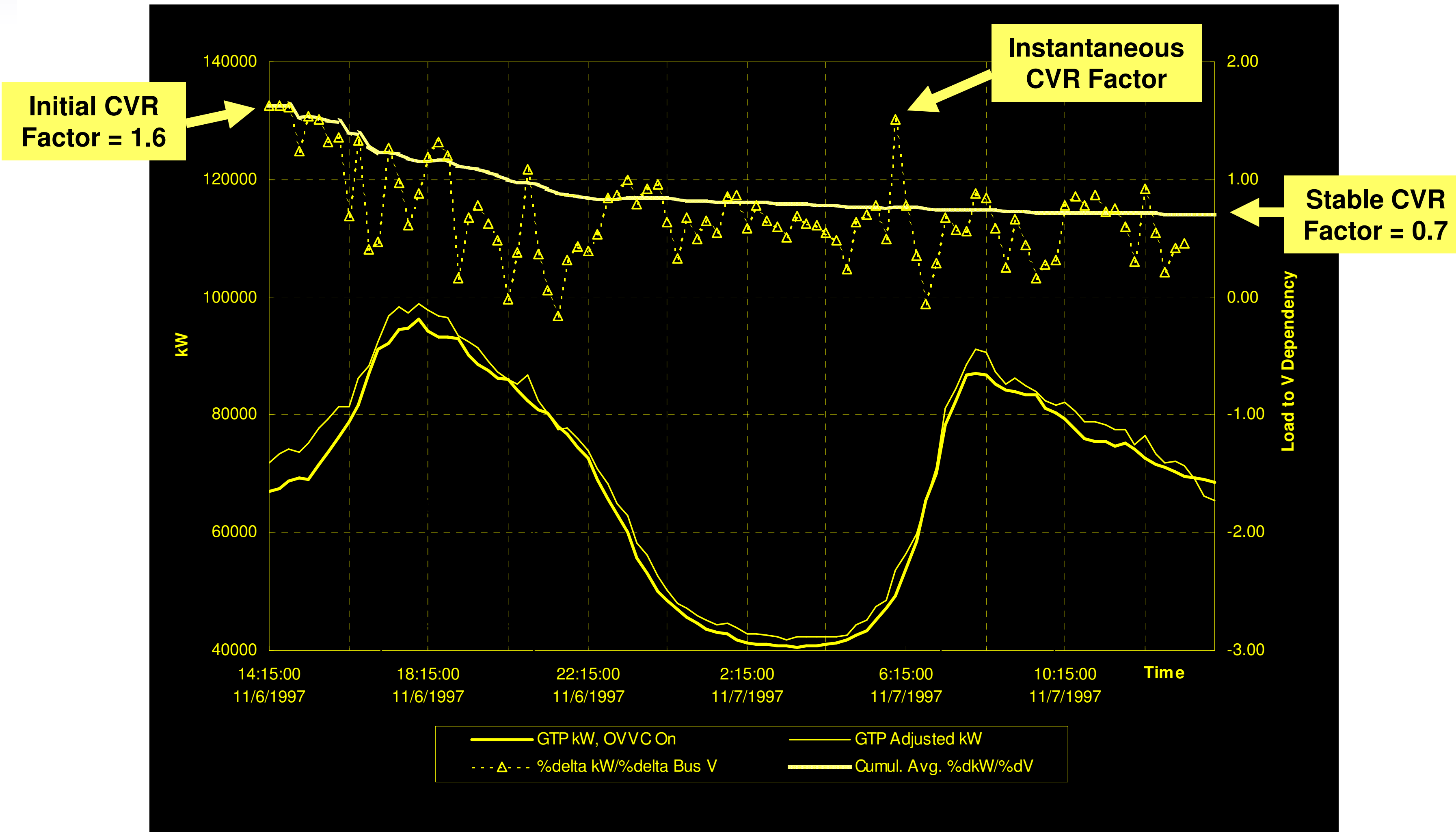


# A simple approach – measure instantaneous response (CVR response drops off with time)



# Determining the benefits over time

- To overcome this issue, should observe CVR/VVO operation over time
- **Benefit** is difference between **electrical conditions when CVR/VVO is running** minus **electrical conditions if CVR/VVO was not running**
- For example:
  - Reduction in energy consumption = **energy consumed** when running CVR/VVO – **energy that would have been consumed** if CVR/VVO was not running
- **Trick is determining what would have happened if CVR/VVO was not running!**



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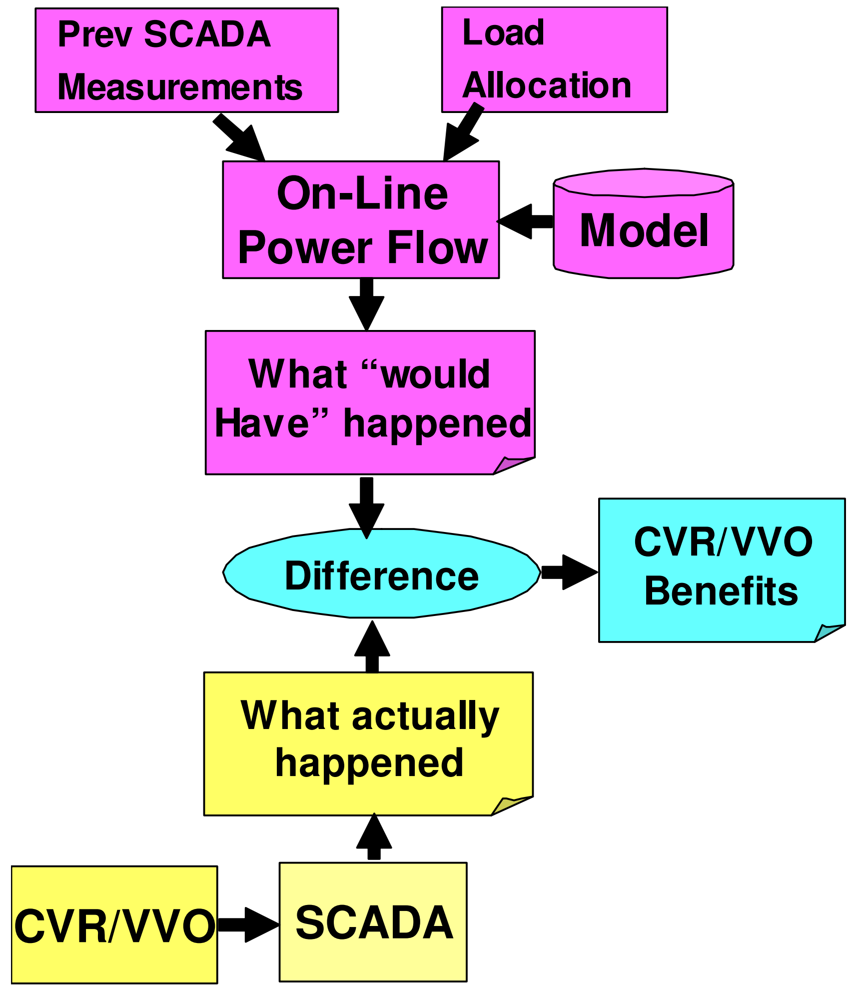
# S&C/Current Group approach to CVR/VVO M&V

- Use **Powerflow** program to determine what would have happened if CVR/VVO was not running
  - Most recent SCADA real/reactive power measurements
  - Load allocated from standard load profiles for each customer class
  - Voltage regulators and switched capacitor banks use standard controls
  - Compare power flow output with actual measures while running CVR/VVO



## CVR/VVO “Time On – Time Off” Demonstrations

- Approach summary:
  - Turn CVR/VVO **ON** for period of time and record results
  - Turn CVR/VVO **OFF** for similar time period and record results
  - CVR/VVO Benefit is difference between the two

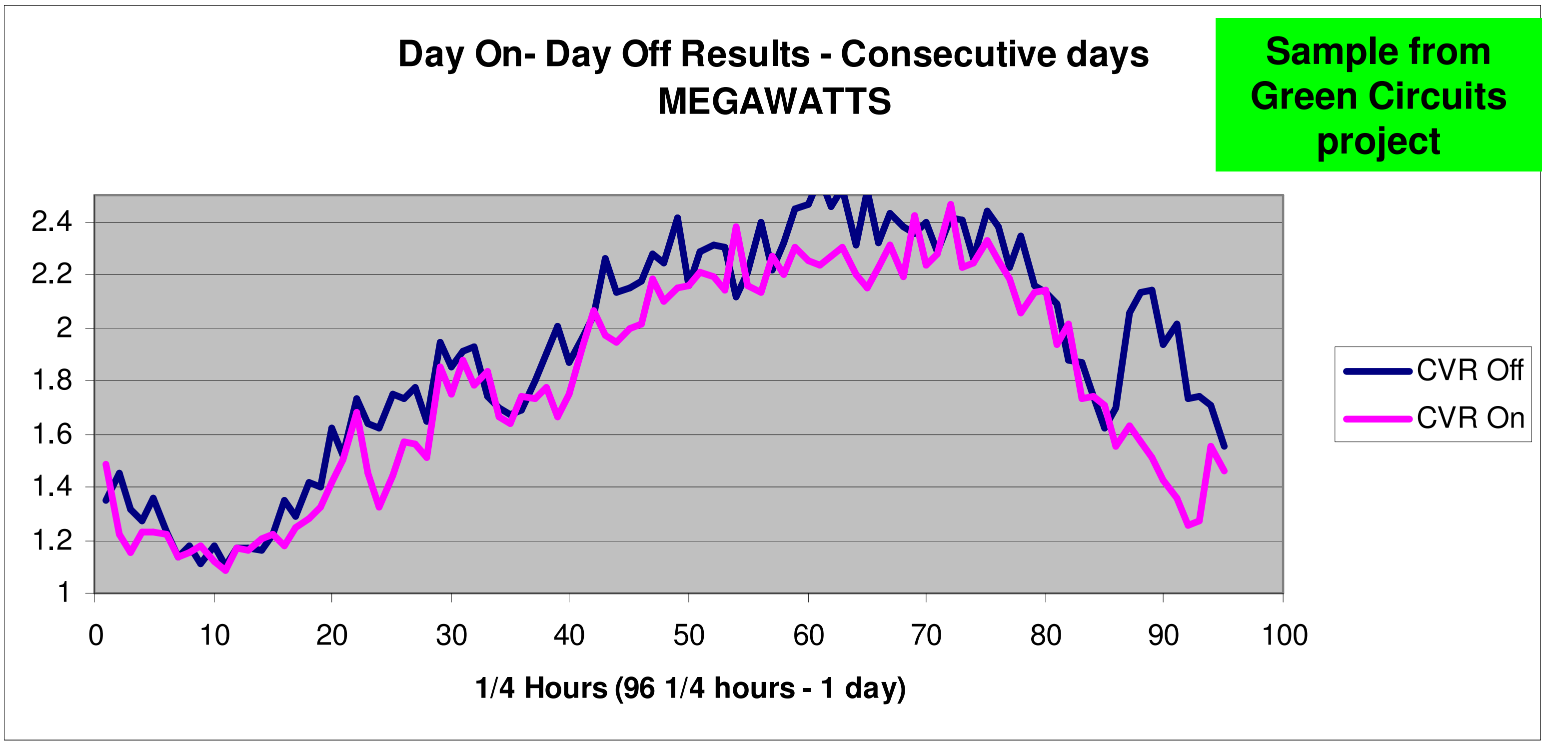
| TIME | MW | MVAR | VOLTAGE | CVR On/Off |
|---|---|---|---|---|
| 01:30:00 | 1.5351 | -0.6036 | 123.9707634 | Off |
| 01:45:00 | 1.626 | -0.6147 | 123.9192437 | Off |
| 02:00:00 | 1.7889 | -0.6281 | 123.7390301 | Off |
| 02:15:00 | 1.6447 | -0.649 | 118.846097 | On |
| 02:30:00 | 1.7859 | -0.6947 | 119.0263457 | On |
| 02:45:00 | 1.5786 | -0.6539 | 118.8975816 | On |
| 03:00:00 | 1.8166 | -0.7025 | 118.9490662 | On |

CVR/VVO OFF

CVR/VVO ON

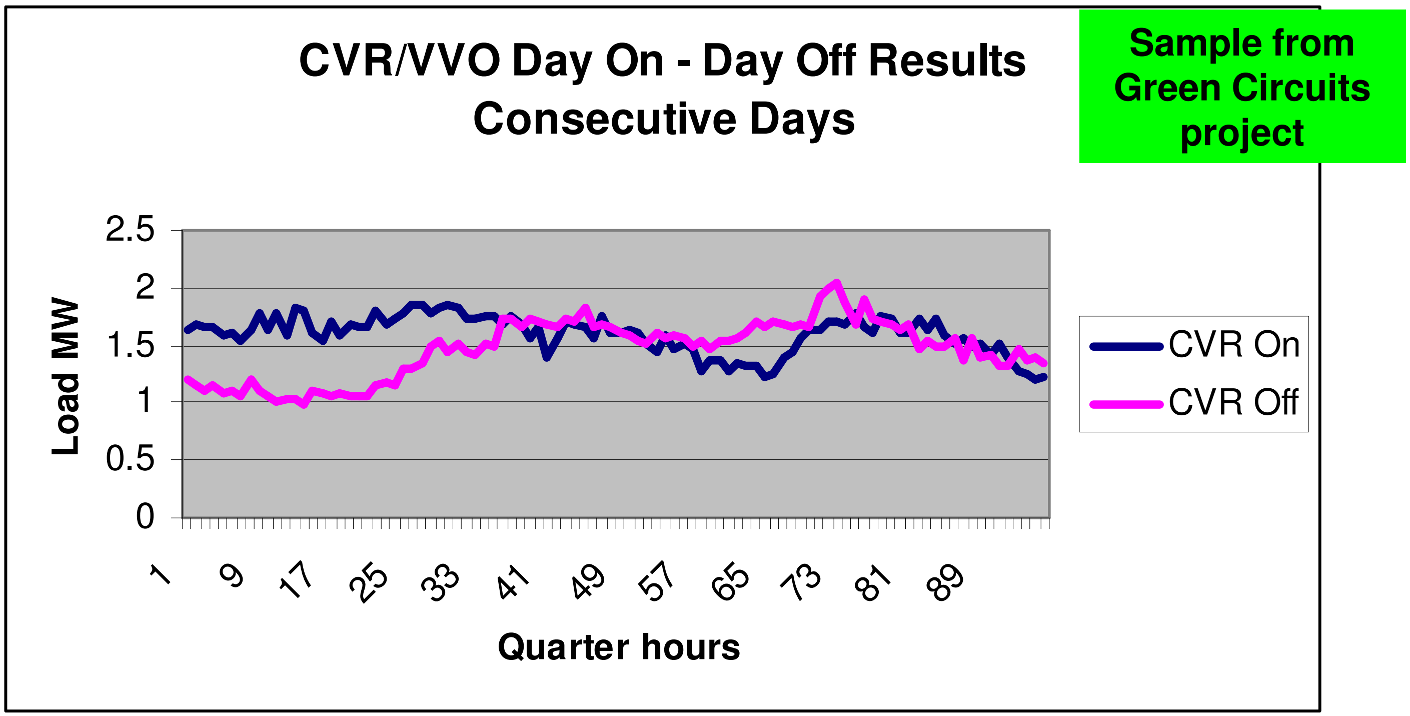
# CVR/VVO "Time On – Time Off" Demonstrations

- Issues:
  - Easy to see benefits if load is nearly the same for the 2 time periods



# CVR/VVO "Time On – Time Off" Demonstrations

– If natural load fluctuations occur, results are corrupted:
  - Load variation due to temperature
  - Random (stochastic) customer behavior
  - Feeder outages, load transfers
  - Weekday/weekend, holidays
– Need to exclude "outlier" data (missing data, bad data) that can distort results



# Techniques for dealing with fluctuations

- Exclude all missing and obviously bad data
- Exclude all data for weekends and special days (holidays)

- Normalize load to adjust for day to day variations due to:
  - Temperature/weather changes
  - Random (stochastic) customer behavior

- Two strategies
  - CVR Protocol Number 1 (developed by David Bell of PCS Utilidata) – used by Northwest Energy Efficiency Alliance (NEEA)
  - EPRI "Green Circuits" analysis (developed in cooperation with Dr Bobby Mee of Univ Tenn.)

# Techniques for dealing with fluctuations

- **Exclude bad/missing data** and data for special days
- Perform statistical analysis to **identify and eliminate potential outliers** data. (Minimum Covariance Determinant (MCD) Robust Regression )
- **Normalize the load:**
  - NEEA
    - Adjust for temperature variations
  - EPRI Green Circuits
    - Adjust based on another circuit with a similar load composition
    - Similar circuit cannot be affected by voltage reduction on CVR fdr

## NEEA

$$kW = \beta_0 + \beta_1 * hdh + \beta_2 * cdh$$

*Where: hdh = heating-degree hours*

*cdh = cooling-degree hours*

**2 methods for determining what load "would have been" without CVR**

## EPRI GREEN CIRCUITS

$$kW = k_1 * kW_{comparable} + k2 * V_{state}$$

*Where: $kW_{comp}$ = avg power measured at a comparable circuit*

*$V_{state}$ = 1 for normal voltage, 0 for reduced voltage*

# Some other points about POC

- Should pick substations that include representative feeder designs and customer mix
- POC time period should be long enough to capture seasonal variations
- CVR control system used for POC doesn't necessarily have to be the final vendor solution

# Together…Shaping the Future of Electricity

**Robert W. Uluski, PE**

ruluski@epri.com

**215-317-9105**

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# Volt / VAR Optimization – Several Case Studies

Prepared by:
Thomas Wilson, Principle, DA Solutions
on behalf of
UTILIDATA
(509) 385-1194
wilson.dasolutions@comcast.net

2012 NWESS – March, 21 and 22, 2012

## VVO in the Pacific Northwest

- VVO and CVR typically results in a 3% average demand reduction for utilities
- Northwest Power and Conservation Council has assigned a value of 400 aMW available using V/VO in the Pacific Northwest through 2025
- Enough savings to power 317,391 average American homes each year



## Benefits of VVO in Other Regions

- VVO and CVR provides an average demand reduction of 3% for utilities
  - Reduce TVA peak approximately 1004 MW
  - Reduce regional energy consumption 5,220 GWh per year

- Almost equivalent to 1 Browns Ferry BWR unit
- Enough savings to power 522,000 average American homes each year!



## Who Wins with CVR and VVO?

The Utility Companies

End use customers – Residential, rural, commercial and industrial

Regional Transmission and Generation

## Measurement & Verification

- How do we know...
  
  - That we have reduced energy consumption and demand
  - That CVR or VVO is the cause?
- How do we measure it?
- Protocol #1
  - Washington State University
  - University of Waterloo
  - Bonneville Power Administration
  - Regional Technical Forum
- Approved in April 2004

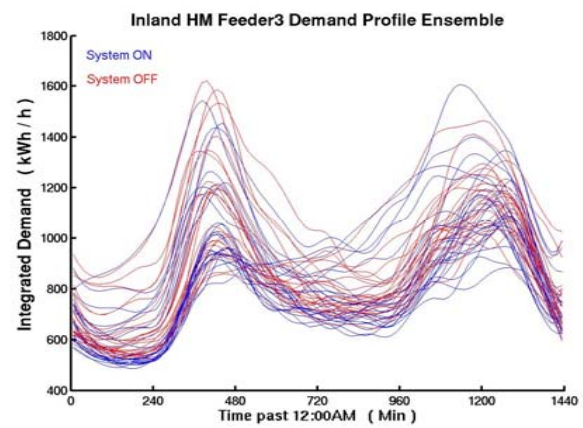
5

## Assumptions and Models

- Linear model for demand and energy consumption:
  - Linear dependence on delivered voltage
  - Asymmetric linear dependence on ambient temperature
  - Stochastic customer behavior, average & random components
- Time Series approach
  - Improved analysis based on robust regression methods
  - Analysis of demand profile ensembles

## Methodology

- Compare demand on a uniform basis
  - *operation on alternate days*
  - *exposure to same environment*
- Exploit prior knowledge of the demand processes and the resulting signals, such as:
  - *daily periodicity*
  - *utilization devices efficiency vs. voltage*
  - *customer demand behavior*
- Demand processes are locally linear
- Apply results only within bounds of observations

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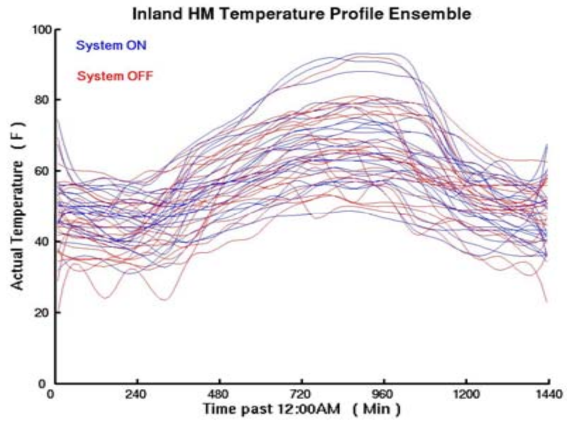




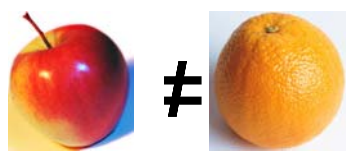

## Benefits of the Time Series Analysis Approach

- Feeder acts as it own control or baseline Feeder
- No constraints on regression methods or models
- No implied constraints on probability density of random data
- Estimates of demand profiles require no extrapolation
- Estimates bounded by observations
- Estimation of performance can be based on limited survey measurements

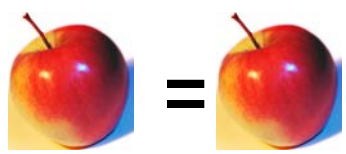


## Measurement and Verification Protocol for Industrial Processes

Must use Process Compensation to avoid comparing



And to assure comparison of



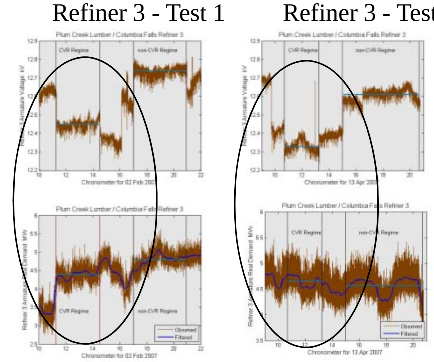
## Without Process Info

Refiner 3 - Test 1 Refiner 3 - Test 2

Voltage

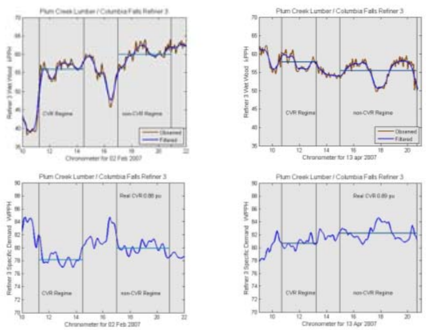
Voltage ↓ Demand ↓

Demand

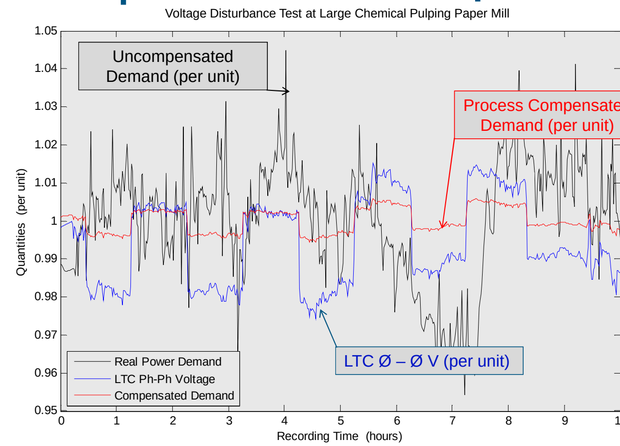


Voltage ↓ Demand ↑

## With Process Info




## Example of Process Compensation

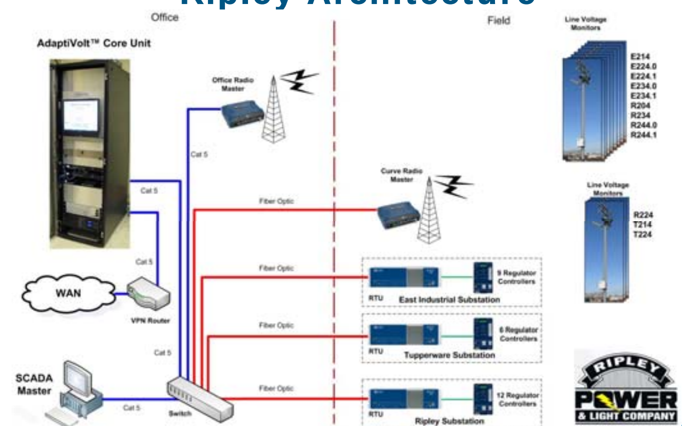



## Ripley Power and Light

- Demand Reduction VVO Pilot sponsored by TVA and EPRI "Green Circuits" program
  - AdaptiVolt™ deployed as a central system
  - 3 substations
  - 9 feeders, each feeder has 3 single-phase regulators
  - Licensed RF telemetry system
- August 4, 2009 – Commenced project
- March 3, 2010 – Project commissioned



## Ripley Architecture



## Ripley Results at High Level

- M&V testing indicates:
  - Energy reduction range of 1.3% to 5.4% across all feeders
  - 5.96 GWh per year energy savings
  - Demand reduction up to 3.4% or 1.64 MW
- Opportunities for further improvements identified

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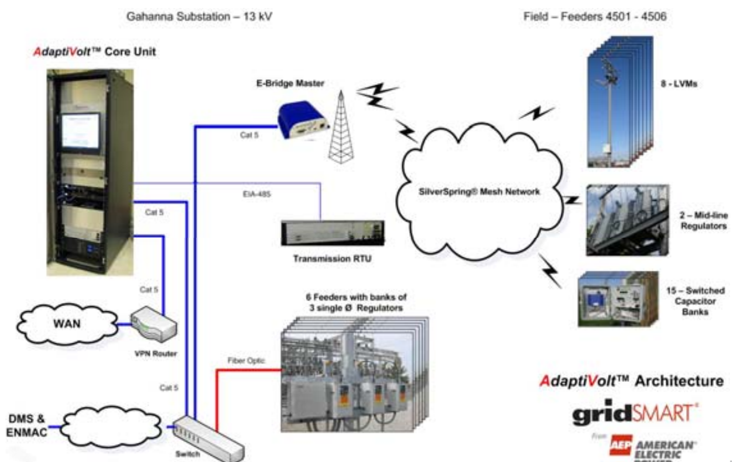
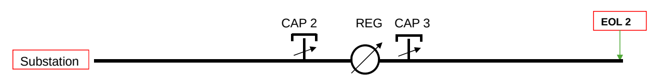
## AEP OHIO A unit of American Electric Power — GridSmart® VVO Pilot

- GridSmart® pilot project in Gahanna, Ohio
  - 1 of the 13.2 kV feeders had a 3Φ regulator and 5 had banks of 3 single Φ regulators – now 6 do!
  - Fifteen (15) - field located switched capacitor banks
  - 2 feeders have mid-line regulators
  - Field communications using Silver Spring Networks, substation communications using fiber optic
  - EPRI "Green Circuits"
- AdaptiVolt™ system live December, 2010

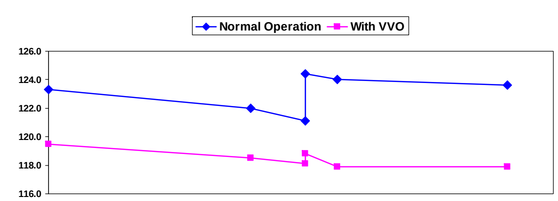
## AEP Gahanna Architecture




## AEP Ohio: Gahanna – 4505 (13 KV) Voltage Profile




Without *AdaptiVolt*™ = 6-7-11 @ 4:30pm
With *AdaptiVolt*™ = 6-6-11 @ 4:30pm

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## AEP Gahanna Results

- Used "Protocol #1 for Automated CVR"
- Average Energy Reduction was > 3%
- Station Peak Demand Reduction > 3% (higher than Energy Reduction %)
- Approximately 1/3 reduction in tap operations with no significant change in capacitor switching operations (approximately 1 operation every other day).

**Operational results better than expected.**

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## Plum Creek Timber (IVO)

- 40 MW load Medium Density Fiberboard facility located in Columbia Falls, MT
- Thermo-mechanical pulping process
- Plum Creek is the largest private landowner in the US
- Project sponsored by BPA and Flathead Electric cooperative
- Operational in September, 2008



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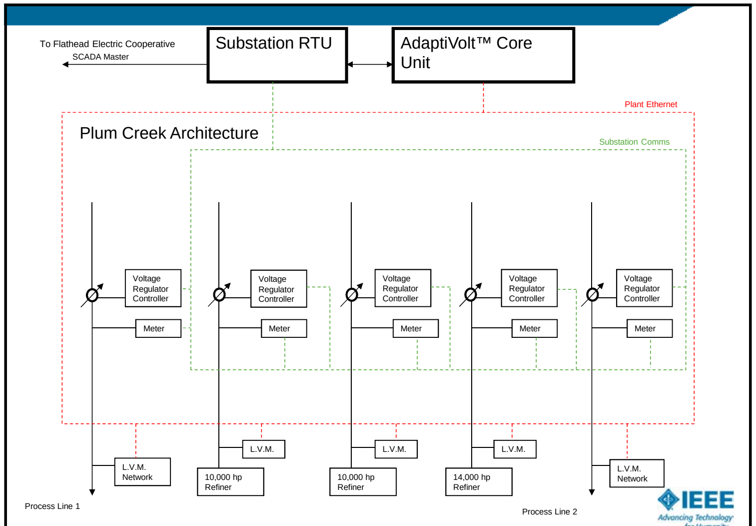


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## VARMINT & VIPER

- VARiable
- Moment
- INTegrator
- Protects large motors
  - Synchronous
  - Induction

- Voltage
- Integrating
- Probability
- Estimating
- Regulator
- Provides close voltage control without excessive regulator operations

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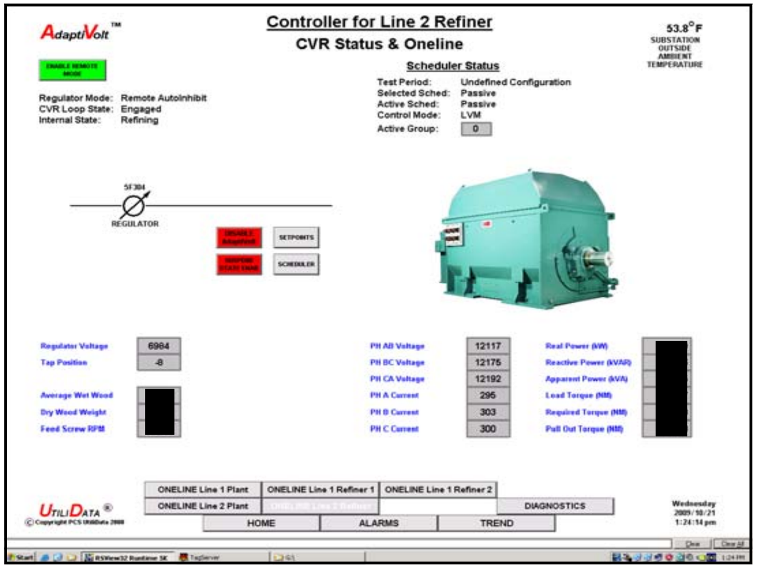


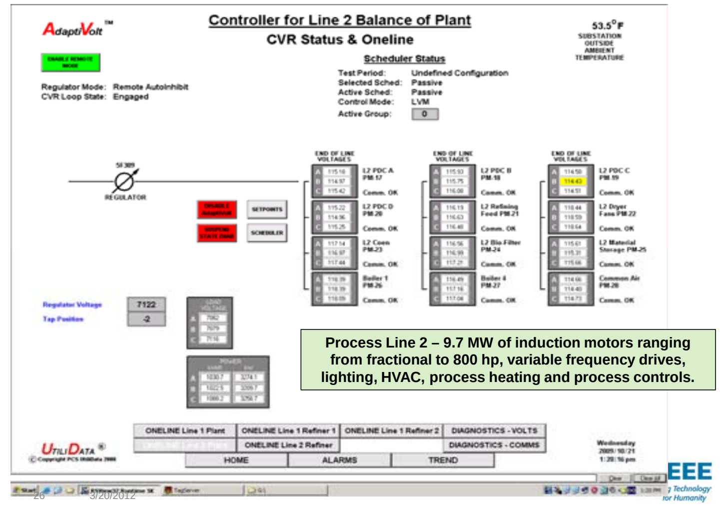


## Overall Results

PlumCreek


Overall Demand Reduction – 3.72%

**Energy savings at full production – 9,063,800 kWh / year!**

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## Murray State University

MURRAY STATE UNIVERSITY

- Demand Reduction Pilot sponsored by TVA
- AdaptiVolt™ on isolated college campus served by 2 on-Load Tap Changing transformers
- 4 Feeders
- Uses 22 power monitors that were installed for their new EMS system

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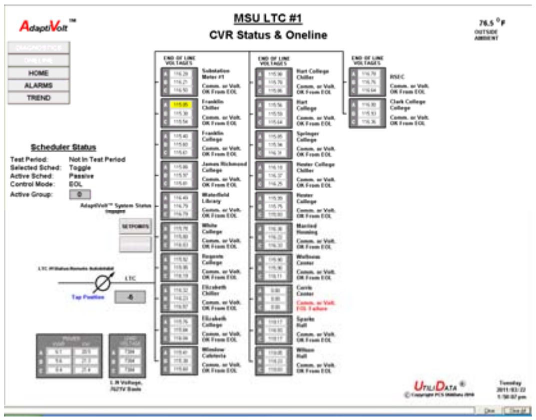
## MSU Graphics Display






## Results for MURRAY STATE UNIVERSITY

- Demand Reduction Pilot sponsored by TVA
  - AdaptiVolt™ on isolated college campus served by LTC
  - Uses 22 power monitors that were installed for their new EMS system
- Final M & V testing Results:
  - 4.38% peak reduction
  - 4.82% energy conservation
  - 27.5% mean reactive reduction



## Challenges in VVO Solutions

- Load model accuracy
  - Understanding of Load Reaction to differing voltage levels
- Physical model accuracy
- Some evidence of tap change frequency increase
- Communications reliability
- Compute power required for large systems



## DSP is a Relatively New Technology

- DSP roots are in the 1960's and '70's with the advent of available digital computers
- DSP is now ubiquitous. We use in in our daily life.
- Now being used widely in system protecion, power monitoring and is being considered for short-term load forcasting.

## One Area where DSP Changed our Lives?




## DSP VVO Paradigm is Somewhat Analogous to:

or maybe




## Potential Advantages of DSP based VVO

- Load model and physical model accuracy is removed as a limit on VVO performance
- Significant tap changer life improvements
- Better overall performance
  - Capacitor and tap changer operation detection
  - Better CVR and demand reduction performance
- Much lower compute power costs leading to more economic and cost effective VVO



## Discussion