Retrofit Energy Savings Device (RESD) Seminar

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Electric Power Research Institute (EPRI)
Industrial PQ Services/R&D
RESD Seminar Outline

1. What is an RESD?
2. EPRI Assessment of Retrofit Energy Savings Devices
3. Power Basics & Utility Rate Structures
4. Capacitor Based RESD Devices
5. Motor Voltage Controller RESD Devices
6. Lighting Voltage Controller RESD Devices
7. Voltage Regulation RESD Devices
8. Conventional & Leading Edge Energy Savings Technologies
9. Techniques for Evaluating Vendor Claims
1.0 What is an RESD?
Definition

• RESD – Retrofit Energy Savings Devices
  – Retrofit energy saving devices are added after-the-fact to existing residential, commercial or industrial electrical systems with the intent to improve energy efficiency, usually without directly affecting end-use equipment.

Black Box
Technology

• Typically incorporate common, passive electrical sub-devices
  – **Capacitors** (VAr support, power factor correction)
  – **Inductors/chokes/reactors** (Dampening of fast current pulses)
  – **TVSS: Metal-Oxide Varistors** (MOVs, lightning/transient protection)
  – **TVSS: Gas tubes** (lightning/transient protection)

• Some devices, such as power factor (PF) Controllers, Motor Voltage Controllers, and Lighting Voltage Controllers, are “active”

• Most often pre-packaged, modular systems that are easily added to existing facility electrical systems (i.e. low installation cost, minimal down time)

• Other devices are as simple as a magnet, rectifier, or even a piece of metal
Common Claims

• Improved power factor
• Reduced harmonics
• Improved voltage imbalance
• Reduced electrical current levels
• Cooler device operation
• Prolonged motor and other device life
• Improved voltage level (higher or lower)
• Quick payback

• Improved energy efficiency
  – 10%, 20%, or even 30% reduction in energy cost is commonly claimed or implied
Formal Definition: 1 of 2

• A device that is retrofit to an existing and otherwise fully operational end-user installation. Such devices are, in general, not an available option from the original equipment manufacturer (OEM).

• A device that provides power conditioning including but not limited to either voltage regulation and/or surge suppression.

• A device that the manufacturer or vendor claims or indicates will, at a minimum, save energy such that the user’s electric bill will decrease. Other notable claims or indicated benefits for the device may also include power quality benefits or surge suppression.
Formal Definition: 2 of 2

• A device that has electricity as its main input and output and connects to an electrical circuit either in series or in parallel between the utility supply and the load.

• A further requirement is that the device not be significantly addressed by voluntary efficiency organizations such as ENERGY STAR. Moreover, nationally recognized standards and protocols for measurement and verification either do not exist or are perceived to be inadequate.

• Series or parallel retrofit or replacement of connected power conditioners that offer energy saving benefit.

• Power converter or conditioner
2.0 EPRI Assessment of Retrofit Energy Savings Devices
Introduction

• EPRI is has an ongoing research project to evaluate retrofit energy savings devices (RESD).
  – RESD Phase I - Completed
  – RESD Phase II - Ongoing
• The research findings and analysis confirm the need for independent measurement and verification of retrofit energy savings devices.
• The Electric Power Research Institute, Inc. (EPRI, www.epri.com) conducts research and development relating to the generation, delivery and use of electricity for the benefit of the public.
• An independent, nonprofit organization, EPRI brings together its scientists and engineers as well as experts from academia and industry to help address challenges in electricity, including reliability, efficiency, health, safety and the environment.
BACKGROUND:
EPRI RESD Assessment Project

• The past two decades have seen the introduction of a number of new technologies, such as retrofit energy-savings devices, which are intended to save energy.

• Retrofit energy-savings devices are added after-the-fact to existing residential, commercial or industrial electrical systems with the intent to improve energy efficiency, usually without directly affecting end-use equipment.

• Devices have been offered to homeowners, retail outlets, supermarkets, universities, manufacturing facilities, and other commercial and industrial enterprises with a general intent that energy consumption will fall, other factors being held constant.

• Claims or implications of reduced energy bills, electric equipment protection, and other electrical system performance improvements are often associated in connection with these devices.

• EPRI is conducting research to survey existing devices, select a limited number for further evaluation, establish protocols for examining energy savings and other potential understood benefits of the technologies, and assess the need for further independent evaluation of these types of devices.
EPRI RESD Research

• EPRI is has an ongoing research project to evaluate retrofit energy savings devices (RESDs).
  – RESD Phase I - Completed
  – RESD Phase II - Ongoing

• The research findings and analysis confirm the need for independent measurement and verification of retrofit energy savings devices.
RESD Phase I

• Phase I sponsored by New York State Energy Research and Development Authority (NYSERDA) and the California Energy Commission (CEC).

• Project now completed and publically available.

• Two Devices Evaluated
  – USES
  – MiniEVR™
# RESD Phase II (RESD II) Project

## RESD II Project Sponsors

<table>
<thead>
<tr>
<th>Sponsor</th>
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<tr>
<td>HECO</td>
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<td>NYSERDA (Pending)</td>
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<td>SDG&amp;E (Pending)</td>
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<td>Southern Co.</td>
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<tr>
<td>SRP</td>
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<td>TVA (Pending)</td>
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</tbody>
</table>
RESD II: Technologies Evaluated Thus Far…

- IDim Line Side Electronic CFL Dimmer
- Eaton Power-R-Command 3000 (Lighting Voltage Controller)
- Dollar Energy Lighting Control Unit (Lighting Voltage Controller)
- KVAR Energy Controller (Capacitor Based RESD)
- Power Efficiency Corp Motor Efficiency Controller (Motor Voltage Controller)
- Somar PowerBoss (Motor Voltage Controller)
RESD Phase II: How Are Devices Chosen for Testing?

• Round 1:
  – Utilities and EPRI identified 17 potential devices
  – 15 utilities who (project advisors or funders) independently ranked devices from 1-17 based on their preference
  – EPRI compiled results and determined top 5 items
  – An additional RESD was added based on tests done for SCE (SCE agreed to have this added to larger project).

<table>
<thead>
<tr>
<th>Rank (1-17)</th>
<th>Company/Distributor</th>
<th>Device</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Power Efficiency Corporation</td>
<td>E-Save Single Phase Motor Efficiency Controller</td>
</tr>
<tr>
<td>2</td>
<td>Enerlume</td>
<td>EnerLume</td>
</tr>
<tr>
<td>3</td>
<td>Power Save Energy Company</td>
<td>Flourescent Light Manager</td>
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<tr>
<td>4</td>
<td>Blue Diamond International, LLC</td>
<td>KVAR Unit</td>
</tr>
<tr>
<td>5</td>
<td>Dollar Energy Group, Inc.</td>
<td>Lighting Correction Unit (LCU)</td>
</tr>
<tr>
<td>6</td>
<td>Georgia Energy Control</td>
<td>Energy Saver Plus</td>
</tr>
<tr>
<td>7</td>
<td>KVAR Green Solutions</td>
<td>KVAR Energy Saver Plus</td>
</tr>
<tr>
<td>8</td>
<td>Power Save Energy Company</td>
<td>Power-Save 1200</td>
</tr>
<tr>
<td>9</td>
<td>Precision Power Labs</td>
<td>Integra Power</td>
</tr>
<tr>
<td>10</td>
<td>KVAR Energy Products</td>
<td>Kvar PFC 1200</td>
</tr>
<tr>
<td>11</td>
<td>Nevvus International Group</td>
<td>PowerGard</td>
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<tr>
<td>12</td>
<td>PowerwoRX Now.com</td>
<td>EcoPower4 / PowerwoRx e^3</td>
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<tr>
<td>13</td>
<td>Energy Automation Systems Incorporated</td>
<td>EasiLiner</td>
</tr>
<tr>
<td>14</td>
<td>Green Plug</td>
<td>Green Plug Energy Saver</td>
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<td>15</td>
<td>Efficient Future Inc.</td>
<td>Electricity Saver Nitro</td>
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<td>16</td>
<td>Dollar Energy Group, Inc.</td>
<td>Power Correction Unit (PCU)</td>
</tr>
<tr>
<td>17</td>
<td>Boondee (Thailand)</td>
<td>Boondee Energy Saver</td>
</tr>
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</table>

Round 1

<table>
<thead>
<tr>
<th>Ranking Received?</th>
<th>Company</th>
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<tr>
<td>Yes</td>
<td>AEP</td>
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<tr>
<td>Yes</td>
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<td>Con Ed</td>
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<td>Yes</td>
<td>Dominion</td>
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Process will be repeated for Future Rounds of Testing
RESD II General Project Steps

1. Conduct a survey of candidate RESD technologies and develop a short list of candidates for ranking by advisors and funders.

2. Develop RESD testing protocol.

3. Conduct RESD testing

4. Report results of the testing.

5. Develop simple evaluation methodologies based on product function.
General Project Deliverables

- Tutorial materials on the application of voltage and current control devices to change how facilities, loads and processes use (and or save) power
- An “Energy Savings Estimator” that will provide guidance on expected energy savings for typical residential, commercial, and/or industrial applications as appropriate for each technology type
- Documented energy performance results for each RESD technology evaluated
- A Web cast workshop reviewing project results
- A standardized testing protocol useful for evaluating RESD technologies in both laboratory and field settings.
3.0 Power Basics & Utility Rate Structures
Generation to Transmission to Distribution to Customers: The Power System

Generator Plant (12500V)

Generation Step-Up Transformer (161000V)

161000V

Industrial Service (4160V, 480V/277V)

Transmission Substation (69000V)

69000V

Industrial Service (4160V, 480V/277V)

13800V

Distribution Substation

Commercial Service (120V/208V)

Home Service (120V/240V)

Farm Service (120V/240V)

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Why Start with Basics?.... Confusion

• Understanding the concept of energy is difficult.
  – A lot of difficult terms:
    • kW, Power Factor (PF), kVA, kVAR, Volts, Amps, kA, kW, Hertz, Frequency
  – Some lame metaphors:

  ![Images of beer glasses illustrating the concept of VARS and Watts.](image)
Breaking Down AC Power…..

• AC power flow has the three components:
  – Real power (Active power) (P),
    • measured in watts (W)
  – Apparent power (S)
    • measured in volt-amperes (VA)
  – Reactive power (Q)
    • measured in reactive volt-amperes (VAr).
Breaking Down AC Power….. The Power Triangle

- Power Factor (PF) = ratio of real power/apparent power (PF = P/S)
- Also PF = Cos (Φ) for purely sinusoidal waveforms
- Power = S Cos (Φ) = VxI Cos (Φ)

\[ P = \text{Real Power (W, kW)} \]
\[ Q = \text{reactive power (VAr, kVar)} \]
\[ S = \text{is apparent power = V x I (VA, kVA)} \]
\[ (vector \ sum \ of \ the \ P \ and \ Q) \]
\[ P = V \times I \cos (\Phi) = S \cos (\Phi) \]

(motors & transformers need this to produce magnetizing current)
What is Power Factor?

• Power factor is a measure of how effectively your equipment converts electric current from the utility system to useful power output.
• Power factor is the ratio of real power (kW) to apparent power (kVA).
• With harmonics present, the angle between and the ratio of kW to kVA will differ.
  – Displacement Power Factor (DPF)
  – True Power Factor (TPF)
True versus Displacement Power Factor

• True power factor, or TPF, is the ratio between kW and kVA, including all the harmonics.

  – PF = P / S = kW / kVA

• Displacement power factor, DPF, is the cosine of the angle between the voltage and current. This is for the fundamental (60 Hertz) component only.

  – PF = Cos (Φ)

• When no harmonics are present, True Power Factor = Displacement Power Factor

• Capacitors Correct Displacement Power Factor
Another “Angle” on Power Factor

• The tension in the chain is higher due to the sideways component of pull, but the work done in moving the boxcar is exactly the same as if the locomotive was directly in front of the boxcar.

• The increased tension in the chain when pulling from the side is analogous to the increased current necessary to supply the reactive power in an electrical circuit.
With a Purely Resistive Load…or Corrected Power Factor

- Voltage & Current are “in phase” with one another
- Maximum transfer of power
  - Power Always stays positive
  - Average Power at Maximum
- Calculate Power Factor
  - PF = \cos(\Phi) = \cos(0) = 1
  - Or PF = P/S, P = S, so PF = 1

\[ \Phi = 0 \text{ Degrees} \quad S = P \]  

\[ P = \text{Real Power (W, kW)} \]  

(Does work, provides Heat, Torque, etc)
With Reactive Load + Resistive Load…

- Current is “Lagging” Voltage due to inductance from motors, transformers, etc
  - In example, $\Phi = 45$
  - PF = $\cos(45) = 0.707$

- No longer transferring Maximum Power
  - instantaneous power is negative when the current and voltage have opposite signs ($P=V \times I \cos(\Phi)$)
  - Average power is lower
With Purely Reactive Load …

- This would occur if capacitor or inductor were only items in circuit
- In example, current is “Lagging” Voltage by 90 degrees due to a purely reactive load
  - In example, $\Phi = 180-90=90$
  - $PF = \cos (90) = 0$
- No real power transfer – inductor or capacitor absorbs energy during part of the AC cycle, which is stored in the device's magnetic (inductor) or electric field (capacitor), only to return this energy back to the source during the rest of the cycle.
  - instantaneous power oscillates around zero.
  - Average power is 0 Watts
  - $P = V \times I \cos (\Phi) = V \times I \times (0) = 0$

$S = V \times I$

$P = 0$

Capacitance induces Leading Vars
Inductance induces Lagging Vars
PF and Beer – An imperfect but useful analogy.

- kW – The thirst quenching, good part. Does the work.
- kVAR – Foam. Does not quench the thirst.
- kVA – Total contents of the mug.
  - PF=kW/(kW+kVA)
  - PF=Beer/(Beer+Foam)

For a given KVA: The more foam you have (the higher the percentage of KVAR), the lower your ratio of KW (beer) to KVA (beer plus foam). Thus, the lower your power factor.

The less foam you have (the lower the percentage of KVAR), the higher your ratio of KW (beer) to KVA (beer plus foam). In fact, as your foam (or KVAR) approaches zero, your power factor approaches 1.0.
Using the Common Imperfect Analogy of Beer and Foam to Help in Understanding of Power Factor…

• Many Customers do not pay for the Foam on Top!
  – Residential specifically!
• Some RESD Demos often show drastic reduction in RMS Current (thus kVAR and kVA).
  – This does not directly equate to lower kWh usage!
Why Should we care about PF?

- If a Commercial or Industrial customer is penalized for low (a.k.a. “poor”) power factor, then improving power factor can:
  - **Lower your utility bill**
    - Low power factor requires an increase in the electric utility’s transmission and distribution capacity in order to handle the reactive power component caused by inductive loads.
    - Utilities usually charge large customers with power factors less than about 0.95 an additional fee. You can avoid this additional fee by increasing your power factor.
  - Increase your internal electrical system capacity. Uncorrected power factor will cause increased losses in your electrical distribution system and limit capacity for expansion.
  - **Reduce voltage drop at the point of use (a.k.a. “Voltage Support”)**
    - Voltages below equipment rating will cause reduced efficiency, increased current, and reduced starting torque in motors.
    - Under-voltage reduces the load motors can carry without overheating or stalling.
    - Under voltage also reduces output from lighting and resistance heating equipment.

- **Residential Customers are not billed based on poor power factor but on kWh.**
  - Can PF Correction Devices Reduce kWh? (More Later!)
Case Example

Power Factor = $100/143 = 0.7$
Cosine $45.6^\circ = 0.7$

Apparent power = $143$ kVA
Phase angle = $45.6^\circ$
Reactive power = $102$ kVAR
Real power = $100$ kW

Customer has 100kW load with 0.7 power factor. It is desired to increase power factor to 0.95.

### How many VARs are required? From IEEE Red Book

IEEE Std. 141-1993

#### KVAR Required = Real Power (kW) x Factor

<table>
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<tr>
<th>Original PF</th>
<th>Desired PF in percent</th>
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<tr>
<td>0.990</td>
<td>1.000</td>
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</table>

kVAR Required = 100kW * 0.692 = 69kVar
Example Result of Power Factor Correction

Power Factor = 100/143 = 0.7
Cosine $45.6^\circ = 0.7$

Apparent power = 143 kVA
Phase angle = $45.6^\circ$
Real power = 100 kW
Reactive power = 102 kVAR

Power Factor before = 100/143 = 0.70
Power Factor after = 100/105 = 0.95

Apparent power
Reactive power before = 143
after = 105
Real power = 100 kW
Reactive power before = 102 kVAR
Reactive power after = 33 kVAR
Capacitance added = 69 kVAR
Voltage Rise with Capacitors

• Capacitors will raise a circuit’s voltage
• It is typically not economical to apply them for that reason alone
• Voltage improvement can be regarded as an added benefit

\[
% \Delta V = \frac{\text{capacitor kvar} \cdot \text{transformer impedance}}{\text{transformer kVA}}
\]
Voltage Rise

- For example, 500 kVAR on a 1500 kVA transformer with 6% impedance will cause a 2.0% voltage rise.

\[ \% \Delta V = \frac{500}{1500} \times 6\% = 2.0\% \text{ voltage rise} \]
Early History of Electric Rates

• The earliest rates were very simple;
  – $10 per month per light bulb
• The first electric meter read in “cubic feet”
• Soon, meters displayed “lamp-hours”, then kWh
• Increasing numbers of customers caused a night-time “peak load” that caused operational problems
  – As motors replaced mechanical, steam, and horse operated systems, a similar peak occurred during the day as well.

Source: aee CEM training course
Residential Rate Structures

• Residential Customers are billed on Kilo-Watt Hour (kWh) only
  – For example, if a residential customer requires 1kW of power for one hour he will be billed for 1kWH
  – Power Factor Correction may not lead to lower kWh

• Therefore, a technology that save kWh will result in energy savings and lower monthly bills for the Residential Customer.

• Residential Customers can also be billed based Real Time Pricing
  – In this case, curtailing the use of electricity (kW) during peak demand times will lead to savings
Commercial and Industrial Electric Rate Structure

• While rates vary greatly between utilities, all share common features
  – Commercial and Industrial customers may have bills with 3 to 4 components
    • Customer cost
      – Constant monthly cost, cost of meter, cost of providing & reading meter, sending a bill
    • Energy cost
      – Factor based on number of kWh used per month
        • Fuel, operational & maintenance expenses
    • Demand cost
      – Recovery of capital cost of infrastructure
      – Based on kW of power
    • Others – power factor, time of day, voltage levels, interruptible rates, and customer class

Source: aee CEM training course
The Demand Ratchet

- Added to rate structure so that customer pays a reasonable share of the cost of providing them electrical power
  - Customer pays a percentage of the highest demand recorded at any time over the previous 11 months – even if this occurs only one time
- Typically 60% to 100%

Source: aee CEM training course
Electric Cost – Typical Components

- Energy Cost – $0.06 / kWh
- Demand Cost – $6.50 / kW / month
- Fuel Adjustment – $0.025 / kWh
- Power Factor (PF) Penalty
  - $6.50 / kVA / month
  - Or kW billed = kW x 0.85 / PF
- Ratchet Clause – maximum of kW this month or 70% of maximum kW in last 11 months

Source: aee CEM training course
Electric Rate Structure (Charges per Month) - Example

• Rate Structure:
  – Customer Cost $50 per month
  – Energy Cost $0.06 per kWh
  – Demand Cost $6.50 per kW per month
  – Fuel Adjustment $0.025 per kWh
  – Taxes 8% of entire bill

Bill Calculation:
• A large office building receives electrical service at the above rate; find the cost of
  – Energy Consumption = 150,000 kWh
  – Metered Demand = 525 kW

Source: aee CEM training course
Bill Calculation Solution

- Rate Structure:
  - Customer Cost = $50 per month $50.00
  - Energy Cost = $0.06 per kWh $9,000.00
  - Demand Cost = $6.50 per kW per month $3,412.50
  - Fuel Adjustment = $0.025 per kWh $3,750.00
  - Taxes = 8% of entire bill $1,297.00

$16,212.50

$17,509.50

Source: aee CEM training course
### Typical Utility Rate Structures

#### Common Rate Class Categories and Charges

<table>
<thead>
<tr>
<th></th>
<th>Residential</th>
<th>General Service</th>
<th>Industrial</th>
<th>Time-of-Use</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Eligibility</strong></td>
<td>Unincorporated farms and households</td>
<td>Customers not elsewhere covered (default rate)</td>
<td>Customer engaged in manufacturing and larger sized customer loads</td>
<td>Usually available to higher use customers first</td>
</tr>
<tr>
<td><strong>Customer Charge</strong></td>
<td>Based on meter costs, meter reading, billing costs</td>
<td></td>
<td>Higher metering expense and billing costs</td>
<td>Much higher meter and meter reading and billing costs</td>
</tr>
<tr>
<td><strong>Demand Charge</strong></td>
<td>none</td>
<td>• Applied to highest <strong>fifteen</strong> minute (integrated or clock) in billing month</td>
<td>Voltage discounts to reflect transformer ownership and reduced losses</td>
<td>Applied to highest <strong>thirty</strong> minute kW (integrated or clock) in billing month</td>
</tr>
<tr>
<td><strong>Energy Charge</strong></td>
<td>$/kWh – flat, declining or inverted block rates</td>
<td>Fixed or variable declining blocks rates</td>
<td>Lower losses</td>
<td>On and Off peak periods vary across the country</td>
</tr>
<tr>
<td><strong>Common Charges</strong></td>
<td>• Power Factor • Demand Ratchets • Minimum Bill</td>
<td>Not normally applied</td>
<td>Common charges normally applied although special contract terms may be used</td>
<td>Same as base class rate</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Absent kVA billing, power factor penalties for use that lags by 85% or leads by 115% • Recovery of generation equipment, Based on highest kW established in previous year • Recovery of distribution equipment, Based on peak usage during contract term</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Fuel &amp; Other Cost Adjustments ($/kWh)</strong></td>
<td>Applied on kWh basis</td>
<td></td>
<td>Larger customers often have additional facilities whose costs are applied to the monthly bill</td>
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## New “Dynamic” Rate Designs

<table>
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<th>Rate Type</th>
<th>Description</th>
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<tbody>
<tr>
<td>Critical Peak Pricing (CPP)</td>
<td>A time of use rate with utility callable critical price periods. Price is known beforehand and is limited to a number of called events</td>
</tr>
<tr>
<td>Peak Time Rebate (PTR)</td>
<td>Credit paid based on reduced usage during peak times</td>
</tr>
<tr>
<td>Variable Peak Pricing (VPP)</td>
<td>Similar to CPP but price level is not known beforehand</td>
</tr>
<tr>
<td>Real Time Pricing (RTP)</td>
<td>Hourly charges $/kWh apply that reflect current system conditions</td>
</tr>
<tr>
<td></td>
<td>Hedged (two-part) or un-hedged (one-part)</td>
</tr>
<tr>
<td>Contract for Differences (CFD)</td>
<td>Load shape is estimated then adjusted to reflect actual market prices</td>
</tr>
</tbody>
</table>
Cost Per kWh Varies Nationwide (2008 Data)

Total average residential rates by state
(cents per kilowatt-hour)

Reflects average residential utility rates for 12 months ending June 2008.
Average Retail kWh Costs (2009 Data)

Source: Electric Power Monthly with data for August 2009
Report Released: November 13, 2009
Next Release Date: Mid-December 2009

As posted on: http://www.eia.doe.gov
4.0 Capacitor Based RESD Devices

\[ kVA_{\text{old}} \quad \text{kVA}_{\text{lag}} \]
\[ kW \quad kVA_{\text{new}} \quad kVA_{\text{lag\_new}} \]
\[ kVA_{\text{lead}} \]
Capacitors as Energy Savings Device

• Specific application benefits of capacitors
  – Lowering of the purchased-power costs for utility customers that are penalized for low power factor,
  – Lowering of kVA demand charge,
  – Releasing of electrical system capacity,
  – Improving voltage regulation, and
  – Lowering of electrical system losses.

Capacitors/Harmonic Filters DO save Energy; The problem is “Inflated” claims of energy savings can mislead customers and they often seek utility customer serviced representative and/or PQ engineer advise on potential energy savings benefits
Basic Power Delivery Losses

\[ P_{\text{LOSSES}} = I_1^2 R_1 + I_2^2 R_2 + \text{(Transf Losses)} + \text{(Load Losses)} \]

Delivery Losses
A little tidbit about \((I^2)R\) Losses

- Resistive losses in a wire can be calculated based on the resistance in the conductor and the RMS current in the conductor – thus \((I^2)R\).

  - Savings = \(((I_{rms\,High})^2 - (I_{rms\,Low})^2)\)\*R

  - If the load is 10 Amps and we reduce to 9 amps, the savings would be
    - \((10^2 - 9^2)\)\*R = 19*R Watts

  - If the load is 100 Amps and we reduce to 99 amps, the savings would be
    - \((100^2 - 99^2)\)\*R = 199*R Watts

**Bottom Line:** The losses in electrical circuits increase as the current increases (squared function).
Typical Delivery Losses

• Typical: 3-4 % average
• If heavily loaded: 8% peak load
  – This is the level where it is common for other problems to start such as low voltage
• Some systems with unusual conductor arrangements may have higher losses such as single conductor with earth return (15%)
• Some transmission systems have incremental losses of as much as 30% when greatly overloaded
  – Incremental loss = losses for last increment of load added
  – Total loss may only be 8-10%
Savings Depends on Location

Frequently convenient to locate capacitors at the main bus, but this reduces only part of the current and not the current that is likely to yield the greatest loss savings.
Savings Depends on Location

Placing the capacitor as close to the load as possible will generally yield the greatest power delivery loss savings.
Example

12.47 kV

2 mi, 336 MCM Overhead

%R=1

300 ft, 1000 MCM Cable

1076 kW

12.47/0.48

500 kW
PF=.88

500 kW
PF=1

LOSSES:

4.73 kW  5.1 kW  71.2 kW
0.44%  0.47%  6.65%

Total Circuit Losses: 81 kW / 8.1%
Example, Capacitor at Mains

12.47 kV 2 mi, 336 MCM Overhead %R=1

1070 kW 300 ft, 1000 MCM Cable

250 kvar 500 kW PF=.88

12.47/0.48

LOSSES:

4.03 kW 0.38%
4.33 kW 0.40%
66.4 kW 6.23%

Total Circuit Losses: 74.8 kW / 7.48%

Saved a little here because voltage improved

End User Loss Savings: 76 kW - 70 kW = 6 kW

Bottom Line of Example:

This is 8% savings in losses, but net power into load decreases only 6 kW or 0.6% of load
Example, Capacitor at Load

12.47 kV
2 mi, 336 MCM
Overhead

12.47/0.48
%R=1

300 ft, 1000
MCM Cable

(250 kvar)

500 kW
PF=.88

500 kW
PF=1

1065 kW

LOSSES:
4.03 kW
0.38%

4.32 kW
0.40%

60.6 kW
6.23%

Total Circuit Losses: 68.9 kW / 6.89%

End User Loss Savings: 76 kW - 65 kW = 11 kW

This is nearly 15% savings in losses, but net power into load decreases only 11 kW or 1.1% of load.
Simplified Formula: Potential for Reducing $I^2R$ Losses

\[
\text{% Loss Reduction} = 100 \left[ 1 - \left( \frac{pf_{\text{old}}}{pf_{\text{new}}} \right)^2 \right]
\]

• As an example, with an old power factor 0.7 and a new power factor of 0.9, the system losses are reduced by 39.5%.

Source: IEEE Red Book Std 141-1993
Overall Impact of Energy Savings as Percentage of Plant Total Energy Consumption

Impact of Power Factor Correction Capacitor on Total Facility Load

Assumption: System Losses due to Reduced Power factor is 2% of Total Load

Bottom Line: You can only save the energy that is wasted.
Capacitor Based RESD Typical Vendor Claims

“Residential Customers Can Save up to 25% on your monthly electric bills”

“NASA Approved Green Technology”

“Residential customers could see a realized savings of 8% - 10% typically and as much as 25% on their electrical usage (and thus power bills).”

“Commercial Savings from 6%-17%”

“Industrial Savings from 6%-25%”
Without Capacitor Based RESD Year Before

With Capacitor Based RESD Current Year

Source: Deal or Dud Story
FOX10 News, Phoenix Arizona
Sunday December 14th, 2008

www.myfoxphoenix.com
http://www.youtube.com/watch?v=ZrTVxNxnHao
What's in the Can?

• These devices typically contain:
  – A couple of capacitors
    • In example residential unit, 1.52 kVAR total (one size)
  – A Red/Blue Power Light
  – A bleeder Resistor
  – Could also contain a surge arrestor

kVAR Calculation:

\[ P = \frac{V^2}{Z} \]

\[ = \frac{(240V)^2}{\frac{1}{(2\pi*60Hz*70uF)}} \]

\[ = 1.52 \text{ kVAR} \]

1.52 kVAR at 240V
Test 1: Unloaded Motor Demo

- Typical Test Shown in vendor demonstrations.
- Completely Unloaded Motor is used to demonstrate energy savings.
- Current Shown with and without RESD in place.
- Lets do this experiment and see what happens!
Unloaded Motor Demo Test Setup

- Test Setup utilizes readily available 120Vac voltage source
- Fluke 41 Harmonics Power Harmonics Analyzer used to measure
- Unloaded motor connected to outlet strip
- Capacitor based RESD connected as well through another switched outlet strip
Initial Motor Measurements

- Step 1: Turn on outlet strip 1
- Step 2: Allow motor to start up and power measurements to stabilize
- Step 3: Measure and record Power without RESD in the circuit

<table>
<thead>
<tr>
<th>Summary Information</th>
<th>Voltage</th>
<th>Current</th>
</tr>
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<tbody>
<tr>
<td>Frequency</td>
<td>43.57</td>
<td></td>
</tr>
<tr>
<td>Power Watts</td>
<td>232.00</td>
<td>1195.00</td>
</tr>
<tr>
<td>VA</td>
<td>0.00</td>
<td>-4.00</td>
</tr>
<tr>
<td>Vars</td>
<td>162° lag</td>
<td></td>
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<tr>
<td>Peak W Phase</td>
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<td></td>
</tr>
<tr>
<td>Total PF DPF</td>
<td>0.19</td>
<td>-0.95</td>
</tr>
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</table>
Test with RESD in Circuit

• Step 1: Turn on outlet strip 2

• Step 2: Allow Cap to come on and power measurements to stabilize

• Step 3: Measure and record Power with RESD in the circuit

### Single Phase Readings - 08/04/10 11:19:18

<table>
<thead>
<tr>
<th>Summary Information</th>
<th>Voltage</th>
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<tr>
<td>Power</td>
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<tr>
<td>Watts</td>
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<td>VA</td>
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<tr>
<td>Vars</td>
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<tr>
<td>Peak W</td>
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<td>Phase</td>
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<tr>
<td>Total PF</td>
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<tr>
<td>DPF</td>
<td>-0.97</td>
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## Unloaded Motor Measurements (paste screen shots)

**Unloaded motor w/o RESD**

<table>
<thead>
<tr>
<th>Summary Information</th>
<th>Voltage</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Frequency Power</td>
<td>43.57</td>
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</tr>
<tr>
<td>Watts</td>
<td>232.00</td>
<td>1.99</td>
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<tr>
<td>VA</td>
<td>1195.00</td>
<td>-0.38</td>
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<tr>
<td>Vars</td>
<td>0.00</td>
<td>0.19</td>
</tr>
<tr>
<td>Peak W</td>
<td>-4.00</td>
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<tr>
<td>Phase Total PF DPF</td>
<td>162^* lag</td>
<td>10.22</td>
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<td></td>
<td>-0.95</td>
<td>2.14</td>
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<tr>
<td>RMS Peak DC Offset</td>
<td>116.96</td>
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<tr>
<td>THD Rms THD Fund HRMS KFactor</td>
<td>2.66</td>
<td>0.02</td>
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</table>

**Unloaded motor w/RESD**

<table>
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<tr>
<th>Summary Information</th>
<th>Voltage</th>
<th>Current</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency Power</td>
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<td></td>
</tr>
<tr>
<td>Watts</td>
<td>232.24</td>
<td>6.81</td>
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<tr>
<td>VA</td>
<td>798.81</td>
<td>1.82</td>
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<tr>
<td>Vars</td>
<td>0.00</td>
<td>0.08</td>
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<tr>
<td>Peak W</td>
<td>-5.12</td>
<td>0.27</td>
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<tr>
<td>Phase Total PF DPF</td>
<td>166^* lag</td>
<td>3.57</td>
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<tr>
<td></td>
<td>-0.97</td>
<td></td>
</tr>
<tr>
<td>RMS Peak DC Offset</td>
<td>117.32</td>
<td></td>
</tr>
<tr>
<td>THD Rms THD Fund HRMS KFactor</td>
<td>3.57</td>
<td>0.08</td>
</tr>
</tbody>
</table>

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Discussion

• Compare Power Readings
• What is reduced with RESD in circuit?
• Will this cause a reduction in a residential customers power bill?
• Is it realistic to have an unloaded motor used for the demo?
• Is our test fair since the source is 120Vac rather than 240Vac?
Unloaded 120Vac Motor Tests In EPRI Lab (Capacitor RESD Connected at 240V)
Unloaded 120Vac Motor Tests
In EPRI Lab (Capacitor RESD Connected at 240V)

• Single-Phase 1HP motor shown in unloaded condition
  • Very Poor Power Factor, 0.21 PF
  • 260 W measured on L2-N,
    • RMS Current =10.25A

• With Capacitor Based RESD Switched in circuit:
  • Power Factor Improved, 0.45 PF
  • 250 W measured on L2-N
    • RMS Current =4.56A
Unloaded 120Vac Motor Tests In EPRI Lab (Capacitor RESD Connected at 240V)

- Unloaded 120Vac Motor w/o Unit
- Unloaded 120Vac Motor w/ Unit

But, Real Power (kW) only drops by 10watts

RMS Current more than cut in half!
Additional Example Test Results from Lab

Unloaded 120Vac Motor w/o Unit

<table>
<thead>
<tr>
<th>Without EUT</th>
<th>With EUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Watts</td>
<td>VA</td>
</tr>
<tr>
<td>Average</td>
<td>244.1</td>
</tr>
<tr>
<td>Max</td>
<td>247.0</td>
</tr>
<tr>
<td>Min</td>
<td>243.0</td>
</tr>
</tbody>
</table>
Thermal Image of Motor with and without EUT

Unloaded 120Vac Motor w/o Unit

Unloaded 120Vac Motor w/ Unit
Bar Chart of Tabularized Data – Unloaded 120Vac Motor

Watts, VA, VAR and PF With and Without KVAR

Without KVAR

With KVAR

<table>
<thead>
<tr>
<th></th>
<th>Watts</th>
<th>VA</th>
<th>VAR</th>
<th>PF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ave</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Min</td>
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<tr>
<td>Ave</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Max</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Min</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Test 2: Mix of Loads

- Scenario: Similar to setup where RESD is installed at main breaker panel
- Test setup includes:
  - 120V Fan Motor with slide gate (for adjusting load)
  - 120V 500W Shop Light
  - 120V PC Power Supply
- Fluke 41 Harmonics Power Harmonics Analyzer used to measure power
- Capacitor based RESD connected through another switched outlet strip
Initial Measurements (max Load, No RESD)

- Step 1: Turn on outlet strip 1
- Step 2: Do not block Fan intake with gate.
- Step 3: Allow motor to start up and power measurements to stabilize
- Step 4: Measure and record Power without RESD in the circuit

<table>
<thead>
<tr>
<th>Summary Information</th>
<th>Voltage</th>
<th>Current</th>
</tr>
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<tbody>
<tr>
<td>Frequency Power</td>
<td>59.98</td>
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</tr>
<tr>
<td>KW</td>
<td>1.05</td>
<td></td>
</tr>
<tr>
<td>KVA</td>
<td>1.55</td>
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<tr>
<td>KVAR</td>
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<td>Peak KW</td>
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<td>Phase</td>
<td>47° lag</td>
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<td>Total PF</td>
<td>0.68</td>
<td>107.68</td>
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<tr>
<td>DPF</td>
<td>0.68</td>
<td>152.49</td>
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<tr>
<td>RMS</td>
<td></td>
<td>20.76</td>
</tr>
<tr>
<td>Peak</td>
<td></td>
<td></td>
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<tr>
<td>DC Offset</td>
<td>-0.08</td>
<td>-0.38</td>
</tr>
<tr>
<td>Crest</td>
<td>1.42</td>
<td></td>
</tr>
<tr>
<td>THD RMS</td>
<td>0.88</td>
<td>3.43</td>
</tr>
<tr>
<td>THD Fund</td>
<td>0.88</td>
<td>3.43</td>
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<tr>
<td>HRMS</td>
<td>0.95</td>
<td>0.49</td>
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<tr>
<td>KFactor</td>
<td>1.02</td>
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</table>
Examine Change of Motor Load – Adjust Gate to 100% Closed (min load, No RESD)

• Step 1: Slide block gate 100% closed over fan intake.
  - Minimum Fan Load

• Step 2: Allow motor to start up and power measurements to stabilize

• Step 3: Measure and record Power without RESD in the circuit

<table>
<thead>
<tr>
<th>Summary Information</th>
<th>Voltage</th>
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<tbody>
<tr>
<td>Frequency</td>
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<td>RMS 109.84</td>
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<tr>
<td>Power</td>
<td></td>
<td>Peak 154.77</td>
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<tr>
<td>KW</td>
<td>0.88</td>
<td>DC Offset -0.02</td>
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<tr>
<td>KVA</td>
<td>1.43</td>
<td>Crest 1.41</td>
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<td>KVAR</td>
<td>1.13</td>
<td>THD Rms 0.91</td>
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<td>Peak KW</td>
<td>2.48</td>
<td>THD Fund 0.91</td>
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<tr>
<td>Phase</td>
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<td>HRMS 0.99</td>
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<tr>
<td>Total PF</td>
<td>0.61</td>
<td>KFactor 1.03</td>
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</table>
Examine Change of Motor Load – Remove Fan Gate (max load, with RESD)

- **Step 1:** Turn on outlet strip 2
- **Step 2:** Do not block Fan intake with gate.
- **Step 3:** Allow power measurements to stabilize
- **Step 4:** Measure and record Power without RESD in the circuit

### Single Phase Readings - 08/04/10 11:29:13

<table>
<thead>
<tr>
<th>Summary Information</th>
<th>Voltage</th>
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<tr>
<td>Power</td>
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<td>KVAR</td>
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<td>RMS</td>
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<td>Peak</td>
<td>152.82</td>
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<td>DC Offset</td>
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<tr>
<td>Crest</td>
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<td>THD Rms</td>
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<tr>
<td>KFactor</td>
<td>1.02</td>
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</tr>
</tbody>
</table>

**Note:**
- **120V 500W Shop Light** (Resistive Load) (410W 1.0 PF)
- **¼ Hp 120Vac Fan** (Inductive Load) Full Load – 320W, 0.82PF
- **120V (80-100W, 0.98PF) Tower PC** (Power Electronic Load)
Examine Change of Motor Load – Adjust Gate to 100% Closed (min load, with RESD)

- Step 1: Slide block gate 100% closed over fan intake.
  - Minimum Fan Load
- Step 2: Allow motor to start up and power measurements to stabilize
- Step 3: Measure and record Power without RESD in the circuit

<table>
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<tr>
<th>Summary Information</th>
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<th>Current</th>
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<td>KVAR</td>
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<tr>
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Measurements (paste screen shots)

### Max Load w/o RESD

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<td>20.76</td>
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<td>KVAR</td>
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<tr>
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<tr>
<td>Phase</td>
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<tr>
<td>Total PF</td>
<td>0.68</td>
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</tr>
<tr>
<td>DPF</td>
<td>0.68</td>
<td>1.42</td>
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</table>

### Max Load w/RESD

<table>
<thead>
<tr>
<th>Summary Information</th>
<th>Voltage</th>
<th>Current</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency Power</td>
<td>60.17</td>
<td>108.46</td>
</tr>
<tr>
<td>KW</td>
<td>1.05</td>
<td>152.82</td>
</tr>
<tr>
<td>KVA</td>
<td>1.31</td>
<td>0.11</td>
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<td>KVAR</td>
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### Minimum Load w/o RESD

<table>
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<th>Voltage</th>
<th>Current</th>
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<tbody>
<tr>
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<tr>
<td>KW</td>
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<td>KVA</td>
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<td>Phase</td>
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<td>Total PF</td>
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<tr>
<td>DPF</td>
<td>0.61</td>
<td>3.88</td>
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### Minimum Load w/RESD

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<tr>
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<th>Voltage</th>
<th>Current</th>
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</thead>
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<tr>
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<td>KW</td>
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<td>KVAR</td>
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<tr>
<td>Peak KW</td>
<td>2.22</td>
<td>1.45</td>
</tr>
<tr>
<td>Phase</td>
<td>42° lag</td>
<td>1.02</td>
</tr>
<tr>
<td>Total PF</td>
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<td>4.75</td>
</tr>
<tr>
<td>DPF</td>
<td>0.74</td>
<td>4.75</td>
</tr>
</tbody>
</table>
Discussion

• Compare Power Readings
  – kW
  – Peak kW

• How does motor load change results

• What is reduced with RESD in circuit?

• Will this cause a reduction in a residential customers power bill?

• Would the general result be the same with a 240Vac Fan?
Test with 240Vac Fan Motor Load and 240Vac Connected Cap Based RESD (using Fluke 41)
Example Test in EPRI Lab with 240Vac Motor and RESD (using Fluke 41)

- **RMS Current Increases w/RESD**
- **20W Reduction w/RESD**
- **240Vac Loaded Motor w/o Unit**
- **240Vac Loaded Motor w/ Unit**

- **Power Factor goes from 0.93 (21 degree lagging) To 0.59 (54 degrees leading)**
Test with 240V Fan Example (Hioki Meter)

- This test involved a loaded 240V fan
- Data was recorded with the fan running as normal
- The KVAR unit was then added to the circuit
- Data was recorded with the KVAR unit in the circuit
240V Fan Example Continued

### 240Vac Loaded Motor w/o Unit

**Watts** | **VA** | **VAR** | **PF**
--- | --- | --- | ---
**Average** | 735.0 | 756.6 | 179.0 | 1.0 | 734.37 | 1547.51 | -1362.14 | -0.48
**Max** | 770.0 | 802.0 | 223.0 | 1.0 | 752.00 | 1551.00 | -1339.00 | -0.47
**Min** | 725.0 | 744.0 | 167.0 | 1.0 | 729.00 | 1536.00 | -1368.00 | -0.49

### 240Vac Loaded Motor w/ Unit

**Watts** | **VA** | **VAR** | **PF**
--- | --- | --- | ---
**Average** | 735.0 | 756.6 | 179.0 | 1.0 | 734.37 | 1547.51 | -1362.14 | -0.48
**Max** | 770.0 | 802.0 | 223.0 | 1.0 | 752.00 | 1551.00 | -1339.00 | -0.47
**Min** | 725.0 | 744.0 | 167.0 | 1.0 | 729.00 | 1536.00 | -1368.00 | -0.49

---

**Without EUT**

**With EUT**

---

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Summary of Power Measurements-240Vac Fan

[Graphs showing power measurements with and without KVAR units]
• For residential purposes, with the KVAR unit in the system, there was an energy savings of 0.09%.
• KVA and VAR’s more than doubled due to the added capacitance.
  – Leading PF
• Average %Ithd without the KVAR Unit is 2.18%
• Average %Ithd with the KVAR Unit is 9.63%
  – Harmonic Sink
Thermal Image of Motor with and without EUT
Bar Chart of Tabularized Data – Loaded 240Vac Fan Motor

Watts, VA, VAR and PF With and Without KVAR

-2000  -1500  -1000  -500   0   500   1000   1500   2000

AVE Max Min AVE Max Min

Without KVAR With KVAR

Watts VA VAR PF
EPRI Residential Test Stand Setup (240Vac Cap Hook Up)

Initial Tests show savings with all loads running in range of 10-30Watts – more tests to be done to finalize results
Example Payback Calculation

- Assume 20W Savings
- Product Cost ($399 Typical)
  - Installation could run $200 to $300 more
- Based on TN 2009 Average Residential Rate of $0.09/kWh
  - Simple Payback = Net Investment/Net Annual Return

  - Net Investment (Self Install – not counting breaker) = $399
  - Net Annual Return = \((0.02\text{kW}) \times ($0.09/\text{kWh}) \times (365 \text{ days/year}) \times (24 \text{ h/day}) = $15.77/\text{year}\)

  - Payback = $399/($15.77/\text{year}) = 25.3 years
What about Harmonics? AC Cap acts as a Harmonic Sink

Cap Based RESD Out of Circuit

Cap Based RESD In Circuit
For our Electrical Engineers in the Crowd – Power Triangles

Power Triangle for Unloaded 120Vac Blower without and with EUT

Power Triangle for 240Vac Fan Motor without and with EUT
Energy Star Perspective Power Factor Correction RESDs...

Can I determine Energy Savings By Looking at my previous bills?
Background

• One of the most common used proofs of energy savings is comparing month to month charges from previous year energy bills
  – This is an erroneous means of comparison or proof
  – Every year and every month there are different temperatures which change the energy usage
  – There are also different conditions,
    • Commercial: one month may have 22 “business days” while another has 21
    • Residential: family may be on vacation one week, etc
  – Failing equipment could have been replaced with newer more efficient appliances
• Laboratory testing under controlled conditions is the only verifiable means of testing for energy savings.
Degree Days

- Heating Degree Day (HDD): An indication which reflects the demand for energy required to heat a home or business.
  - Defined relative to base temperature of 65
  - If the temperature for a given day is 30 degrees, the Heating degree day is 65 - 30 = 35 HDD
  - Best used over time to indicate what is expected in the area
- Cooling Degree Day (CDD): An indication which reflects the demand for energy required to cool a home or business
  - Defined relative to base temperature of 65
  - If the temperature for a given day is 90 degrees, the cooling degree day is 90 – 65 = 25 CDD
- The HDD and CDD are cumulative for a given month.
Now Let's Look Closer at this…
Case Study – Fox 10 News Story, Phoenix Arizona
Sunday December 14th, 2008

Without Capacitor Based RESD Year Before

Source: Deal or Dud Story
FOX10 News, Phoenix Arizona
Sunday December 14th, 2008
www.myfoxphoenix.com
http://www.youtube.com/watch?v=ZrTVxNxuHao
CDD Analysis of Phoenix 2007-2008

• As shown with the representation of the Cooling Degree Days (CDD), 2007 required more cooling than 2008 did
  – From www.degreedays.net
  – Airport: Phoenix, AZ, US (112.01W,33.43N), Weather station ID KPHX
  – This is one reason for the difference shown on the utility yearly statement.

• What other changes were possibly made in the home?
  – This is by no means a controlled experiment
  – More energy efficient appliances?
  – Cooking at home more a given month than eating out?
  – CFLs replacing incandescent?
  – Work schedules?
  – Changes in habits
  – Etc.
Phoenix Historically

- 2007 the average temperature from April 1st through September 30th was 87.3 degrees
- In 2008 for the same span, the average was 84.7, or 3% difference
- During the same time span, in 2007 there were 88 days above 90 degrees, compared to only 73 in 2008, a difference of 17%
- All the above data indicates that between the two years, 2008 required less cooling, and therefore this will account for a good part of the lower monthly power bills.
Conclusion

• As shown by the graphs and the data, it is not accurate to use a previous years electrical data to verify energy savings of an installed device.

• The trend of savings follows the CDD days closely.

• True energy savings can only be measured under controlled settings.
5.0 Motor Voltage Controller RESD Devices
Motor Energy Savings by Voltage Reduction

• These devices are often called power-factor controllers (PFC), torque controllers, energy savers, motor voltage controller (MVC), and other names.

• The technology was originally proposed and developed by Frank Nola (NASA) in the mid to late 70s as a means of reducing energy wastage on small single phase induction motors.

• Many patent applications were made in the early 80s covering variations on the technology as it could be applied to the three phase applications.
Nola’s Clever Motor Controller
Popular Science, July 1979

Nola’s clever motor controller
cuts wasted electricity

Plug in millions of motors, and this NASA-developed circuit could save the U.S. huge quantities of fuel

By E.F. LINDSEY
DRAWINGS BY BUCCONORE STUDIOS

As you read this, millions of electric motors are wasting up to 60 percent of the power fed to them. Undoubtedly, some of these power-guzzlers are right in your own home. Overall, the electrical power waste adds up to hundreds of thousands of barrels of oil, or its equivalent, every day.

If this lies in the face of all you’ve ever been told about the high efficiencies of electric motors, that’s because motor efficiencies are usually specified for near full-load conditions—not no-load or light loads. In the real world, however, very few ordinary motors ever operate at anything near full load, except briefly. But the surprising thing is that they draw almost the same current at no load as they do at full load.

That’s why a simple and inexpensive power saver, invented by Frank J. Nola, an affable electronics engineer at NASA’s George C. Marshall Space Flight Center in Huntsville, Ala., has caused such widespread excitement.

How well does Nola’s power saver work? Clyde S. Jones of NASA says, “The device has been tested at Marshall Center on over 40 types of motors, with power savings ranging up to 60 percent, depending on the loading. The motors tested were both single-phase and three-phase, ranging from small to very large.”

NASA engineer Frank Nola switches on the board a circuit he developed that will save you five to seven percent savings at rated load.”

How does Nola’s device accomplish such remarkable power savings? To begin with, you have to take a look at the peculiar characteristics of induction motors and the alternating current that powers them. Induction motors are the familiar horsepower motors used almost everywhere in homes and factories.

When alternating current is supplied to their stator or field coils, a magnetic field is set up and produces rotating mechanical power.

At full load, very strong magnetic fields are needed. The full 230-m/125-volt line potential keeps full-rated current flowing to build these fields. Under these conditions, an electric motor is a very efficient power user. However, at less than full load, for example, many mechanical forces would keep the motor spinning and do the job just as well with less power.

But, unlike your car engine, with its
Simplified Motor Energy Savings Principle using Voltage Reduction

Lowering of the motor voltage will tend to lower the motor magnetic excitation loss;

If the motor can still drive the reduced load at the reduced voltage level, the motor efficiency should be increased over that of the case of the same motor driving the same reduced load but at full motor voltage.
Reducing the Voltage at $V_0$ (and thus $E_1$)
reduces the $(I_M)^2R_c$ Iron Core Losses.

Worthwhile power savings are only achievable where the iron loss is an appreciable portion of the total power consumed by the motor, and where the amount of the iron loss is significant relative to the motor rating.
Applications for MVCs

• These technologies work best on motors that are lightly loaded.

• Three Phase:
  – Escalators, MG sets, conveyors, mixers, grinders, crushers, granulators, saws, metal scrappers, shredders, slicers, stamping presses, balers, and lathes

• Single Phase:
  – Clothes washer, clothes dryer, fans, blenders, saws, sanders, slicers, conveyors, and compressors
Iron Losses as a Function of Motor Size

Beware: with a partially loaded motor, a reduction in the voltage applied to the motor will reduce the iron loss, but the corresponding increase in the load current can cause an increase in copper loss that is greater than the reduction in the iron loss, resulting in a net increase in motor losses.
EPRI Lab Test Setup - Schematic

Power Quality Meter connected in parallel with respect to Waveform Data Recorder
20 Hp Motor and Eddy Current Brake
Test Setup - Equipment

- MVC RESD
- Waveform Data Recorder
- Eddy Current Brake
- 20 Hp 480V Motor
- Power Quality Meter
- Brake Controller
- Tri-Mode Sag Generator
Test Setup – Thermal Camera
Example RESD MVC Device

- Adjustable Dipswitches
- 24 V<sub>DC</sub> Motor and Energy Saving Mode Enable Signals
- Line
- Load
Example Test E1 – 25% Load w/o MVC Enabled (BASELINE)

- Test Start:
  - Energy Savings mode disabled
  - Brake coupled and loaded to 25%
- Typical Input Measurements
  - $480 \, V_{AC}$
  - 10.1 Amps / phase
  - 2.79 kVA / phase
  - 2.53 KVAR / phase
  - 3.73 kW Total
  - Pf 0.42
  - 35.6 °C (Max Temp)
- 20.1 Hp motor, 15 kW full load
  - Approx 3.73 kW load
  - 24.9% Loaded
- PQ meter (top) and thermal camera (bottom) snapshots taken in the last 5 minutes before finish
Example Test E2 – 25% Load w/ MVC Enabled

- **Test Start:**
  - Energy Saving mode enabled
  - Brake coupled and loaded to 25%
- **Typical Input Measurements**
  - $480 \, V_{AC}$
  - 8.35 Amps / phase
  - 2.66 kVA / phase
  - 2.03 KVAR / phase
  - 3.45 kW Total
  - Pf 0.48
  - 32.2 °C (Max Temp)
  - $\Delta$ Temp = - 3.4 °C
- 20.1 Hp motor, 15 kW full load
  - Approx 3.45 kW load
  - 23% Loaded
  - $\Delta$ Power = - 280 W
- PQ meter (top) and thermal camera (bottom) snapshots taken in the last 5 minutes before finish
EE Comparison of Two MVCs

MVC lowest loading point tested with motor and brake uncoupled

MVC lowest loading point tested with motor and brake coupled without brake engaged
Example Payback Cost Summary for an Example MVC

• Best Case Test Result (12.5% Loading – minimum load capacity of our test stand on 20hp motor)
  – 470W Savings in this scenario
• Product Cost ($1100)
• Based on TN 2009 Average Commercial Rate:
  – $382 Savings per year in this scenario based on 365 x 24 x $0.09/kWh
    2.88 Year Payback if running 24/7 loaded as in this test
• Based on California Average 2009 Commercial Rate:
  – $648.45/ Savings per year in this scenario based on 365 x 24 x $.16/kWh,
    – 1.69 Year Payback if running 24/7 loaded as in this test
MVC Adjustments

- MVC can typically be adjusted for various scenarios to maximize energy savings
- The common adjustments are:
  - Soft Start Time
  - Pedestal Voltage
  - Optimization Voltage
- Some units have preset algorithms for various applications
MVC Test 1: Demo MVC Unit with Varying Motor Loading

• In this test we will demonstrate the use of a single-phase 120Vac MVC.
• The load on the motor will be adjusted to determine the savings at various load levels.
• Tests will be repeated with and without MVC in circuit
• The subject MVC provides for softstart and energy savings (optimization voltage) adjustments.
Measurements (paste screen shots)

Approx 50% Load w/o MVC  Approx 50% Load W/MVC

Minimum Load w/o MVC  Minimum Load W/MVC
Discussion

• Compare Power Readings

• What is the percent energy saved at 1/2 load?

• What is the percent energy saved at minimum load?

• Why not just buy a smaller motor?
Can an MVC with Soft/Start Lower My Peak Demand Charge?

- A common belief is that the use of a soft starter will reduce peak demand on an energy bill.

  - **Stated/Claimed Savings or Payback**: Reduces peak demand and reduces kW billing by (X) amount depending on the size of the motor versus the total load.
Can an MVC with Soft/Start Lower My Peak Demand Charge?

**• Actual/Realistic Range of Payback:**
  - Soft starters reduce the peak draw of (primarily reactive) current during a motor starting condition that typically lasts 3-10 seconds.
  
  - *This short period is a small fraction of 15 minute average demand window where the utility records peak demand.*
  
  - Generally, this can be an innocent oversight based on the lack of understanding of the salesman or end user but sometimes the salesman knows better.
  
  - Soft starters are useful for reducing the voltage drop caused by large inrush currents to motors during the starting condition but do not save energy or demand.
Example Direct on Line Motor Start with MVC

• Test Start
  – MVC in circuit with energy savings disabled
  – Direct on line start
  – Unloaded Motor (Freewheeling)

• Test Results
  – Phase A current graphs
    • Vertical scale = 20A / division
    • Time Scale = 1sec / division
  – Peak Demand (3-phase)
    • 174.33 kW Max Peak
    • 41.11 Average kw/10 Sec
Example Soft Start with MVC

- Test Start
  - MVC in circuit with energy savings enabled
  - Injection molding application set
  - Unloaded Motor (Freewheeling)

- Test Results
  - Phase A current graphs
    - Vertical scale = 20A / division
    - Time Scale = 1sec / division
  - Peak Demand (3-phase)
    - 97.08 kW Max Peak
    - 54.43 Average kw/10 Sec
Motor Start Test Results

• The unit was also subjected to peak loading test in the Injection Molding start-up scheme.

• Peak loading tests demonstrated that the MVC reduced instantaneous peak power during motor startup when using the soft starter function.
  – This peak load is over within 10 seconds

• However, utilities typically bill based on the average peak demand over a 15-minute period.

• Therefore, although the soft start capability may benefit motor life over time, it is not expected that significant energy savings will be realized by the softstart feature alone.

<table>
<thead>
<tr>
<th>Power Consumption in kW</th>
<th>During Start up Test</th>
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<tbody>
<tr>
<td>Avg kw /10Sec</td>
<td>Freewheel DoL</td>
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<tr>
<td>Instant Peak Max</td>
<td>41.11</td>
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<tr>
<td></td>
<td>174.33</td>
</tr>
</tbody>
</table>

Instantaneous Power During a Soft Start in Freewheeling Configuration
Calculation of Peak Demand

Start-up of 20 HP Motor, with Softstart

1st Minute……..15th minute

- Thought Experiment.....using Peak KW for the average of the 1st 10 seconds

- If we measure peak during a motor start up for 10 seconds and have a normal running load of 15kW, the 15 minute average can be calculated

  - There are “90” 10 second intervals in 15 minutes.

    - With Softstart:
      - Calculated at 54.43 kw average over first 10 seconds
      - The average is basically ((54.43*1 ) + 15*89)/90= 15.43 KW Average peak

    - Without Softstart:
      - Calculated at 41.11 kw average over first 10 seconds
      - The average is basically ((41.11*1 ) + 15*89)/90= 15.29 KW Average peak.

- So the Peak Demand Difference is

  • 15.29kW - 15.43 kW = - 0.14kw (More Power Used with SS)

    Not 171kW-97kW = 74kW
6.0 Lighting Voltage Controller (LVC) RESD Devices
LVCs

• These units are designed to lower the output voltage on the ballast of lamps in order to reduce the power requirements.

• Typical applications:
  – T8 Office Lighting
  – Metal Halide Parking Lot Lights

• EPRI Conducted tests on two LVCs used at an office park.
  – Parking Lot Unit
  – Office Building Unit

An LVC in Field Application
Example LVC Schematic & Advertised Features

Lighting Correction Unit LCU Features

- Reduce lighting circuits up to 30 Amps (3600 Watts @ 110 Vac, 8300 Watts @ 277 Vac).
- Completely digital, infinitely variable, and works with standard 0-10 Vdc control signals.
- Operates according to lamp manufacturer's specifications, i.e., 15 minute full power warm-up, slow ramp down, quick ramp up.
- Pushes no harmonics either forward to the load or backward to the line. Absorbs load harmonics.
- Installs quickly next to the electrical panel, requiring no rewiring of existing lighting fixtures.
- Employs simple to sophisticated control sequence, responding to a variety of sensors:
  - Permits adjusting of light levels in response to photo-sensors for daylight harvesting.
  - Allows reduction when areas are not in use with immediate return to full power when needed.
- Will operate to motion detection or photo-sensors.
- Can be used to level normal lumen depreciation and maintain constant lumen output.
LVC Parking Lot Tests
LVC Night Measurements
Parking lot measurement points

Measuring point

Lamp post

18 ft
Parking Lot Illumination with and without LVC

- Illumination for the selected parking lot areas under Poles 1 and 2 met the minimum basic illumination requirements (IESNA RP-20-98)
Parking Lot Unit: Power Measurements with and without LVC

<table>
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<th></th>
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<tbody>
<tr>
<td>kW</td>
<td></td>
</tr>
<tr>
<td>No LCU</td>
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</tr>
<tr>
<td>LCU</td>
<td>13.66</td>
</tr>
<tr>
<td>%savings</td>
<td>25.2%</td>
</tr>
<tr>
<td>Max</td>
<td>18.47</td>
</tr>
<tr>
<td>LCU</td>
<td>13.80</td>
</tr>
<tr>
<td>%savings</td>
<td>25.3%</td>
</tr>
<tr>
<td>Min</td>
<td>18.11</td>
</tr>
<tr>
<td>LCU</td>
<td>13.55</td>
</tr>
<tr>
<td>%savings</td>
<td>25.2%</td>
</tr>
</tbody>
</table>
Office Space Grid
Office Floor Space Illumination - with No LCU

- The IESNA Standard RP-1-4, *Office Lighting & Other Indoor Areas* recommends an illumination level of 30 foot-candles in general offices where common visual tasks are carried out.

- The average illumination in this office with the EUT in the circuit is 46.1 foot-candles.
# LVC Results on Office T8 Lighting

<table>
<thead>
<tr>
<th></th>
<th>Indoor Lights</th>
<th>kW</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>No EUT</td>
<td>EUT</td>
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<tr>
<td>Average</td>
<td>24.05</td>
<td>23.11</td>
</tr>
<tr>
<td>Max</td>
<td>24.78</td>
<td>23.82</td>
</tr>
<tr>
<td>Min</td>
<td>22.90</td>
<td>22.73</td>
</tr>
</tbody>
</table>

![Graph 1](image1.png)

![Graph 2](image2.png)
LVC Output, Vthd and Ithd

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vthd %</td>
<td>0.98</td>
<td>0.97</td>
<td>0.92</td>
</tr>
<tr>
<td>Ithd %</td>
<td>14.07</td>
<td>12.94</td>
<td>28.84</td>
</tr>
<tr>
<td>PF</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Voltage Unbalance</td>
<td>0.51%</td>
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<td></td>
</tr>
</tbody>
</table>
EPRI Lab Tests of Another LVC
Test Setup for Tests 1 – 6: Efficiency vs. Loading and Steady-State Line Voltage

- T1: Efficiency Load 25%
- T2: Efficiency Load 50%
- T3: Efficiency Load 75%
- T4: Efficiency Load 100%
- T5: Low SS Voltage
- T6: High SS Voltage
- T7: Sags & Interruptions
- T8: Swells
- T9: Single-Phasing
- T10: Combo Wave

120/208V 60Hz

Input CT

Output CT

LVC

PQ Meter

Waveform recorder

Computer

Spectrophotometer

Phase A TB Light Load

Phase B TB Light Load

Phase C TB Light Load

EPRI Lighting Load Rack

Amplifier

Input Power Meter

Ballast Analyzer

Ballast

1 amp

Lighting Load 60th Lamp-Ballast

Integrating Sphere
Photos of Fixture Load Bank
More Photos

Tri-Mode Sage Generator

Integrating Sphere

Meter on Sag Generator Showing 120-volt Source

Meter on Sag Generator Showing 208-volt Source
More Photos

Lighting Rack with Voltage Amplifier and Sag Generator

Measurement Screen on PQ Parameter Meter

Original T8 Electronic Ballast were not compatible Inside Fixtures

Lamp & Ballast Analyzer Used with Photometric (Sphere) Tests
Initial Waveforms from EPRI test (from original ballasts that were in fixtures)

85% Setting

68% Setting

Heavy Flicker from Lights

No energy savings were noted with original ballasts.
Triad Universal Ballast Test with LVC
Worked fine with RESD

New Ballast Used: Universal 120V

Voltage

Volts 1Ø

0  100  200
-100  0  100

mSec

2.09  4.18  6.27  8.36  10.45  12.54  14.63

Current

68% Setting

Amps

0  1  2

-1  -2

mSec

2.09  4.18  6.27  8.36  10.45  12.54  14.63

Current

Amps

0.0  0.1  0.2  0.3  0.4  0.5

DC  2  4  6  8  10  12  14  16  18  20  22  24  26  28  30

Harmonic

1  3  5  7  9  11  13  15  17  19  21  23  25  27  29  31
Triad Universal Ballast Test with LVC

Input Voltage: Energy Savings Off

Input_15% Savings

Output_15% Savings
Example with Sylvania Ballast with LVC
Worked fine with RESD

New Ballast Used: Sylvania
Quicktronic 120V

68% Setting

![Graph showing voltage, current, and harmonic data for Sylvania Ballast with LVC at 68% setting.](image)
Sylvania Ballast with LVC

Input Voltage: Energy Savings Off

Input @ 15% Savings Setting

Output @ 15% Savings Setting

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Lighting Controller RESD : Bypass
(single-phase reading)

- This test was with Sylvania ballasts only – 30 installed on 1 phase to load near max
- Single-phase reading shown
  - (can extrapolate to 3 phase)
- The unit was operated in bypass for 30 minutes to allow light stabilization, then data was recorded
- The fluke snapshot was taken 15 minutes after stabilization, or in the middle of the test.
- Total power is shown at 2.22kW in Phase A
Lighting Controller RESD: Savings Mode Engaged (single-phase reading)

- At this point the unit was placed in savings mode (targeted for 15% Savings)
- After the savings was programmed into the PRC 3000, the unit was allowed to operate for 30 minutes to allow stabilization
- The fluke files show the input to the PRC 3000 15 minutes after stabilization.
- Total power is shown at 1.93kW in Phase A
Lighting Controller RESD Savings Achieved (single-phase reading)

- RESD Bypassed
  - 2.22kW Consumed in Phase A
- RESD Engaged
  - 1.93kW Consumed
- Savings
  - 0.290 kW on Phase A
  - This is a realized savings of 13.06%
- Total Savings (3-phase)
  3 phase*0.290kW/phase = 0.87kW
Example LVC Testing by Eaton

100% Setting
100% Power

90% Setting
100% Power

62% Setting
95% Power

60% Setting
90% Power

56% Setting
85% Power
Adjustment of Output by Moving Firing Angle of SCRs

1. Sliders move from 0 to 100%
2. Adjust sliders until the fixture flickers
3. “Tweak” back up until flickering stops
4. This is the operating point for max power savings
Results from LVC Type 2 with Triad Ballast

<table>
<thead>
<tr>
<th>Data Attribute</th>
<th>Bypass</th>
<th>Enabled</th>
<th>Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max</td>
<td>1.67</td>
<td>1.34</td>
<td>20%</td>
</tr>
<tr>
<td>Min</td>
<td>1.65</td>
<td>1.34</td>
<td>19%</td>
</tr>
<tr>
<td>Average</td>
<td>1.66</td>
<td>1.34</td>
<td>19%</td>
</tr>
</tbody>
</table>
Results from LVC Type 2 with Sylvania Ballast

<table>
<thead>
<tr>
<th>Data Attribute</th>
<th>Bypass</th>
<th>Enabled</th>
<th>Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max</td>
<td>1.64</td>
<td>1.48</td>
<td>10%</td>
</tr>
<tr>
<td>Min</td>
<td>1.63</td>
<td>1.47</td>
<td>10%</td>
</tr>
<tr>
<td>Average</td>
<td>1.64</td>
<td>1.48</td>
<td>10%</td>
</tr>
</tbody>
</table>
Example Lighting Output Change to Achieve Savings
Output Voltage from Two Separate LVCs

**Type 1: Input Side of RESD**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>LCV</th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>(V_{ind}%)</td>
<td>0.99%</td>
<td>0.97%</td>
<td>0.92%</td>
<td></td>
</tr>
<tr>
<td>(I_{ind}%)</td>
<td>14.07%</td>
<td>12.94%</td>
<td>28.84%</td>
<td></td>
</tr>
<tr>
<td>PF</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td></td>
</tr>
</tbody>
</table>

Voltage Unbalance 0.51%

Lowers Voltage and Keeps Fairly Sinusoidal

**Type 2: Input Side of RESD**

Lowers Voltage by Chopping Out Part of Waveform (like Dimmer)

Output Voltage Of RESD

Setting
LVC DEMO – Adjustment of Setting for Maximum Savings

• Scenario: Measure baseline load without savings, then adjust settings to lower power requirements.
• Test setup includes:
  – 3-phase 208V LVC
  – Using 1 phase only
  – 4 fixtures with (2) T8 lamps each
  – 2 separate ballast types
• Fluke 41 Harmonics Power Harmonics Analyzer used to measure power
• LVC connected through a switched outlet strip
Measurements (paste screen shots)

- Base-Line Load
- Max Savings Ballast Type 1
- Max Savings Ballast Type 2
- Max Savings Mixed Ballasts
First Order Calculation of Total Energy Savings Based 60 Amp Unit Tested in EPRI Lab

- Simple Payback = Net Investment/Net Annual Return
  - Tennessee Rate of $0.09/kWh
    - Net Investment = $3,700
      - (60 Amp, 3 Phase Unit @ 20A/phase)
    - Net Annual Return = 365 days/year X 24 hours/day X $0.09/kWh X 0.87 kW = $686/year
    - Payback = $3,700/ $686/year = 5.9 Years
  - California Rate of $0.16/kWh
    - Net Investment = $3,700
    - Net Annual Return = 365 days/year X 24 hours/day X $0.16/kWh X 0.87 kW = $1219/year
    - Payback = $3,700/ $1219/year = 3.0 Years

- Note – Payback on a larger unit could be shorter as economies of scale would take place.
Lessons Learned

• LVC RESDs can exhibit savings on lighting systems.
  – 4% to 25% measured in tests
• Check first that your ballast types are compatible with the RESDs.
  – For LVC Type 2, we had to change out 60 ballasts
  – Bought low cost fixture and ballasts via Home Depot (shop light)
• When a site has a mixture of ballasts, it may be difficult to obtain max savings
  – In our lab tests we obtained around 9% with two types of ballasts installed instead of 15%
Discussion

• What applications make sense for LVCs?

• Are all ballasts compatible?
  – Some do not work with universal ballasts while others do

• Work closely with LVC vendor to make sure your ballasts are compatible.
  – Could require change out of a few non-compatible ballasts
7.0 Voltage Regulation RESD Devices
Conservation Voltage Reduction

- In the early 1970’s, U.S. electric utilities began practicing automated voltage reduction of the distribution system voltage via their System Energy Control Center computers such as SCADA.
- The purpose at first was to control the system MW Demand during periods of emergency power supply conditions.
- It also was used when short term high peak loads occurred due to unusual weather related conditions that sent the system peak demand beyond the generating capacity to meet that demand.
- This is what the utilities do; age old practice, primarily geared towards demand reduction, but also saves energy.
- “In the Pacific Northwest, CVR has the potential to achieve energy savings in the range of 0.5 - 1.0 % energy savings per % voltage reduction executed” Source BPA
Utility Side CVR (Green Circuit Initiative)

- Utilities typically set load tap-changing transformers (LTCs) at distribution substations or feeder regulators to ensure that end-of-feeder voltages are maintained within acceptable levels during peak load periods.
- This is generally accomplished by centering the LTC at a voltage above nominal voltage in the range of 122 V to 124 V, with a bandwidth of +/- 2 to 3 V.
- For many hours during the year when the load is much less than peak, the voltages across the circuit are well above minimum criteria and may actually be higher than the nominal 120 V.
- As a result, significant energy reductions may be achievable through CVR without reducing utilization voltages to the minimally acceptable 114 V.
ANSI C84.1 Limits

Table 1 – Standard nominal system voltages and voltage ranges

<table>
<thead>
<tr>
<th>VOLTAGE CLASS</th>
<th>Nominal System Voltage</th>
<th>Nominal Utilization Voltage (Note 1)</th>
<th>Voltage Range A (Note b)</th>
<th>Voltage Range B (Note b)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Maximum</td>
<td>Minimum</td>
<td>Maximum</td>
</tr>
<tr>
<td>Low Voltage (Note 1)</td>
<td>120</td>
<td>115</td>
<td>126</td>
<td>114</td>
</tr>
<tr>
<td></td>
<td>240/240</td>
<td>119/220</td>
<td>128/252</td>
<td>114/218</td>
</tr>
<tr>
<td></td>
<td>240/240</td>
<td>214/240</td>
<td>238/278</td>
<td>221/271</td>
</tr>
<tr>
<td></td>
<td>240/240</td>
<td>450/477</td>
<td>584/621</td>
<td>458/583</td>
</tr>
<tr>
<td></td>
<td>240/240</td>
<td>490</td>
<td>594/624</td>
<td>500/593</td>
</tr>
<tr>
<td></td>
<td>240/240</td>
<td>575</td>
<td>630/689</td>
<td>570/635</td>
</tr>
</tbody>
</table>

- The distribution circuit supplies electrical power to the customer at established nominal voltage levels such as 120Vac.
  - This supply voltage may range from 126V to 114V (±6V), in accordance with ANSI C84.1, as measured at Potential Transformers (PTs) on the feeder transformer secondary at the substation.
  - Depending on location and other factors, the utility voltage may swing +10% or -10% during a 24-hr period. According to the ANSI standard C84.1, electrical appliances should be designed to function properly within this range without affecting performance.
Utility Side CVR (Green Circuit Initiative)

- There are specific times of the year in which the loads could be heavy and voltage drops such that the voltage profile could dip to the lower levels.
- The figure shows the simulated minimum voltage from an actual utility circuit modeled as part of the EPRI Green Circuits collaborative project.
- The minimum primary circuit voltage is shown for each hour of the year for the base-case circuit and with the base circuit altered to reduce voltage by altering the station LTC.

Minimum Customer Service Point Voltage Based on a Yearly Simulation
(Base = 125 V LTC Setting, CVR = 122 V LTC Setting)
CVR Basics

• Any savings realized with CVR depends on the nature of the loads involved.
  – Resistive loads such as incandescent lights would use less power due to the relationship \( P = \frac{V^2}{R} \).
  • Electric heaters set to a thermostat, although initially using less power, would be expected to heat for a longer period of time until reaching the desired temperature setting.
  • A significant part of the problem of determining whether or not to use CVR involves determining the nature of the affected loads.
Voltage Regulation RESD Effectiveness Depends on Loads

- Loads may be accurately characterized as a combination of three different load types:
  - **Constant Current** (I):
    - reduced voltage = reduced power;
  - **Constant Impedance** (Z):
    - reduced voltage = reduced current and reduced power;
  - **Constant Power** (PQ):
    - (P is real power and Q is reactive power):
      - reduced voltage = same power and increased current.
- Many appliances involve more than one of these characteristics
  - A dryer for instance has an electric motor (PQ) as well as a resistance heater (Z).
  - The table shows representative load types for common electrical appliances. A correlation may be made between load type and customer type.

<table>
<thead>
<tr>
<th>Load Type</th>
<th>PF</th>
<th>Constant Power %PQ</th>
<th>Constant Impedance %Z</th>
<th>Constant Current %I</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resistance Heater, Water Heater, Range</td>
<td>100</td>
<td>0</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Heat Pump, Air Conditioning, Refrigeration</td>
<td>80</td>
<td>15-35</td>
<td>20-40</td>
<td>45</td>
</tr>
<tr>
<td>Clothes Dryer</td>
<td>99</td>
<td>0</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>Television</td>
<td>77</td>
<td>0</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>Incandescent Lighting</td>
<td>100</td>
<td>45</td>
<td>35</td>
<td>20</td>
</tr>
<tr>
<td>Fluorescent Lighting</td>
<td>90</td>
<td>0</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Pump, Fan, Motor</td>
<td>87</td>
<td>40</td>
<td>40</td>
<td>20</td>
</tr>
<tr>
<td>Arc Furnace</td>
<td>72</td>
<td>0</td>
<td>30</td>
<td>70</td>
</tr>
<tr>
<td>Large Industrial Motor</td>
<td>90</td>
<td>60</td>
<td>40</td>
<td>0</td>
</tr>
<tr>
<td>Large Agricultural Water Pump</td>
<td>85</td>
<td>0</td>
<td>75</td>
<td>25</td>
</tr>
<tr>
<td>Power Plant Auxiliary</td>
<td>80</td>
<td>40</td>
<td>40</td>
<td>20</td>
</tr>
</tbody>
</table>

Example Results from Voltage Regulation RESD

Example Input and Output Real Power Measurements for Resistive, Motor, and Computer PS Load

Voltage Regulation RESD result with 8V Reduction

- Setpoint: -8V, -4V, 0V, +4V
- Real Power (in Watts):
  - Input: 7000, 8279, 8660, 9523
  - Output: 8219, 3617, 9263

- Real Power Consumption (% of nominal):
  - Resistive Load: 87.3%
  - Motor Load: 94.3%
  - Digital Load: 89.8%
  - Combined Loads: 91.3%
Input and Output Trending of Voltage Regulating RESD

- Example input and output data shown for a Voltage Regulating RESD.
- Input voltage varies with utility grid load from around 122V.
- Output voltage regulated around 114.5V.
A note on CFLs vs. Incandescent Lamps

- As home lighting loads transition from incandescent to CFLs, voltage regulation/reduction will not result significant power savings due to lighting alone.
"Mock" CVR Test

- Using a variac to step down the load, we will simulate CVR by lowering the voltage and look at the power requirement of the combined loads.
- Metering upstream of variac near “service entrance”
- A voltage regulating CVR would adjust up or down to try and control at a given setpoint.
“Mock” CVR Test

• Step 1: Set Variac to 100% and energize circuits
• Step 2: Record power measurements
• Step 3: Reduce voltage by 3Volts (roughly 2.5%, 117Vac)
• Step 4: Record power measurements
• Step 5: Reduce voltage another by 3Volts (roughly 5%, 114Vac)
• Step 6: Record power measurements
“Mock” CVR Test Data

Nominal Voltage 2.5% Reduction

5% Reduction
Discussion

• What happens to loads when voltage is lowered?

• Would a different mix of loads make these test results different?
  – How?

• What happens if voltage is lowered further?
Mock “CVR” Test 2 - Adding 300ft #14 between “voltage regulator” and loads

• With the tap remaining at 5% down, add 300ft of #14 extension cord.

• Repower circuit
  – How do the power measurements compare?

• Take voltage measurement at switching outlet #3
  – Is the voltage within C84.1 limits for Range A?
Discussion

• What would happen if Utility also did CVR (also known as Intelligent-Volt Var Control (IVVC) on distribution circuit?

• Would there be an advantage to doing voltage regulation RESDs at the facility service entrance also?
8.0 Conventional Energy Savings Techniques
Conventional and Leading Edge Energy Savings Techniques

- Use of Energy Efficient Motors
- Use of ASDs to Save Energy
- Energy Efficient Lighting
- Energy Efficient Appliances
- Consumer Electronics

*Poor Utilization of Energy is like throwing money down the toilet*
Use of Energy Efficient Motors
Electric Motors

- Different kinds of motors
  - AC Motors
    - Induction motor
    - Synchronous motor
      - Synchronous Wire Wound
      - Permanent Magnet Synchronous Motor
      - Brushless DC Motor
      - Synchronous Reluctance
  - DC Motors
- Most popular electric motor is the induction motor (especially three-phase)
Electric Motor Use

• The DOE estimates that there are about 12.4 million motors of more than 1 hp in service in U.S. manufacturing facilities.

• The Consortium for Energy Efficiency (CEE) reports that about 2.9 million of these motors fail each year, of which 600,000 are replaced.

• According to DOE estimates, potential industrial motor system energy savings, using mature, proven, cost-effective technologies range from 11-18 percent of current annual usage or 62 to 104 billion kWh per year in the manufacturing sector alone.
  – Savings is valued up to $5.8 billion.
  – Would also avoid the release of up to 29.5 million metric tons of carbon equivalent emissions to the atmosphere annually.

DOE, 1998
Electric Motor Use

• Industrial electric motor driven systems used in production account for about 679 billion kWh, or about 23% of all the electricity sold in the USA

• Motors used in industrial space heating, cooling and ventilation systems use an additional 68 billion kWh, bringing total industrial motor system energy consumption to 747 billion kWh

• Motor efficiency upgrades can achieve potential savings of about 19.8 billion kWh per year

• Improved methods of rewinding failed motors can contribute an additional 4.8 billion kWh

• Energy savings from system efficiency improvements are potentially much larger: 37 to 79 billion kWh per year
Electric Motor Use

• Process motor systems account for 63% of all electricity used in industry
• Most motors are at least 30% under loaded
• A third of motors are run below 50% load


Motor Decisions Matter web site

"Introduction to Premium Efficiency Motors" - by the Copper Development Association
Induction Motor Losses (1)

- Induction Motor Losses
  - Power Loss
  - Magnetic Core Loss
  - Friction and Windage Loss
  - Stray Load Loss

<table>
<thead>
<tr>
<th>Type of Loss</th>
<th>Typical % of Losses 4-Pole Motors</th>
<th>Factors Affecting These Losses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stator winding losses</td>
<td>35 to 40</td>
<td>Stator conductor size and material</td>
</tr>
<tr>
<td>Rotor losses</td>
<td>15 to 20</td>
<td>Rotor conductor size and material</td>
</tr>
<tr>
<td>Stator core losses</td>
<td>15 to 20</td>
<td>Type and quantity of magnetic material</td>
</tr>
<tr>
<td>Stray load losses</td>
<td>10 to 15</td>
<td>Primarily manufacturing and design methods</td>
</tr>
<tr>
<td>Friction and windage</td>
<td>5 to 10</td>
<td>Selection/design of fans and bearings</td>
</tr>
</tbody>
</table>

Reference: NEMA Std. MG 10-1994, Table 2-2

The above values show the typical loss distribution for medium induction motors. Speed, size, and enclosure type lead to wide variations in some of these proportions, particularly the core and friction and windage losses.

"Introduction to Premium Efficiency Motors" - by the Copper Development Association

Induction Motor Losses (2)

• Power losses (also called I²R losses) and stray load losses appear only when the motor is operating under load
• Power losses are comprised of stator and rotor I²R losses
  – They are therefore more important — in terms of energy efficiency
  – Stator losses may make up to 66% of power losses
• Magnetic losses can account for up to 20% of total losses
Typical Induction Motor Efficiency

Improving Induction Motor Efficiency (1)

WHAT MAKES AN ELECTRIC MOTOR ENERGY EFFICIENT?

- More copper wire of larger diameter in the stator saves energy by reducing the resistance of the stator winding.
- Thinner steel laminations decrease eddy current losses.
- Larger conductive bars and end rings reduce rotor resistance losses.
- Modified stator slot design helps to decrease magnetic losses and makes room for larger diameter wire.
- Efficient cooling fan design improves airflow and reduces power required to drive the fan.
- Longer stator lowers magnetic density and increases cooling capacity. As a result, both magnetic and load losses are reduced.
- Premium grade steel core reduces hysteresis power losses.
Efficiency Opportunity Through Motor Rewinding

- Traditional fast rewinding can decrease efficiency by 20%
- Since motors are frequently operated for 20 to 30 years, a motor may be repaired 3 to 5 times in its service life
- For every new motor sold, approximately 2.5 motors are repaired
- Improper rewinding can significantly decrease motor efficiency (actual numbers vary from source to source, but in the range of 5-20%)
- Sophisticated rewind can increase efficiency
- Improved methods of rewinding failed motors can contribute an additional 4.8 billion kWh (DOE, 1998)

Guidelines for maintaining motor efficiency during rebuilding, Electrical Apparatus Service Association (EASA), 1999
Induction Motor Energy Opportunities Summary

• Use of copper rotors can decrease rotor losses
• Use of thinner laminations may decrease magnetic losses
• Use of better steel lamination materials
• Careful motor selection based on load
• Proper operation – balanced supply, less voltage harmonics…
• Specialized rewinding can improve efficiency
• The next step – Super Premium Efficiency Motors
• Large scale improvements also possible in single-phase induction motors
Use of ASDs to Save Energy
Constant Speed Control

- Equipment is typically oversized to meet most extreme system requirements
- Motors are upsized to the nearest horsepower about the required for the oversized equipment
- In most cases, full performance is not required by the system
- The motor is usually in continuous full speed operation.

Running a motor at full speed wastes energy ($$$) when full output is not required by the process.
Constant Speed Control Example

- **3Φ, 60 Hz 460 Volt Source**
- **Flow Element**
- **FIC**
- **Control Valve**
- **Flow**
- **Motor**
Motor Driven Process Using Flow Control Valve
**Constant Speed**

Pump must overcome Pressure Losses due to mechanical valve

Power Source

**Motor**

Efficiency 0.90

Efficiency 0.75

**Required HP = 100**

\[
\text{Input kW} = \frac{\text{HP} \times 0.746 \text{ kW}}{0.9 \times 0.75}
\]

\[
\text{Input kW} = \frac{100 \times 0.746}{0.9 \times 0.75} = 110.5 \text{ kW}
\]
Adjustable Speed Control

- Valves, clutches, brakes, and dampers typically adjusts the output of the equipment, wasting energy to varying degrees.
- Variable Speed Drives (a.k.a. Adjustable Speed Drives (ASDs)) save energy by modulating the output of the motor to satisfy the changing system requirements.

ASDs Allow for Energy Efficient Control of Process Outputs
Adjustable Speed Control Example

3 Φ, 60 Hz
460 Volt Source

FIC

Flow Element

Flow

Variable Speed Pump

Motor
Adjustable Speed

Input kW = HP x 0.746 kW
System Efficiency

Input kW = 34.4 x 0.746 = 40.75 kW
0.93 x 0.9 x 0.75
Example Losses In System Elements With Mechanical Control Versus ASD Control at four load levels
Use of ASDs on Chillers

An OptiSpeed drive is the single largest energy-saving retrofit you can apply to your chiller plant.

From York Optispeed Literature
(1-3 year payback)
Screening Methodology
Screening Methodology

• Good Candidate for ASD if:
  – High Annual Operating Hours
  – Variable Load Characteristics
  – Moderate To High Horsepower Rating
Required Information

• Motor Horsepower Rating
• Annual Equipment Operating Hours
• Fraction of Time Operate at Less Than Rated Load
• Amount of Flow Variation
Load Duty Cycle

Example of an Excellent ASD Candidate

Percent Rated Flow vs. Percent Operating Hours
Load Duty Cycle

Example of a Moderate ASD Candidate

Percent Operating Hours

Percent Rated Flow

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Load Duty Cycle

Example of a Poor ASD Candidate

Percent Operating Hours

Percent Rated Flow

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Energy Efficient Lighting
Potential Lighting Energy Savings Opportunities

• Fluorescent Upgrades
• De-Lamping
• Incandescent Upgrades
• HID Upgrades
• Controls Upgrades
• Daylight Compensation

Ref: aee CEM training material
Three Major Areas for Lighting Improvement

I. Replace Incandescent lamps with fluorescent or compact fluorescent lamps (CFLs)
II. Upgrade fluorescent fixtures with improved components
III. Install lighting controls to minimize energy costs

Ref: aee CEM training material
Application of Compact Fluorescent Lamps

• Task lights
• Downlights
• Wallwashers
• Outdoor fixtures
• Exit lights
• Dimmable for use in home or conference room
• Refrigerators and freezers
Opportunities in End Use Energy Efficiency: Compact Fluorescent Lamps

• Savings from replacing all incandescent bulbs with CFLs in a US household: \(~1200\) kWh/yr

• Savings nationwide if all households switched:
  – Total residential electricity consumption reduced by \(~10\)%
  – US electricity consumption reduced by \(~3.7\)%

>113 million US households

CFLs use \(\frac{2}{3}\) to \(\frac{3}{4}\) less than incandescent bulbs
Upgrading Fluorescent Fixtures

- Improved fluorescent lamps
  - T-8, T-10, T-12 Tri-phosphor lamps
  - New T5 Lamps
  - New Induction Lamps
- Electronic Ballasts
  - Standard non-dimmable ballasts
  - Consider dimming ballasts
  - New programmable ballasts
- Reflectors

Ref: aee CEM training material
Fluorescent Retrofits

- Existing System: T12 lamps with Magnetic Ballasts
- Retrofit Alternatives:
  1. T12 low wattage lamps (34W) – replace lamps only
     - Less light, less energy consumption
  2. T8 (32W) – replace lamps and ballasts
     - Same light, less energy consumption, better color, rendering, less map flicker, less ballast hum
     - Can operate 4 lamps per ballast
     - Can be tandem wired
     - Electronic ballasts can be parallel wired

Ref: aee CEM training material
Fluorescent Retrofits

3. T10 (42W) – replace lamps only
   • More light, same energy consumption
4. T10 (42W) – replace lamps and ballasts
   • Much more light, same energy consumption, same benefit as T8’s
5. T5 (28W) – replace lamps and ballasts
   • Same light, less energy consumption than T8’s
6. New 28W and 30W T8’s now available
   Super T8s with 3100 Lumens (32W)
7. New 25,000 and 30,000 hour life lamps available with use of programmable start ballasts matched to lamps

Ref: aee CEM training material
New Lighting Technologies

• Induction lamps
  – Long Life --- 100,000 hours for lamp and ballasts
  – Philips QL lamps in 55W, 85W, and 165W
  – New application with reflector to replace metal halides as signs lights for road and commercial signs.
  – Lasts four times as long

Ref: aee CEM training material
New Technology - LED lighting

• 80% of all new exit lights are LED Lights
• Other uses:
  – Traffic Signals
  – Commercial Advertising Signs
• EPRI is working on LED street light demonstration project
Basic and Advanced LED Lighting Technologies

Fewer Light Rays Exit the Lens
- Gold Wire Bond
- Small LED Chip
- Reflector Cup
- Anode Lead
- Combined therm conductive paths
- Cathode Lead
- Short Life Epoxy Dome

Basic Technology
Lower Efficiency

More Light Rays Exit the Lens
- Enhanced lens & optics
- Separate thermal and conductive paths
- Cathode Lead
- Gold Wire
- Heat Sink Slug
- Silicone Encapsulant
- Larger die capacity InGaN Semiconductor Flip Chip
- Silicon Sub-mount Chip with ESD Protection
- Plastic Lens

Advanced Technology
Higher Efficiency

Courtesy: Philips Lighting
Efficacies of Different Common Light Sources

*Incandescents, Fluorescents, HID, and LEDs*

We are at the beginning of the most significant improvements in efficiency
## Comparison of LED and HID Lighting

<table>
<thead>
<tr>
<th>HID Lamp</th>
<th>HID Photopic Initial Delivered Lumens</th>
<th>HID Photopic Average Delivered Lumens</th>
<th>HID System Watts</th>
<th>LED Recommended Number of Light Bars</th>
<th>LED Photopic Initial Delivered Lumens</th>
<th>LED Photopic Average Delivered Lumens Over 50,000 hours</th>
<th>LED System Watts</th>
<th>LED Energy Savings %</th>
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<tbody>
<tr>
<td>PS 70 (H)</td>
<td>3,500</td>
<td>2,200</td>
<td>90</td>
<td>2</td>
<td>3,400</td>
<td>3,230</td>
<td>55</td>
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<tr>
<td>PS 100 (H)</td>
<td>5,650</td>
<td>3,550</td>
<td>127</td>
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<tr>
<td>PS 150 (V)</td>
<td>9,800</td>
<td>7,200</td>
<td>190</td>
<td>4</td>
<td>6,800</td>
<td>6,460</td>
<td>104</td>
<td>-45%</td>
</tr>
<tr>
<td>MH 175 (V)</td>
<td>9,800</td>
<td>6,300</td>
<td>210</td>
<td>4</td>
<td>6,800</td>
<td>6,460</td>
<td>104</td>
<td>-51%</td>
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<tr>
<td>MH 250 (H)</td>
<td>13,250</td>
<td>8,300</td>
<td>289</td>
<td>5</td>
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<td>8,075</td>
<td>128</td>
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<tr>
<td>PS 320 (H)</td>
<td>21,000</td>
<td>15,500</td>
<td>368</td>
<td>7</td>
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<td>11,305</td>
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<tr>
<td>MH 400 (H)</td>
<td>22,700</td>
<td>14,500</td>
<td>455</td>
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<td>15,300</td>
<td>14,535</td>
<td>232</td>
<td>-49%</td>
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<tr>
<td>PS 400 (H)</td>
<td>28,000</td>
<td>22,000</td>
<td>450</td>
<td>12</td>
<td>20,400</td>
<td>19,380</td>
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<tr>
<td>HPS 70</td>
<td>4,450</td>
<td>3,900</td>
<td>105</td>
<td>2</td>
<td>3,400</td>
<td>3,230</td>
<td>55</td>
<td>-48%</td>
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<tr>
<td>HPS 100</td>
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<td>6,050</td>
<td>130</td>
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<td>10,100</td>
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<tr>
<td>HPS 250</td>
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<td>19,000</td>
<td>300</td>
<td>6</td>
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<td>9,690</td>
<td>153</td>
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<tr>
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<td>9</td>
<td>15,300</td>
<td>14,535</td>
<td>232</td>
<td>-50%</td>
</tr>
</tbody>
</table>

Ref: Beta-Kramer
The Case For LED Lighting

- Costs associated with the operation and maintenance of street and area lighting (SAL) continue to escalate in accordance with energy and labor costs.
- Traditional SAL systems use magnetically-ballasted high-intensity discharge (HID) fixtures that have low efficiency, and relatively short lamp-life making necessary frequent service visits to change bulbs.
- Magnetic HID systems do not provide real-time diagnostics regarding lamp and ballast operating conditions and life and thus require expensive drive-by inspection to determine functionality of the fixture, ballast, and lamp.
The Solution

• There is a move across the United States to replace existing HID street lighting systems; mercury vapor, high pressure sodium (HPS) or metal halide (MH) lamps.

One possible replacement is LED-based lighting made possible by recent advances in LED technology.

LEDSAL Luminaires Have the Potential to:
• Lower energy consumption
• Provide high quality color rendition
• Lower maintenance costs
• Reduce light pollution
The Issues

• System Compatibility – are manufacturers covering all the bases:
  – Susceptibility to transients, surges and sags
  – Impact on grid power quality
• New Technology – are utilities ready to accept LEDSAL:
  – Understand application
  – Documented real world performance
  – Overcome acceptance hurdles
• The claims – hard data is needed to validate industry performance claims:
  – Long life leading to lower maintenance costs
  – Better color quality
  – Lower energy cost
LED Lighting is also a System Approach—Efficiency is Important at Every Level

**Tertiary optics**
Plastic tertiary optics can be designed to provide any desired light distribution pattern.

**Collimators**
Injection molded plastic collimators maximize light collection from LEDs (over 90% optical efficiency) and offer a wide choice of beam widths.

**Clustered LED arrays**
Clustered high brightness LED modules assembled onto a metal core printed circuit board. Reliable connections provide mechanical sturdiness and good electrical and thermal conductivity.

**Heat sink**
Heat management for optimal system efficiency.

**Driver**
DC current power supply with any control functionality possibilities.
LED* for Street and Area Lighting

Metal Halide vs THE EDGE™


LED – Light Emitting Diode, a semiconductor material that when energized emits light.
Light Patterns and Color Vary
Thermal Properties Vary
Energy Efficient Appliances
Selecting **new equipment** being released in 2009 with innovative technology/design features

U.S. models **up to 33% better** than federal standard

GE Profile (shown top right) and Samsung Quattro (bottom left) both with **inverter-driven compressors**

Maytag (Whirlpool) models (top left), 22 cu. ft.; more efficient compressor; **other energy saving features**
Selected **new equipment** released in September 2009 of highest efficiency with innovative technology/design features

Washer and dryer as system

**WASHER:**
Modified energy factor (MEF) of 2.64 (≥2.20 is CEE Tier 3); the higher the number the better

Water factor (WF) of 3.4 (≤4.5 is CEE Tier 3); the lower the number the better

**DRYER:**
Emphasis on **new, potentially more efficient dryers** since those on U.S. market are generally same

Test innovative features that may affect energy use. Whirlpool reports that its dryer can save up to 40% of energy for small and standard loads, using advanced algorithms for termination
Heat-Pump Washer/Dryer

• Panasonic's heat-pump drying system..., completely eliminating the need for a heater and water.
• The new drying system dries clothes by exchanging heat via heat-pump unit. As it does not let heat or moisture escape outside the dryer drum, it is highly energy efficient.
• Also, the superior drying and moisture removing capability dries garments more quickly.
• For example, three dress shirts will dry in 20 minutes (one-third of the time) and a bulky blanket in one and a half hours (one-half of the time), compared to other conventional dryers.

"Heat Pump Drying System" dries clothes by exchanging heat through a heat-pump unit, and reduces the consumption of electricity, water and drying time to half compared to conventional washer-dryers.*

Heat-Pump Water Heater

From General Electric (GE)*:
“… half the energy… A savings of approximately 2,500 kWh per year.”

“Save approximately $250 per year— that's $2,500 savings in energy costs over a 10-year period based on 10 cents per kWh.”

Consumer Electronics
Challenges in End Use Energy Efficiency: Consumer Preference & Behavior

• Increase in electricity use by adding a 46” plasma TV: ~600 kWh/yr
  – Wipes out half of ~1200 kWh/yr CFL savings

• Increase in household electricity use from adding set-top box with the plasma TV: ~260 kWh/yr
  – Wipes out another ~20% of savings

What is a consumer most likely to do? Switch to CFLs — or buy a plasma TV on sale?
ENERGY COMPARISONS OF LCD, PLASMA AND CRT TV

Energy Comparisons of 27” CRT, 42” LCD and 42” PLASMA

- 42” PLASMA TV = 24.85 kWh
- 42” LCD TV = 20.15 kWh
- DIFFERENCE = 4.70 kWh
- 27” CRT TV = 9.72 kWh

Energy (Wh)

Time (Days)
Impact of Standards on Efficiency of 3 Appliances

Incentives can be effective: 80 Plus Compliant Models!

80 Plus Efficiency Test Results

% of Nameplate Power Output

% Efficiency

80 Plus requirements

Total Samples = 454
80 + Qualified = 352
9.0 Techniques for Evaluating Vendor Claims
Applying PQ for Energy Savings
Retrofit Energy-Saving Devices

- Typically incorporate common, passive electrical sub-devices
  - Capacitors (Var support, power factor correction)
  - Inductors/chokes/reactors (Dampening of fast current pulses)
  - TVSS: Metal-Oxide Varistors (MOVs, lightning/transient protection)
  - TVSS: Gas tubes (lightning/transient protection)
- Some devices, such as PF Controllers and motor soft starters, are “active”
- Most often pre-packaged, modular systems that are easily added to existing facility electrical systems (i.e. low installation cost, minimal down time)
- Other devices are as simple as a magnet, rectifier, or even a piece of metal
Common Claims

- Improved power factor
- Reduced harmonics
- Improved voltage imbalance
- Reduced electrical current levels
- Cooler device operation
- Prolonged motor and other device life
- Improved voltage level (higher or lower)
- Quick payback
- **Improved energy efficiency**
  - 10%, 20%, or even 30% energy cost reductions are commonly claimed
Marketing Approach

There are huge opportunities for easy energy savings in most facilities

The proposed technology is unique and revolutionary

There are many, many satisfied customers

Energy savings are guaranteed and technology warranted

The vendor will verify savings levels
Our Role as Energy Industry Professionals

• Provide useful insights on the realities of saving energy and on the capabilities of different PQ technologies
• To educate and empower the consumer to make informed decisions
• Provide methods and resources for making informed decisions
• When appropriate, evaluate and test technologies to help inform the marketplace.
Unhelpful Responses

• “It’s nothing but snake oil”
• “It doesn’t work”
• “The company/vendor are crooks”
• “Only an Idiot would buy one of these”
Helpful Responses

- Describe what the technology can probably do well based on its components
- Identify claims that, based on experience, seem extraordinary
- Calibrate expectations on energy savings: Anything greater than 1-2% is extraordinary
- Provide hard data when possible, i.e. test reports, etc.
- Give the consumer a methodology to make informed decisions
- Recommend Independent performance verification
- Recommend ignoring warranties and guarantees
- Support testing where appropriate

After providing this information, back away ... the purchase decision is the consumer's to make.
Evaluating RESD Technologies
A Recommended 4-Step Approach for End Users

Require the **Vendor** to prove:

1) That an energy-savings opportunity exists
2) That there is a clear means available to save the energy identified in (1)
3) That the technology offered by the Vendor effectively implements the means identified in (2)
4) That the Vendor’s proposal is cost effective compared to competing solutions
Example: The justification given for saving energy with transient voltage surge suppression (TVSS)

Progression of justification put forward by a vendor:

1. Facilities are subjected to multiple incidents of over-voltages each day
2. Being subjected to these over-voltages causes end-use equipment to over-heat
3. Over-heated equipment operates less efficiently
4. Installing TVSS will attenuate the over-voltages, thereby reducing over-heating
5. This will result in double-digit percentage energy cost savings
Example: Logic for saving energy with TVSS
Step 1: Quantify the Energy-saving opportunity

Progression of justification put forward by a vendor:

1. Facilities are subjected to multiple incidents of over-voltages each day
2. Being subjected to these over-voltages causes end-use equipment to over-heat
3. **Over-heated equipment operates less efficiently**
4. Installing TVSS will attenuate the over-voltages, thereby reducing over-heating
5. This will result in double-digit percentage energy cost savings
   - *Is equipment really over-heated? If so, by how much?*
   - *What is the specific, quantifiable link between equipment temperature and operating efficiency?*
   - *How can this be measured in the field?*
Example: Logic for saving energy with TVSS

Step 2: Proving that a clear means or mechanism exists to save the “wasted” energy

Progression of justification put forward by a vendor:

1. Facilities are subjected to multiple incidents of over-voltages each day
2. Being subjected to these over-voltages causes end-use equipment to over-heat
3. Over-heated equipment operates less efficiently
4. Installing TVSS will attenuate the over-voltages, thereby reducing over-heating
5. This will result in double-digit percentage energy cost savings
   • To what documented extent do facilities experience over-voltages? What is observed at the terminals of typical end-use equipment?
   • Exactly how and to what extent is end-use equipment over-heated by over-voltages?
   • How can this be measured in the field?
Example: Logic for saving energy with TVSS

Step 3: Does the technology implement the means or mechanism to save the “wasted” energy

Progression of justification put forward by a vendor:

1. Facilities are subjected to multiple incidents of over-voltages each day
2. Being subjected to these over-voltages causes end-use equipment to over-heat
3. Over-heated equipment operates less efficiently
4. Installing TVSS will attenuate the over-voltages, thereby reducing over-heating
5. This will result in double-digit percentage energy cost savings
   • To what extent will TVSS, in general, eliminate the over-voltages?
   • To what extent will the vendor’s technology, as installed, eliminate the over-voltages?
   • Is the level of attenuation sufficient to realize the benefits?
   • How can this be measured and quantified?
Example: Logic for saving energy with TVSS

Step 4: Is the technology cost effective compared with alternatives?

Progression of justification put forward by a vendor:

1. Facilities are subjected to multiple incidents of over-voltages each day
2. Being subjected to these over-voltages causes end-use equipment to over-heat
3. Over-heated equipment operates less efficiently
4. Installing TVSS will attenuate the over-voltages, thereby reducing over-heating
5. This will result in double-digit percentage energy cost savings

- If all else is satisfied, how do I know that I have the most cost-effective solution?
- What other vendors offer TVSS, and is their offering less expensive, regardless of energy-savings claims?
- Is there another, more cost-effective way to lower equipment operating temperatures?
Warranties

- A fine reading of many warrantees for some technologies reveals:
  - **Maximum installation**: Some require a “full installation” of the technology for warrantee coverage to apply.
  - **Long “in service” time**: Many require the technology be in service for at least one full year, and some others require two.
  - **Vendor as Tester**: Some require the measurements and analysis to be made by the vendor.
  - **Extensive data**: Most warrantees require 1 to 2 years of detailed energy use, climate, and production/operations data.
  - **Narrow window**: Some warrantees specify a very narrow window during which claims can be filed, sometimes as short as one month following the “in service” time.
  - **Designated arbitrator**: Some warrantees specify a specific vendor-selected arbitrator. Other specify that the vendor themselves will be final arbiter.
  - **Limited Damages**: Financial claims are often limited to the cost of the installed hardware, NOT the “guaranteed” level of energy cost savings.
Performance Verification after Installation
Quotes from a real proposal

“The performance verification process for the [technology] is included in the cost …”*

“After continuous operation of the [technology] for one full month, customers are requested to provide a complete copy of their utility bill, along with production data, to [the vendor] for a final PQ and energy saving performance review and analysis”*

* Highlighting added for emphasis, Edited portions in brackets.
Beware effects unrelated to the Retrofitted Technology

An Interesting Quote from one Proposal:

“Please keep in mind that it may be necessary to drop the voltage setting one or two taps on a main transformer, in order to maximize the efficiencies to be gained through application of [the retrofit energy saving technology]”*

* Highlighting added for emphasis, Edited portions in brackets.
Bending Data: Paper Mill appears to save over 8 percent on its electric energy bill

• Retrofit of “energy saving” device into an existing facility
• Examine utility bill measurements before and after (“macro” data)
• Use these macro results to support the energy saving claims of new technology (“micro” conclusion)
Bending Data – Paper Plant
Comparing Year 1 kWh to the same months in Year 2
(Before & After Installation of the technology)

Proposed conclusion: The new technology saved this facility over 8% on its energy bill
Further examination of Energy Use: Year 3
(No Further reported change in Technology)

- The further reduction of 447 kWh per month (nearly 10%) is unexplained, and apparently achieved with no installation of additional new technology.

- Based on the techniques used in the original analysis, this plant improved efficiency more by doing nothing than by spending money on a new “energy saving” technology.
Data Bending: Using averages to hide data anomalies

Approach:
• Make a number of “energy-related” measurements, typically “with” and “without” the technology in service
• Rather than comparing the data sets to each other point-for-point, simplify the analysis by calculating the average of each data set
• Compare the averages, and claim any benefits as resulting directly from the new technology
### Bending Data – Fabric Plant
Measurements: Before / After Energy Use

<table>
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<tr>
<th>Batch number</th>
<th>Production (kg)</th>
<th>kWh</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>907</td>
<td>181</td>
</tr>
<tr>
<td>2</td>
<td>911</td>
<td>185</td>
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<tr>
<td>3</td>
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<td>181</td>
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<tr>
<td>8</td>
<td>770</td>
<td>180</td>
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<tr>
<td><strong>Average of data</strong></td>
<td><strong>860</strong></td>
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</tr>
</tbody>
</table>

**Average kWh/kT**: 213

<table>
<thead>
<tr>
<th>Batch number</th>
<th>Production (kg)</th>
<th>kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>901</td>
<td>173</td>
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<tr>
<td>10</td>
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<td>179</td>
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<tr>
<td>16</td>
<td>912</td>
<td>180</td>
</tr>
<tr>
<td><strong>Average of data</strong></td>
<td><strong>879</strong></td>
<td><strong>176</strong></td>
</tr>
</tbody>
</table>

**Average kWh/kT**: 201

**Difference (before/after)**: -6%
Another look at the Data: Baseline

Average (213.3 kWh/ton)
Another look at the Data: “After”

Average
(200.6 kWh/ton)
Statistical Analysis of the Underlying Data

• Comparison of averaged before / after data would appear to indicate a 6% reduction in average energy use, as measured in kWh/kT of product.

• A statistical analysis of the raw data shows
  – The correlation between energy use and production volumes is very low (linear regression model).
  – In fact, less that 1% of the variability of energy use can be attributed to production variations.

• The metric of “kWh/kT” is meaningless and, therefore, worthless as a measure of efficiency or any other calculation.
Data Bending – Packaging Facility
Calculations that don’t add up – Savings Estimates for a packaging plant’s main transformers

• KVA reduction for T1 = $\sqrt{3} \times V \times I$
  = $1.732 \times 480 \times 206$
  = 171 kVA

• KVA reduction for T2 = $\sqrt{3} \times V \times I$
  = $1.732 \times 480 \times 401$
  = 333 kVA

• Finding errors of this type is common
Data Bending – “File Cabinet” testing

Of 100 tests conducted:
93 stay “in the filing cabinet”
7 favorable ones are published

Of 100 tests conducted:
93 stay “in the filing cabinet”
7 favorable ones are published
Using Resources

Federal Trade Commission

• The FTC accepts and tracks complaints about business practices and issues of fair trade
• Consumers: Can register complaints about unsatisfactory business dealing
• Businesses: Can register complaints about unfair competition and business practices
• http://www.ftc.gov/ftc/contact.shtm
Using Resources
FTC Challenges

- No established testing protocols for PQ-based energy saving devices
- Uniqueness of technologies makes apples-to-apples comparisons difficult
- Lack of consumer and business filings makes abuse invisible
FTC Warnings about Energy Savings Claims from application of TVSS

For Release: April 18, 2002

FTC Warns Internet Marketers about Making Misleading Claims about the Benefits of Gas-Saving and Other Energy-Related Devices

Consumers Should be Wary of Questionable Claims

- Transient Voltage Surge Suppressors: Although these products can protect equipment from power surges, in the past the Commission and the states have challenged claims that these products provide significant savings for consumers' energy bills.
Favorite Quotes from over the years

- “The technology doesn’t work in the lab … it only works in the field.”
- “The technology works at very high frequencies, so normal instruments can’t be used to measure it’s benefits”
- “The technology converts reactive power to real power AND power factor is improved.”
- “The technology interacts with the whole system to make it more efficient.”
- “The technology ‘settles in’ over time, so efficiency just keeps getting better and better.”
- “We don’t really know how it works. Not even the inventor knows how it works.”
- “I hate talking to engineers … they ask too many difficult questions.”
“Extraordinary claims, require extraordinary evidence”

-- Carl Sagan
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