Power Factor Correction Solutions & Applications

Rick Orman

Americas Sales Manager

Power Factor Correction/Surge Protection/Power Conditioning

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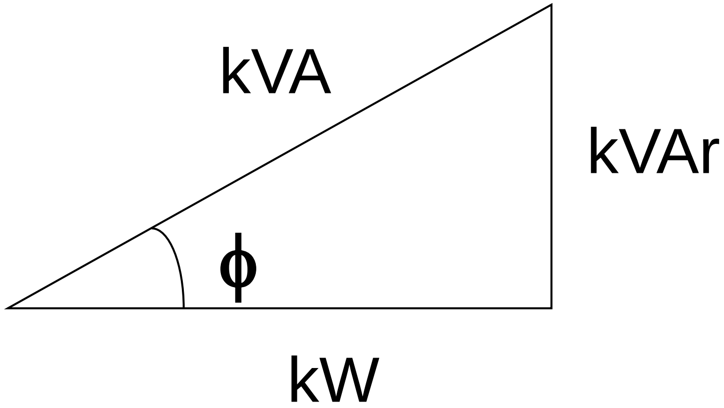
Power factor definition

- Power factor is the ratio between the "real" power and the "apparent" power of an electrical system



- "Real" power = working power = kW
- "Apparent" power = Volts x Amps = kVA
- "Reactive" power = magnetizing power = kVAR

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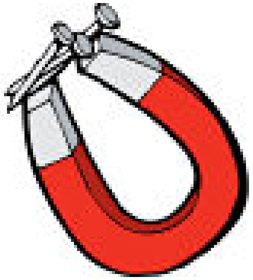
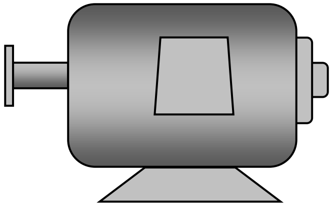
What is a VAR?

- **Active power,** also called **real power,** is measured in **Watts or kW** and performs **Useful Work**
- Electrical equipment like motors and transformers require **reactive power** create a **Magnetic Field** and allow work to be performed.
- This reactive power is called **volt-amperes-reactive or VAR's**
- **Reactive power** is measured in **vars or kvars**
- **Total apparent power** is called **volt-amperes** and is measured in **VA or kVA**





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Somebody has to pay for capacity and losses

Wasted Capacity
(VAR's)

Useful Work
(Watts)

Capacity
(kVA)

Typical Sources of Low Power Factor

- Reactive power is required by many loads to provide magnetizing current for:
  - Motors
  - Power transformers
  - Welding machines
  - Electric arc furnaces
  - Inductors
  - Lighting ballasts

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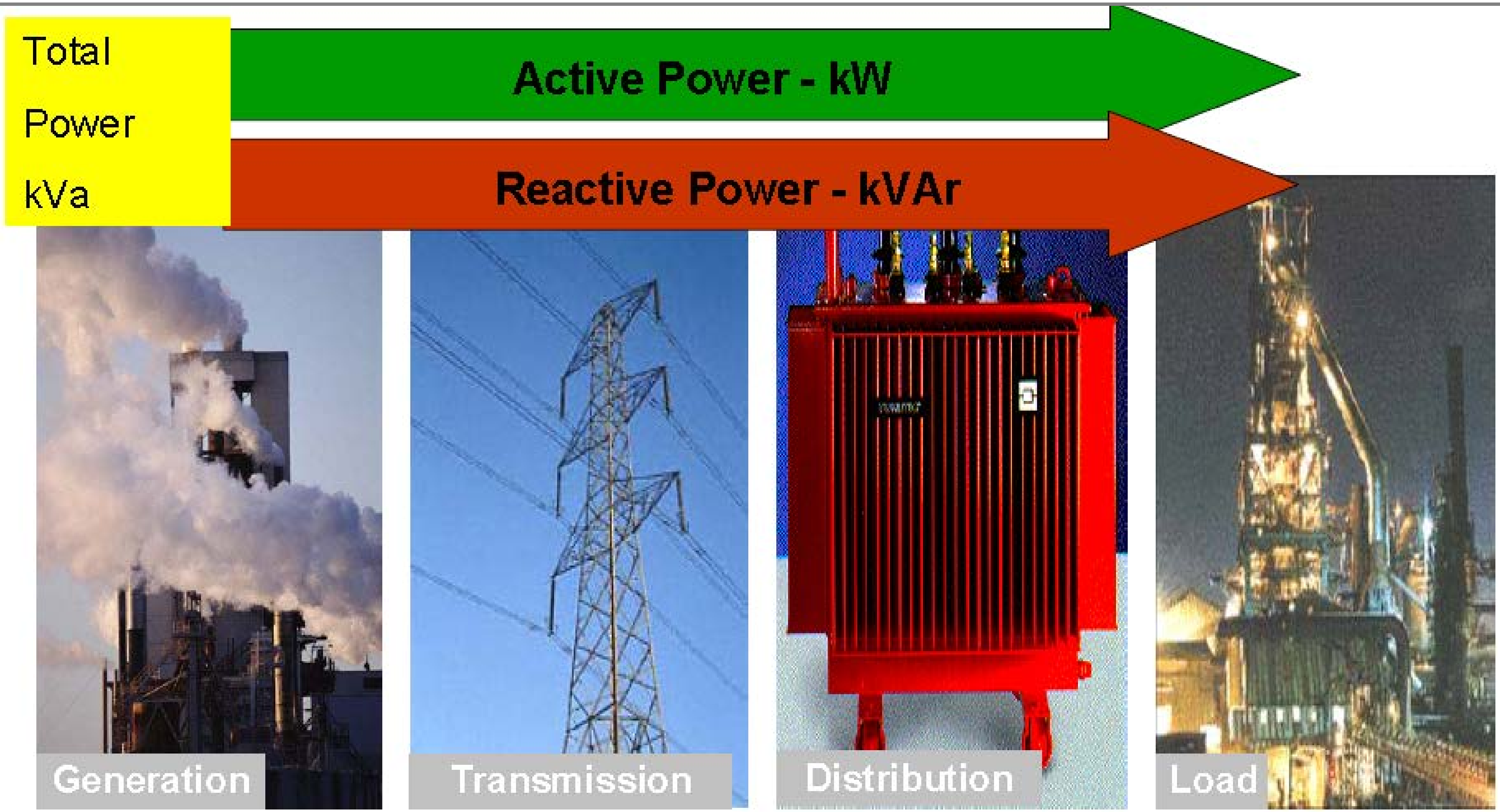
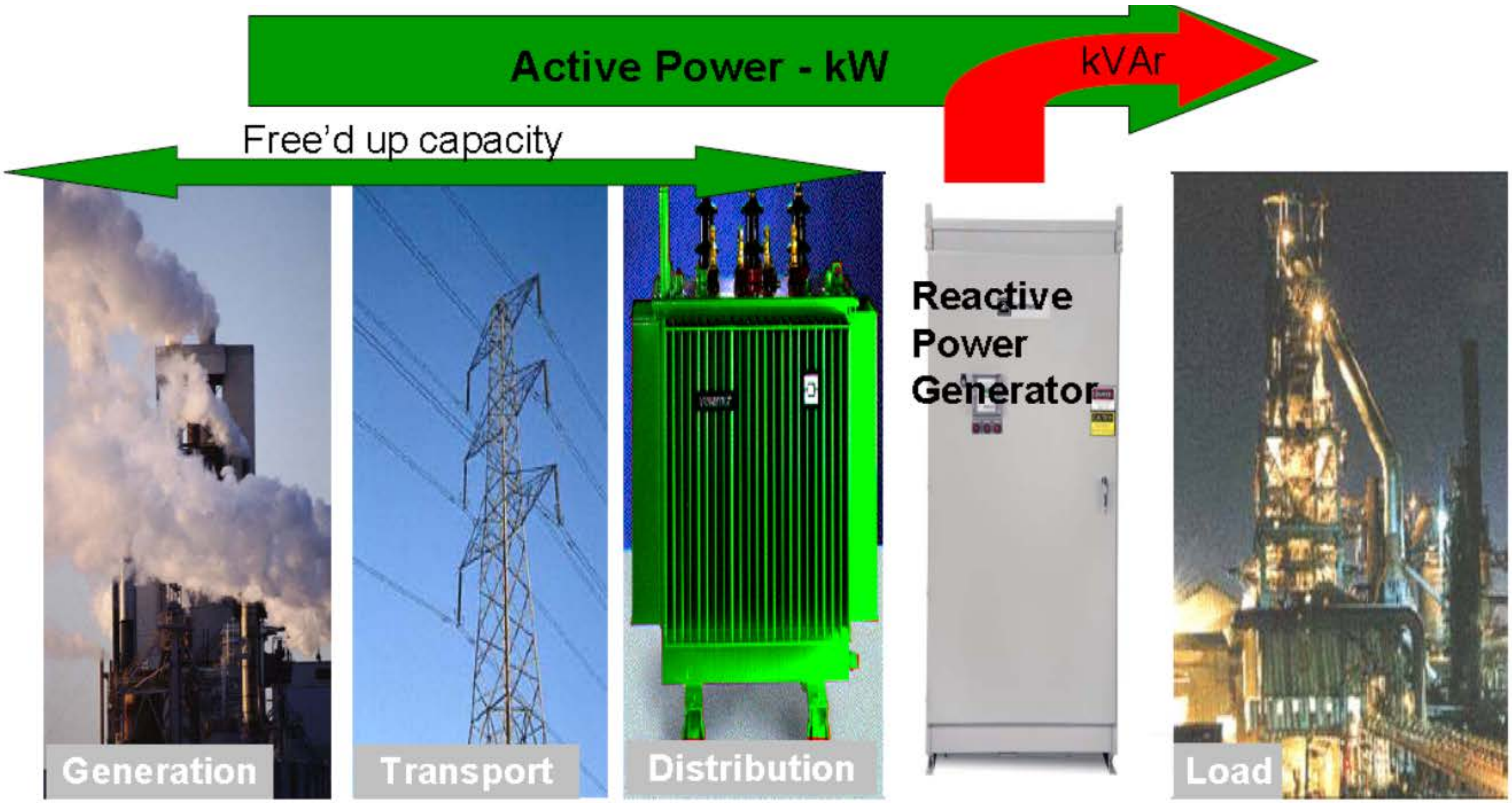
Utility must generate, transmit, and distribute active AND reactive power



If reactive power could come from another source – utility can reduce



What are these magical capacitors?

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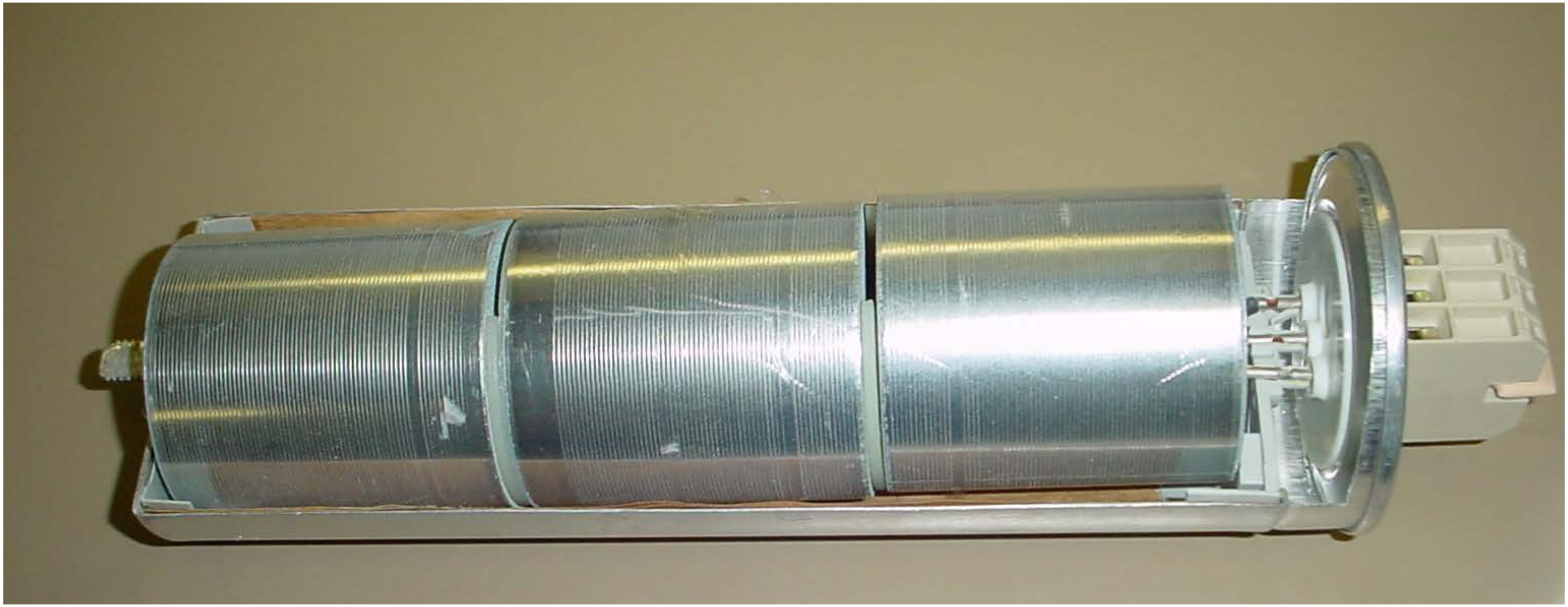

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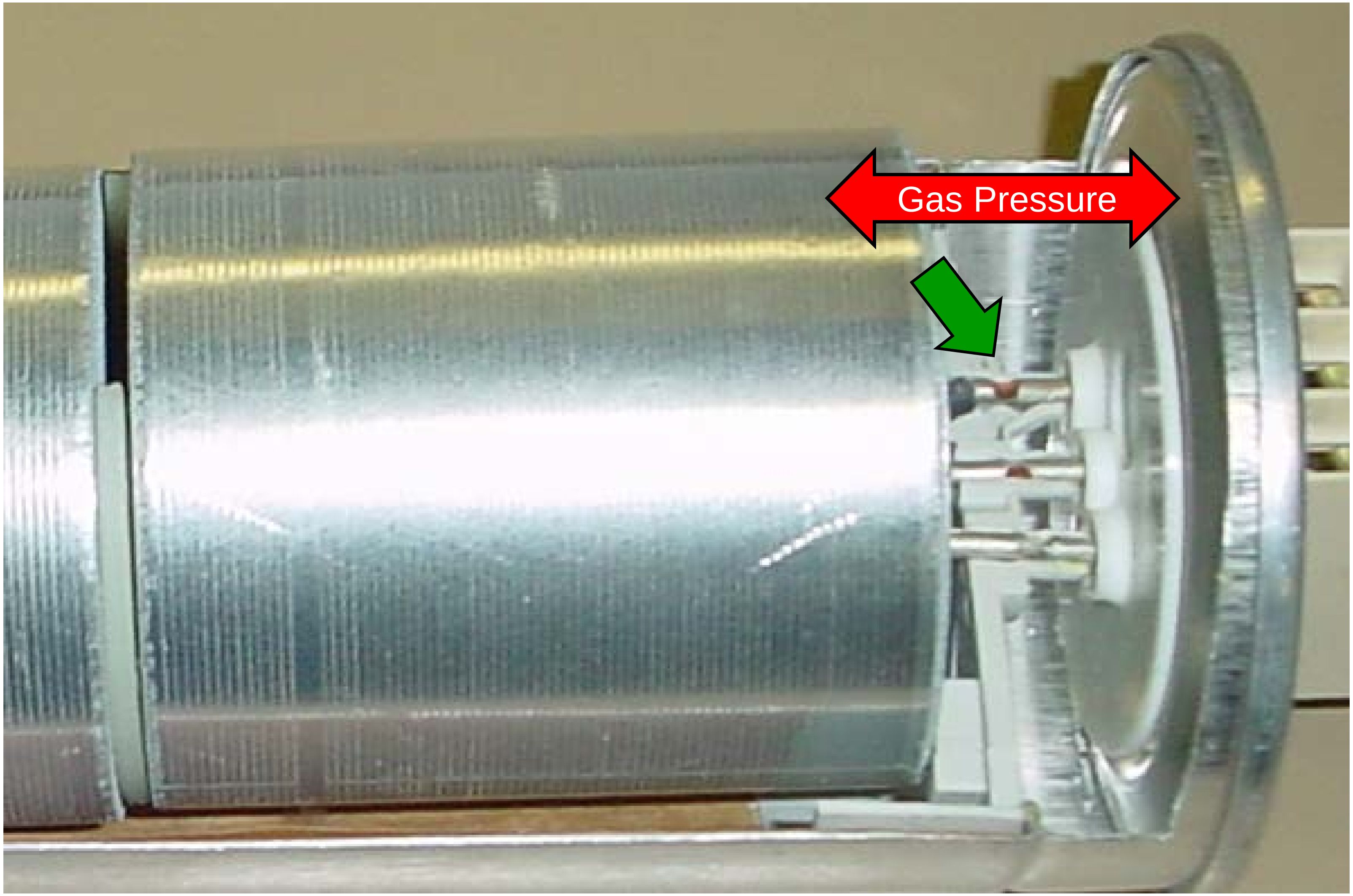
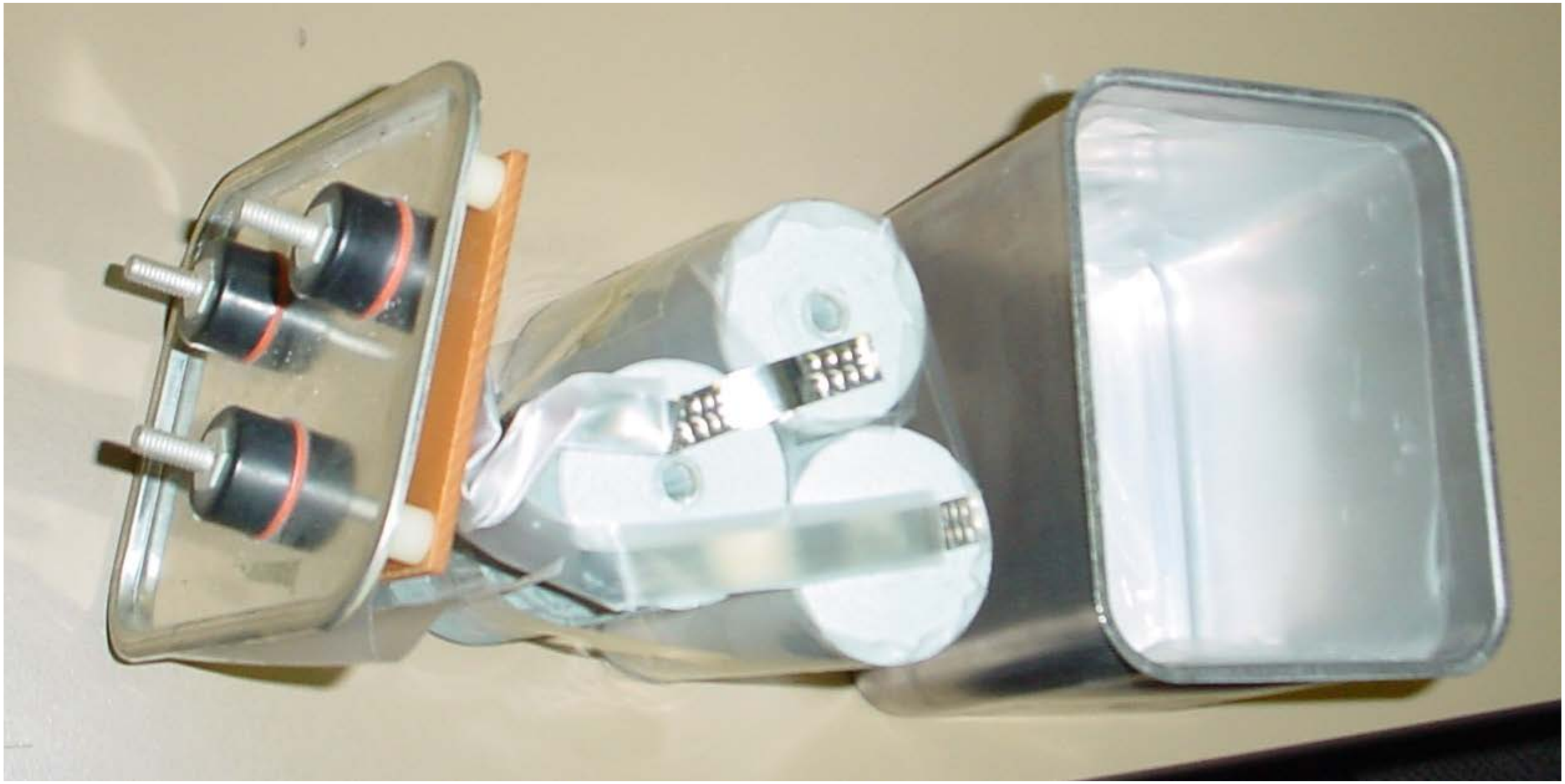


What are these magical capacitors?



Why Consider PFC?

PF correction provides many benefits:

- Primary Benefit:
  - Reduced electric utility bill if there is a penalty

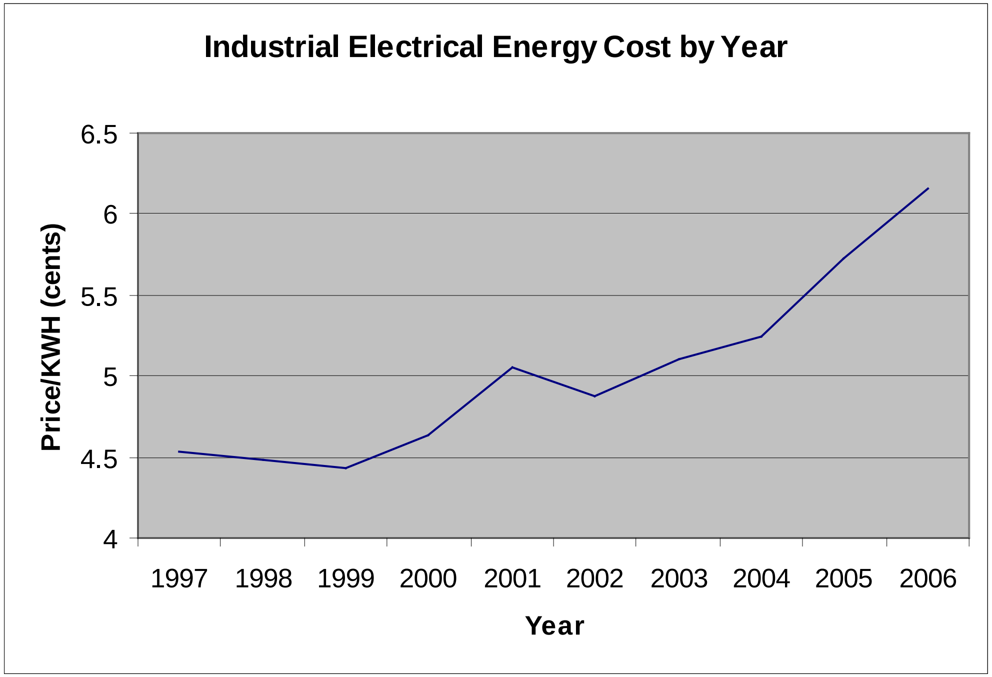
- Other Benefits:
  - Increased system capacity (generators, cables, transformers)
  - Reduced losses in transformers and cables
  - Improved voltage regulation
  - Greening the power system

Where do PF charges appear on a bill?

- Explicit
  - Power Factor Penalty
  - Power Factor Adjustment
  - Power Factor Multiplier
  - Reactive Demand Charge
  - Calculated Demand
  - Billed Demand

Escalation in Electrical Energy Cost

- Electrical Energy cost has increased nearly 50% over the last 10 years
- The rate of increase has accelerated in the past few years
- If your penalty is KW related, such as PF multiplier applied to KW Demand, your penalty amounts will track with Energy Cost.



Source Energy Information Administration

Typical Uncorrected Power Factor

Industry	Percent Uncorrected PF
Brewery	76-80
Cement	80-85
Chemical	65-75
Coal Mine	65-80
Clothing	35-60
Electroplating	65-70
Foundry	75-80
Forge	70-80
Hospital	75-80
Machine manufacturing	60-65
Metal working	65-70
Office building	80-90
Oil-field pumping	40-60
Paint manufacturing	55-65
Plastic	75-80
Stamping	60-70
Steelworks	65-80
Textile	65-75

Source: ***IEEE Std 141-1993 (IEEE Red Book)***

Low PF typically results from unloaded or lightly loaded motors

Unloaded motor – PF = .20

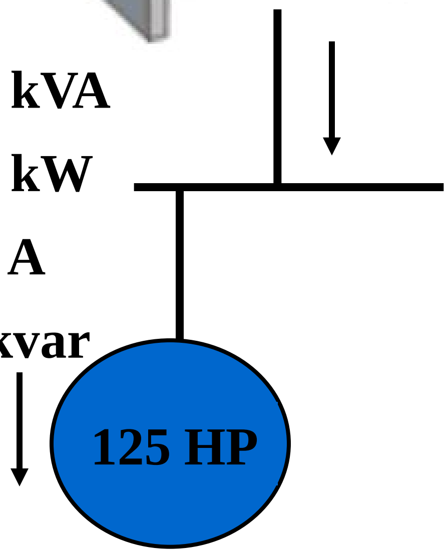
Loaded motor – "rated PF" = .85

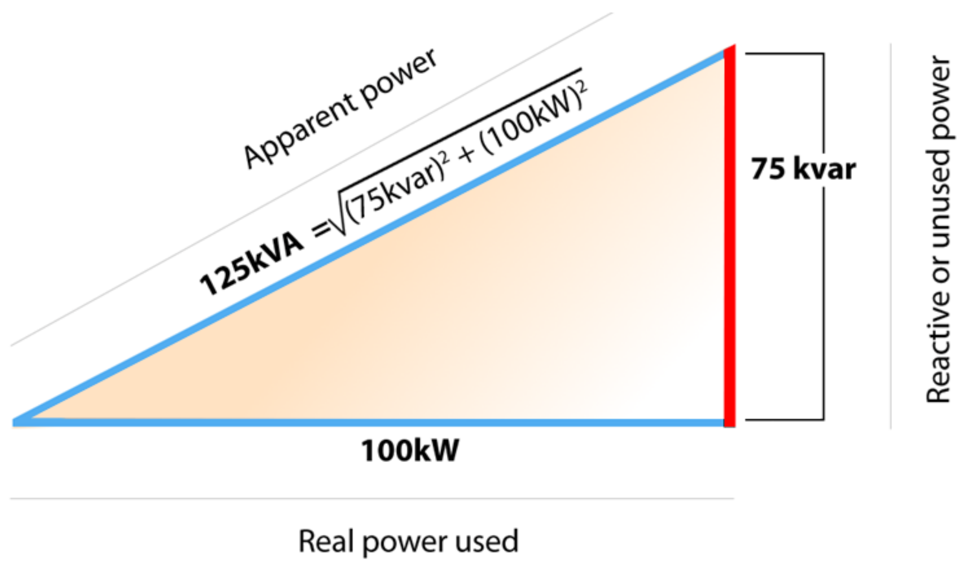
Example: Improving PF

Power Factor = 0.80

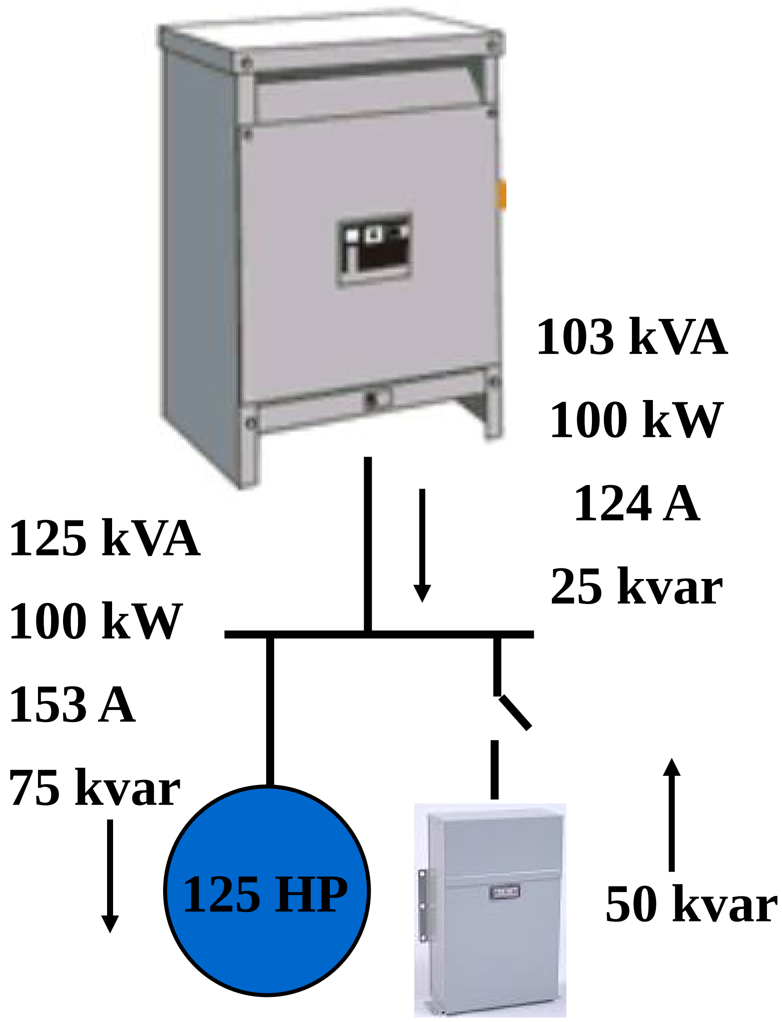
125 kVA
100 kW
150 A

125 kVA
100 kW
150 A
75 kvar



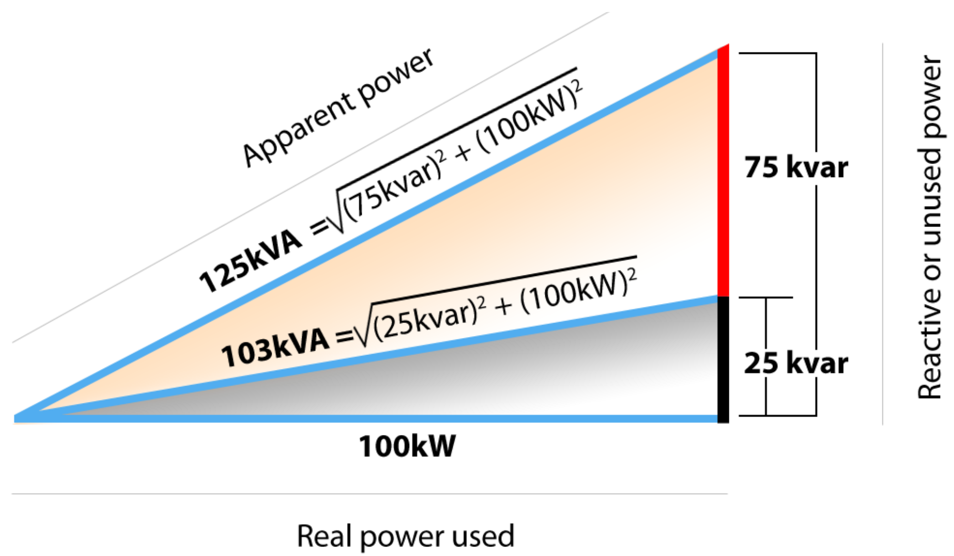


Example: Improving PF Cont.



Power Factor

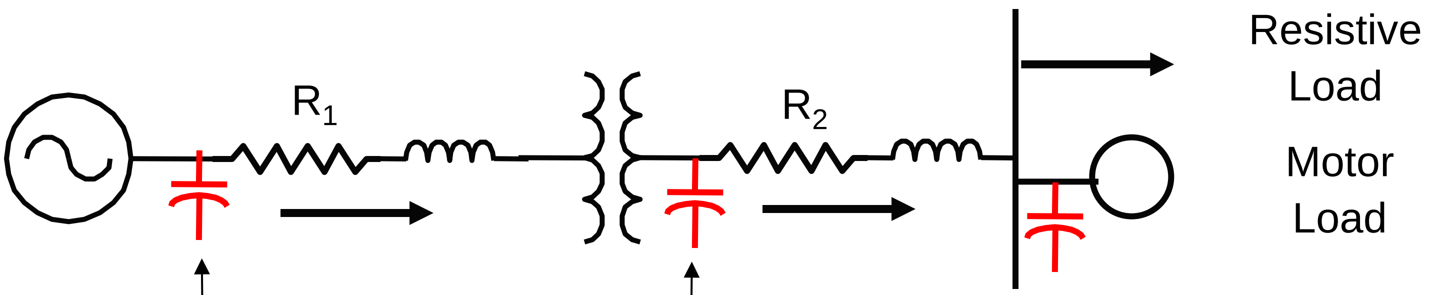
0.80 ==> 0.97



Cost savings due to increased capacity

- Correcting poor power factor can significantly reduce the load on transformers and conductors and allow for facility expansion
  - Transformers are rated by kVA and must be sized accordingly

Effect of Location



Place here for line loss reduction and voltage improvement

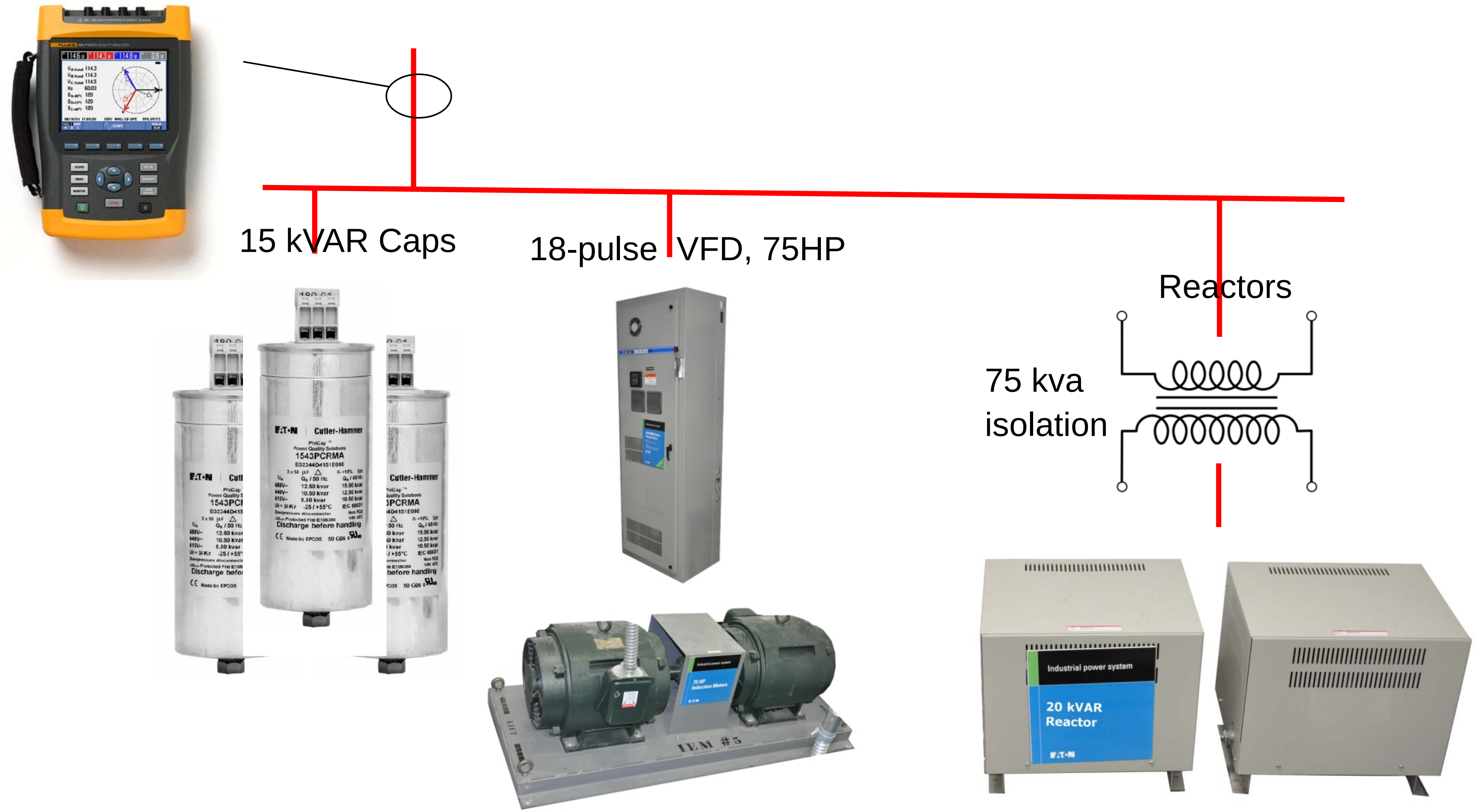
Place here for utility PF penalty

Place here for utility PF penalty (utility owned transformer)

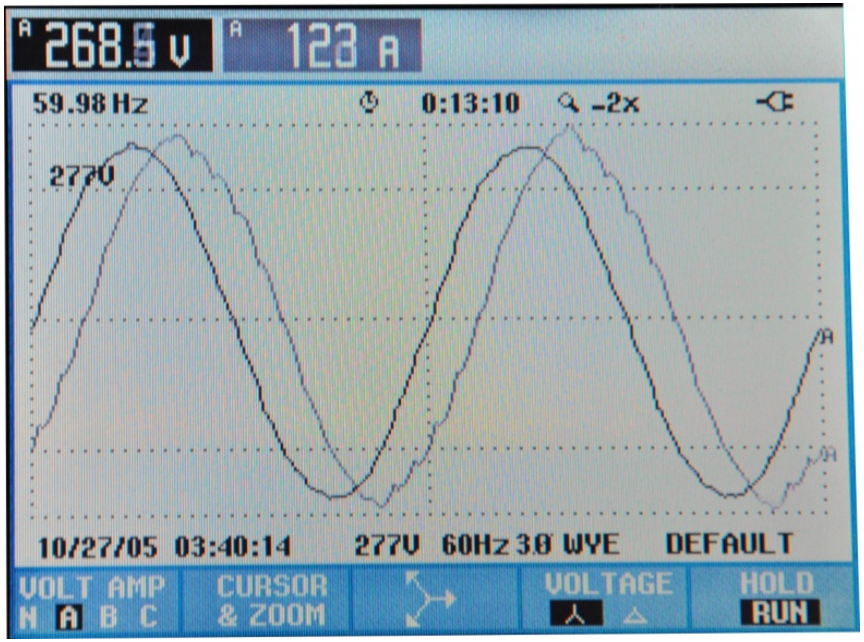
or

Place here to reduce losses in transformer or free capacity

Power Factor Correction – Lab Testing



Power Factor Correction – No Caps



kVAR Added	Phase Voltage	Phase Current	Total kW	Total kVA	Power Factor
0	269	121	69	96	0.72
15					
30					
45					
60					
75					
90					
105					

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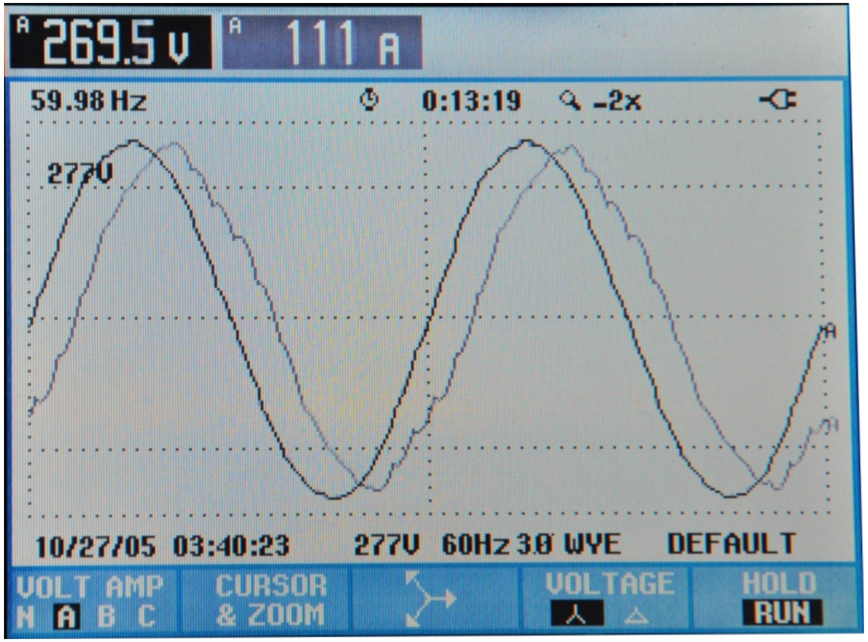
Power Factor Correction – 15 kVAR



kVAR Added	Phase Voltage	Phase Current	Total kW	Total kVA	Power Factor
0	269	121	69	96	0.72
15	**268**	**109**	**69**	**84**	**0.80**
30					
45					
60					
75					
90					
105					

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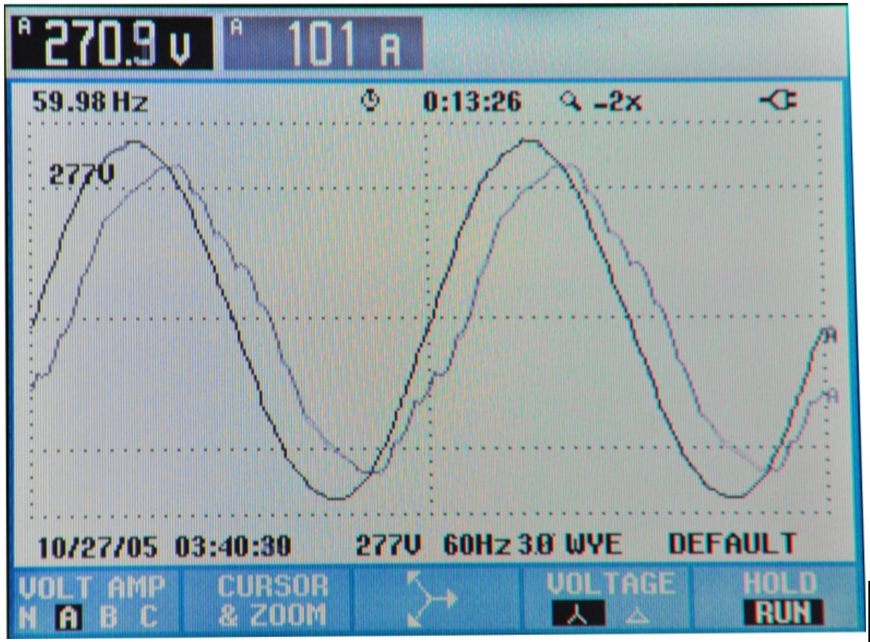
Power Factor Correction – 30 kVAR



kVAR Added	Phase Voltage	Phase Current	Total kW	Total kVA	Power Factor
0	269	121	69	96	0.72
15	268	109	69	84	0.80
30	**270**	**100**	**70**	**80**	**0.87**
45					
60					
75					
90					
105					

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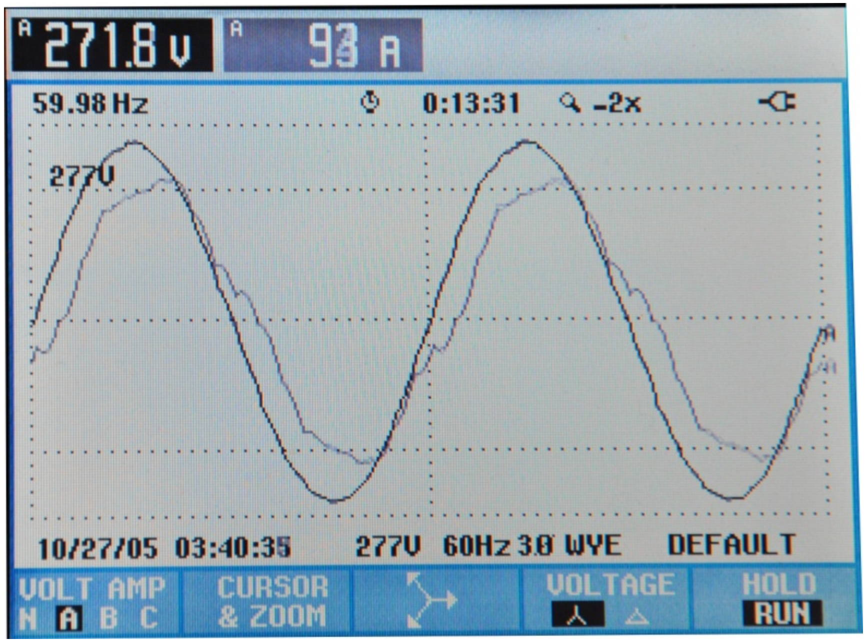
Power Factor Correction – 45 kVAR



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15	268	109	69	84	0.80
30	270	100	70	80	0.87
45	**271**	**92**	**70**	**74**	**0.94**
60					
75					
90					
105					

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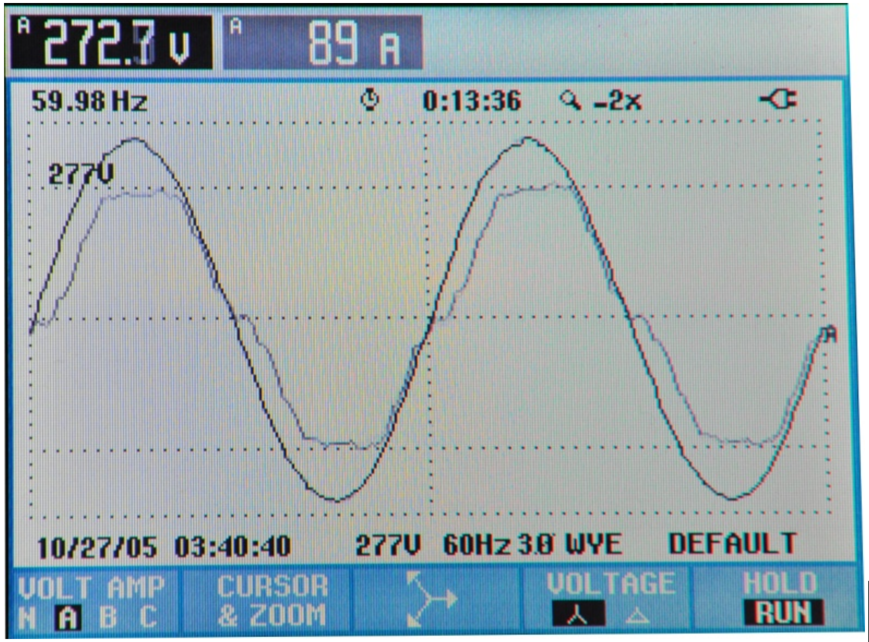
Power Factor Correction – 60 kVAR



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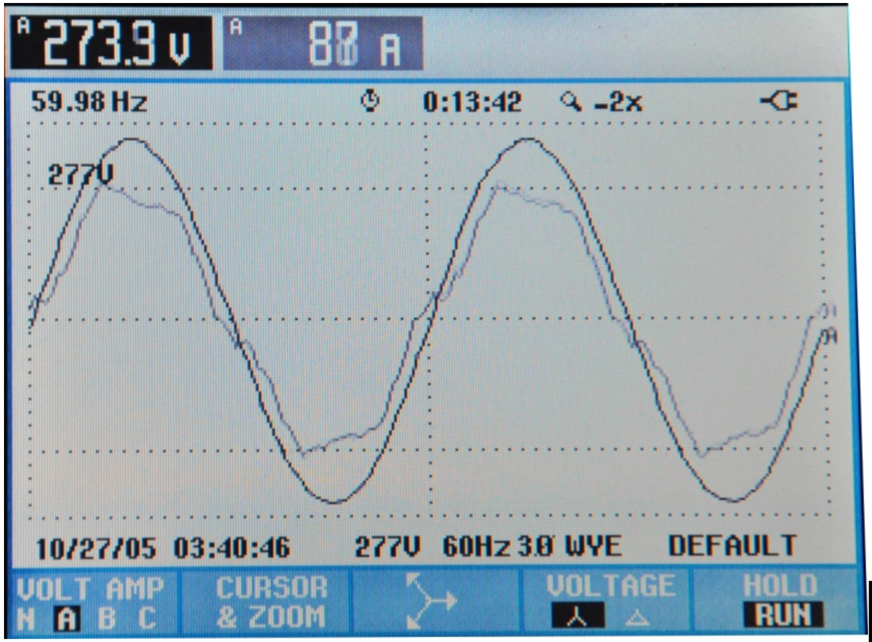
15	268	109	69	84	0.80
30	270	100	70	80	0.87
45	271	92	70	74	0.94
60	**272**	**88**	**70**	**71**	**0.98**
75					
90					
105					

Power Factor Correction – 75 kVAR



kVAR Added	Phase Voltage	Phase Current	Total kW	Total kVA	Power Factor
0	269	121	69	96	0.72
15	268	109	69	84	0.80
30	270	100	70	80	0.87
45	271	92	70	74	0.94
60	272	88	70	71	0.98
75	**273**	**87**	**70**	**70**	**0.99**
90					
105					

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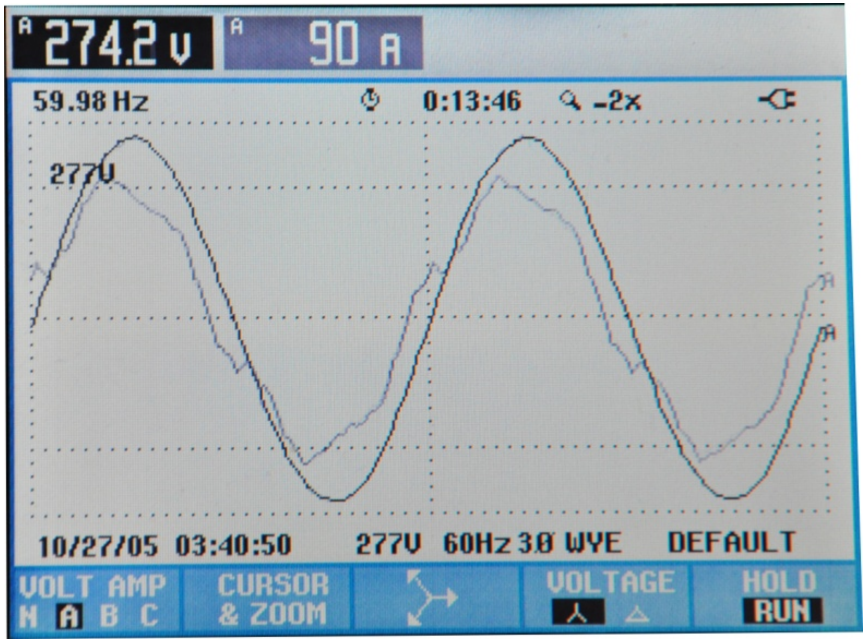
Power Factor Correction – 90 kVAR



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30	270	100	70	80	0.87
45	271	92	70	74	0.94
60	272	88	70	71	0.98
75	273	87	70	70	0.99
90	**274**	**89**	**70**	**73**	**0.95 (1.05)**
105					

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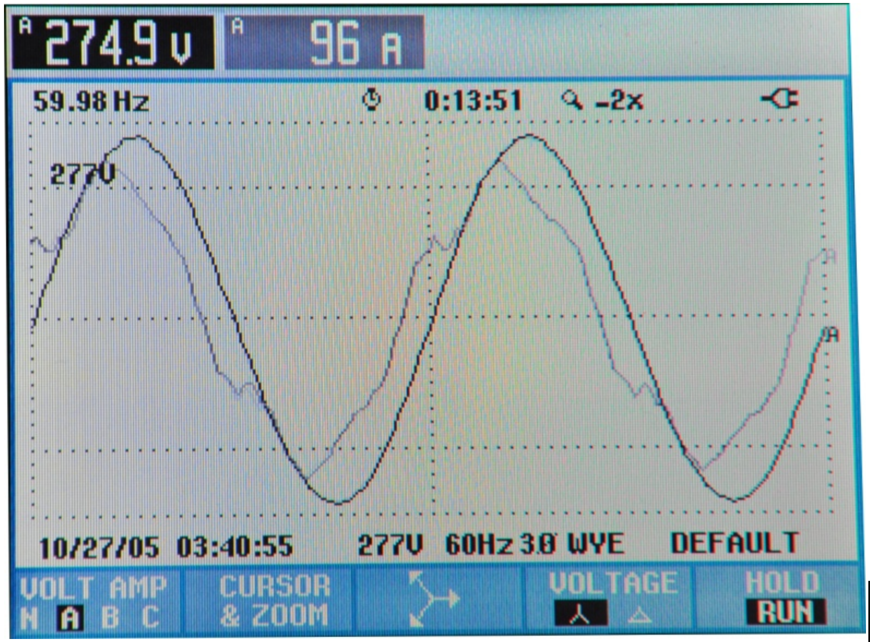
Power Factor Correction – 105 kVAR



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15	268	109	69	84	0.80
30	270	100	70	80	0.87
45	271	92	70	74	0.94
60	272	88	70	71	0.98
75	273	87	70	70	0.99
90	274	89	70	73	0.95 (1.05)
105	**276**	**95**	**70**	**79**	**0.89 (1.11)**

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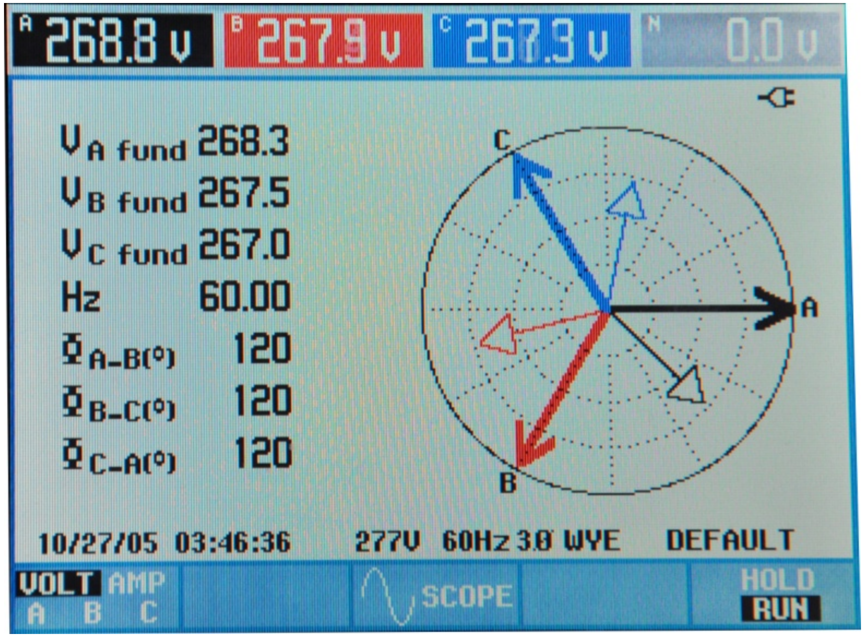
Power Factor Correction – No Caps



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60					
75					
90					
105					

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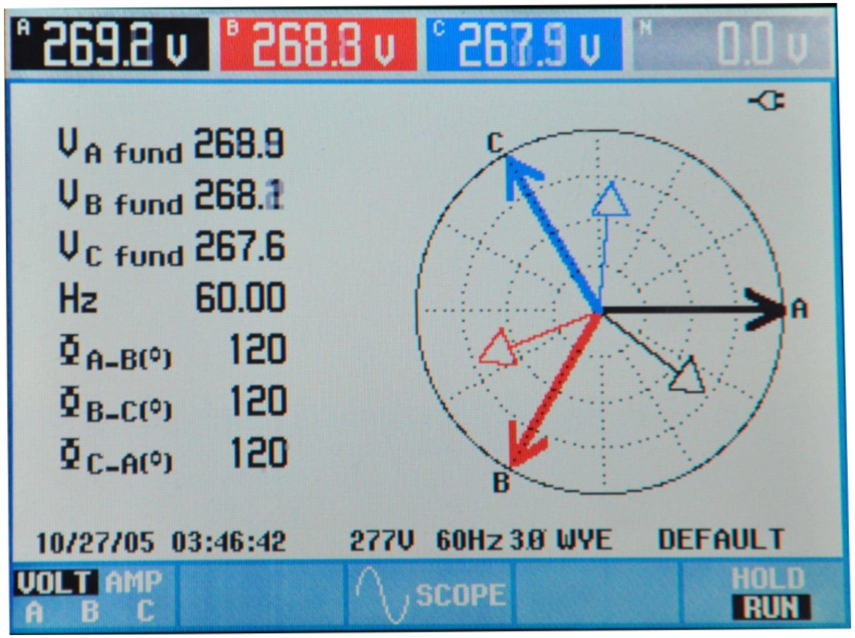
Power Factor Correction – 15 kVAR



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105					

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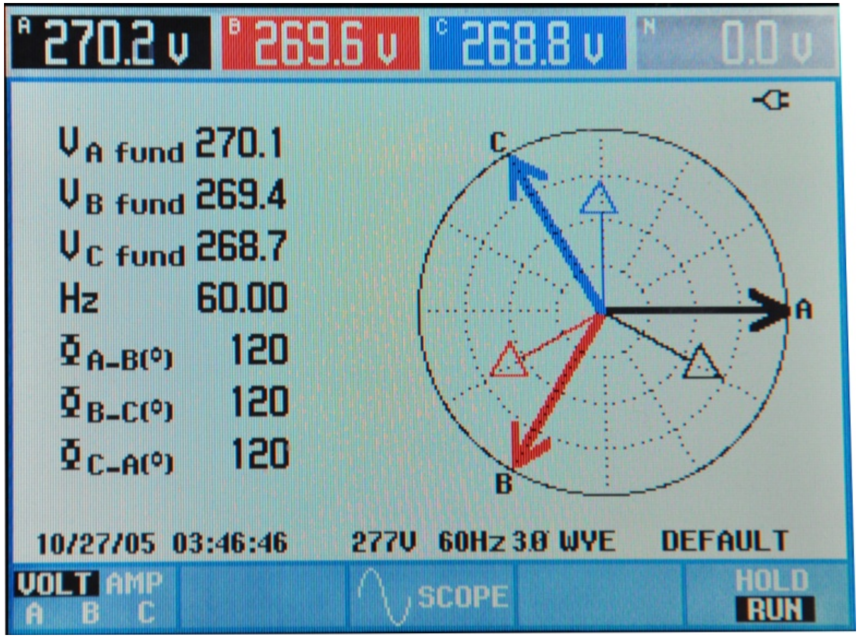
Power Factor Correction – 30 kVAR



kVAR Added	Phase Voltage	Phase Current	Total kW	Total kVA	Power Factor
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45					
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105					

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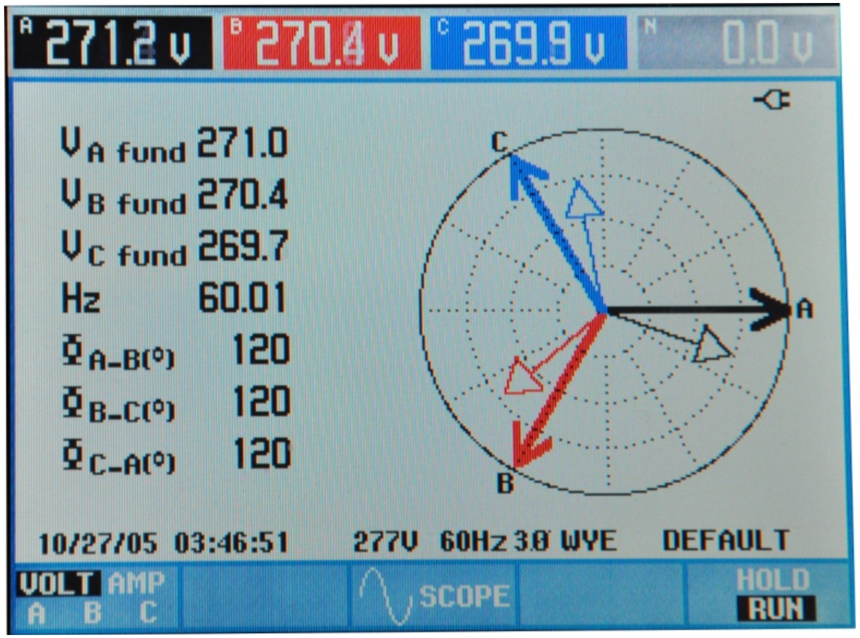
Power Factor Correction – 45 kVAR



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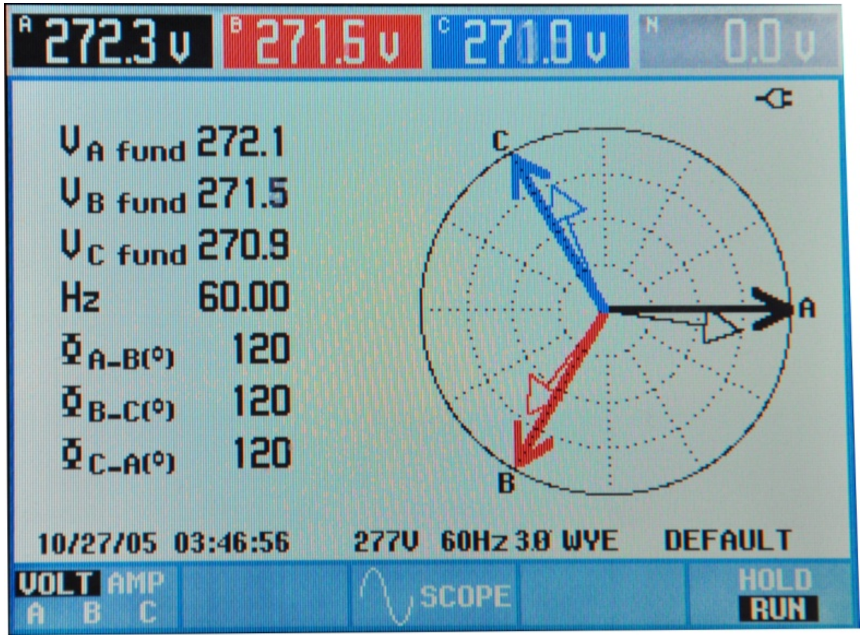
Power Factor Correction – 60 kVAR



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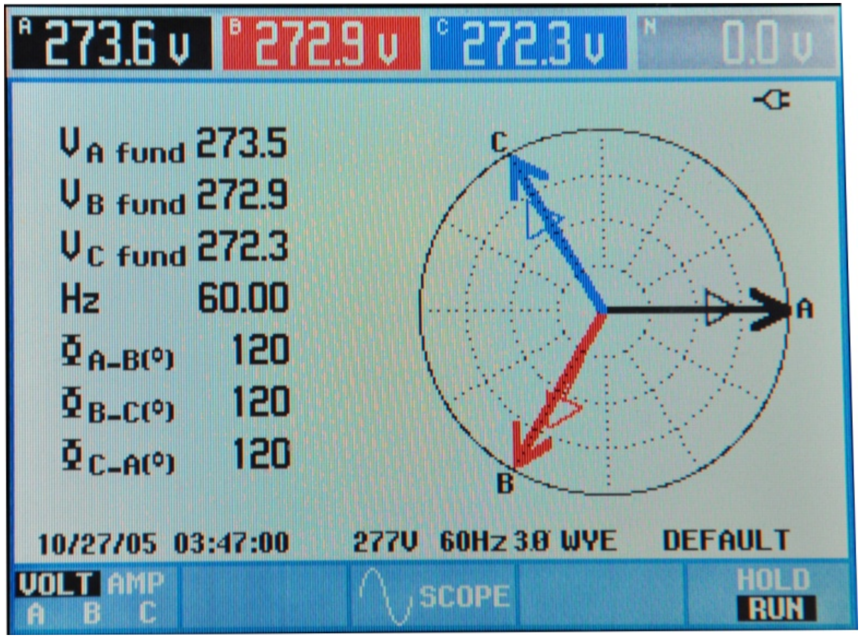
105					

Power Factor Correction – 75 kVAR



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105					

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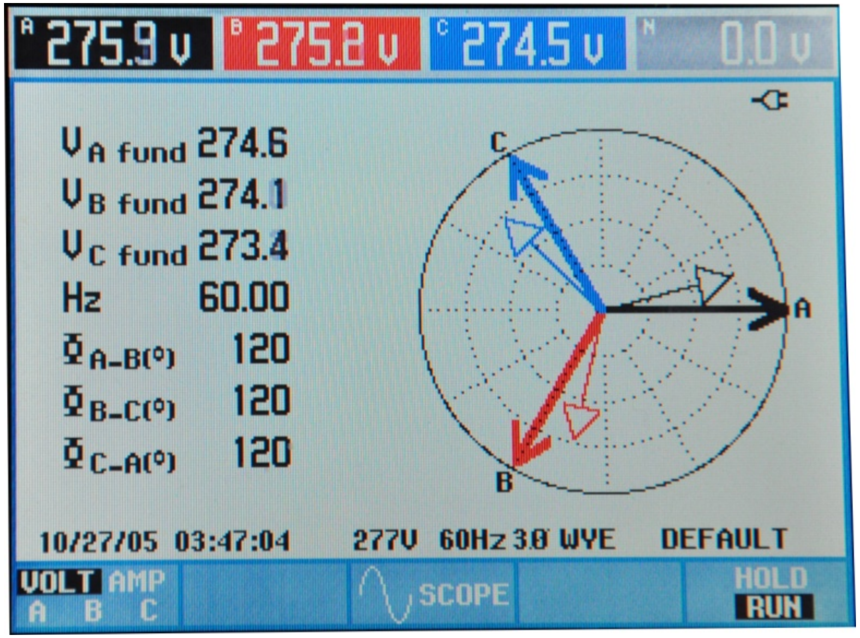
Power Factor Correction – 90 kVAR



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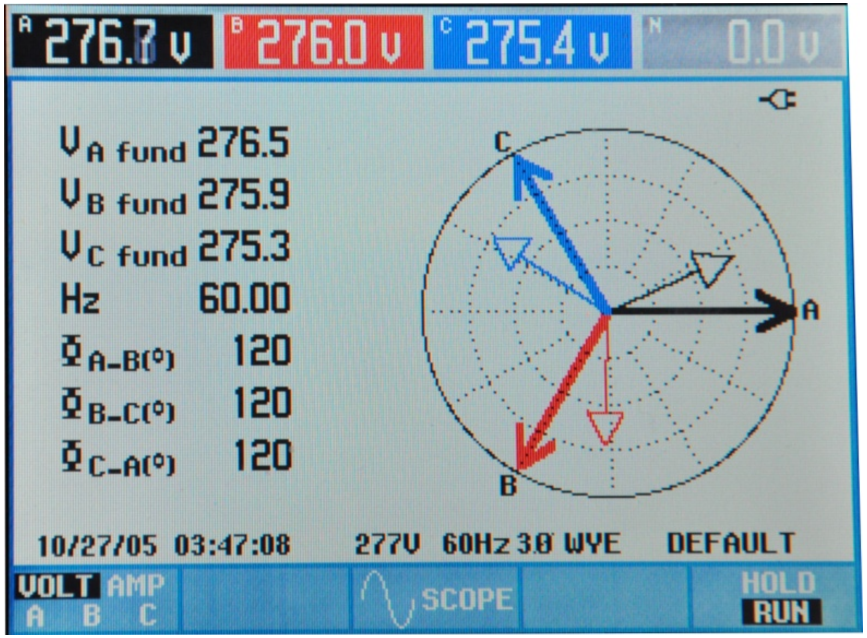
60	272	88	70	71	0.98
75	273	87	70	70	0.99
90	**274**	**89**	**70**	**73**	**0.95 (1.05)**
105					

Power Factor Correction – 105 kVAR



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75	273	87	70	70	0.99
90	274	89	70	73	0.95 (1.05)
105	**276**	**95**	**70**	**79**	**0.89 (1.11)**

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On-Site PFC Demonstration

Power Factor Demonstration Unit – Designed to show phase displacement, system capacity increase, and dispel less than reputable companies claiming 30-40% kW savings from capacitors!

Power Factor Defined –

IEEE Emerald Book IEEE Std 1100-2005

- Power Factor (displacement):
  - The displacement component of power factor
  - The ratio of the active power of the fundamental wave (in watts) to the apparent power of the fundamental wave (in volt-amperes)
- Power Factor (total):
  - The ratio of the total power input (in watts) to the total volt-ampere input.

  NOTE: This definition includes the effect of harmonic components of currents and voltage and the effect of phase displacement between current and voltage.

$$pf = \frac{kw}{kva}$$

Power Factor 'True' Equation

$$pf_{true} \approx \frac{P_{avg1}}{V_{1rms} I_{1rms}} \bullet \frac{1}{\sqrt{1 + (THD_I / 100)^2}} = pf_{disp} \bullet pf_{dist} . \qquad (16)$$

Because displacement power factor pf_{disp} can never be greater than unity, (16) shows that the true power factor in nonsinusoidal situations has the upper bound

$$pf_{true} \le pf_{dist} = \frac{1}{\sqrt{1 + (THD_I / 100)^2}} . \qquad (17)$$

Reference: Dr. Mack Grady, University of Texas at Austin, Proc of the EPRI Power Quality Issues & Opportunities Conference (PQA '93), San Diego, CA, November 1993.
For more info: http://users.ece.utexas.edu/~grady/POWERFAC.pdf

Two Types of Electrical Loads

- Linear

- Non-Linear

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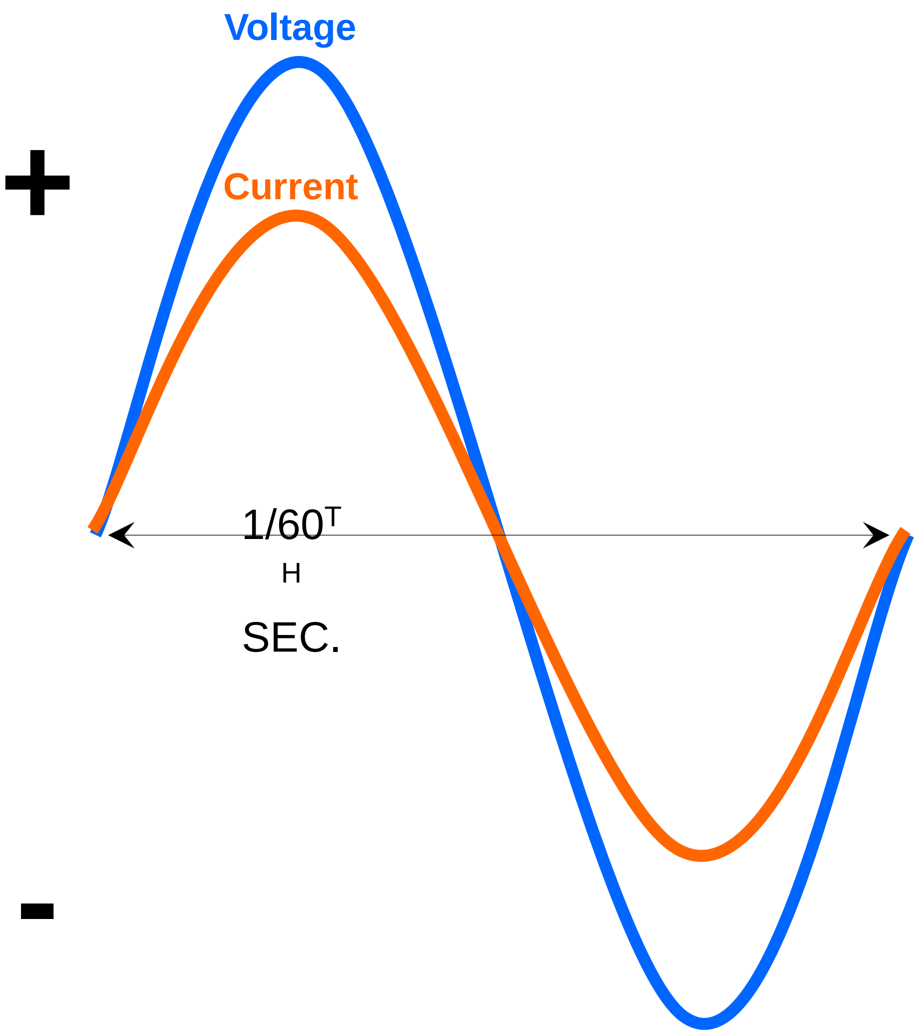
Linear Loads Draw Power Linearly

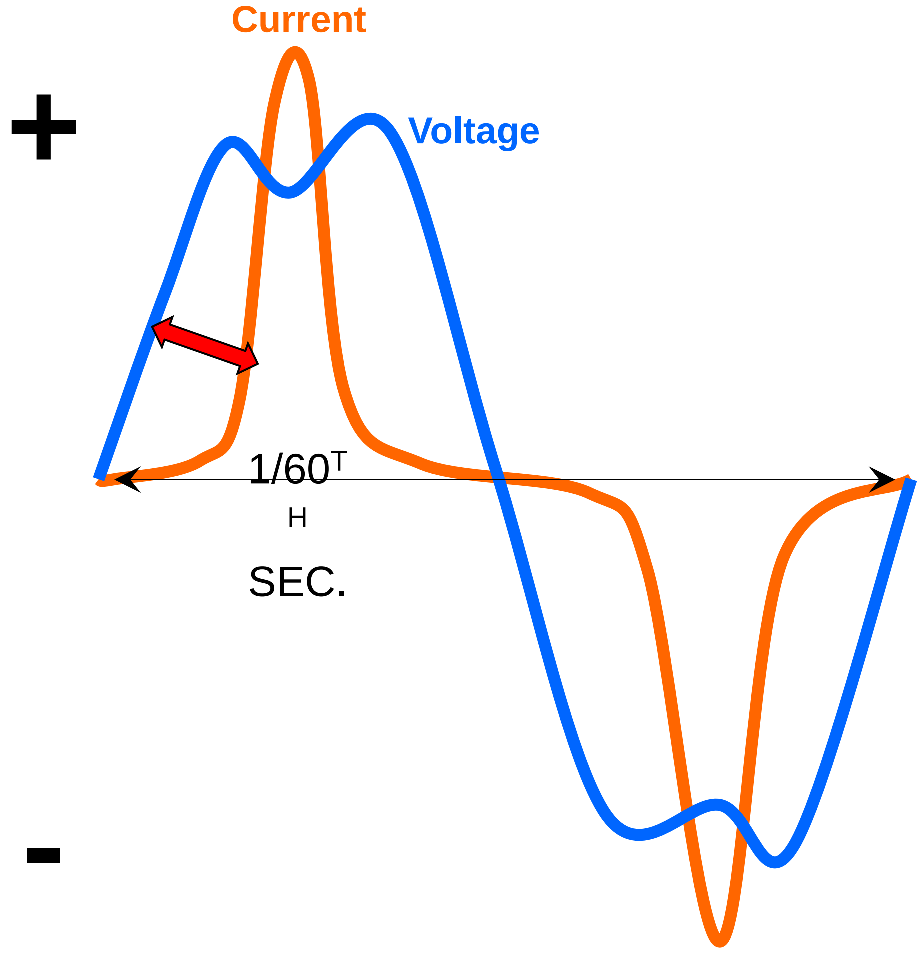
- Electrical voltage and current “ebbs and flows” from plus to minus 60 times per second.

- Voltage and Current follow the same rhythm perfectly in a linear load

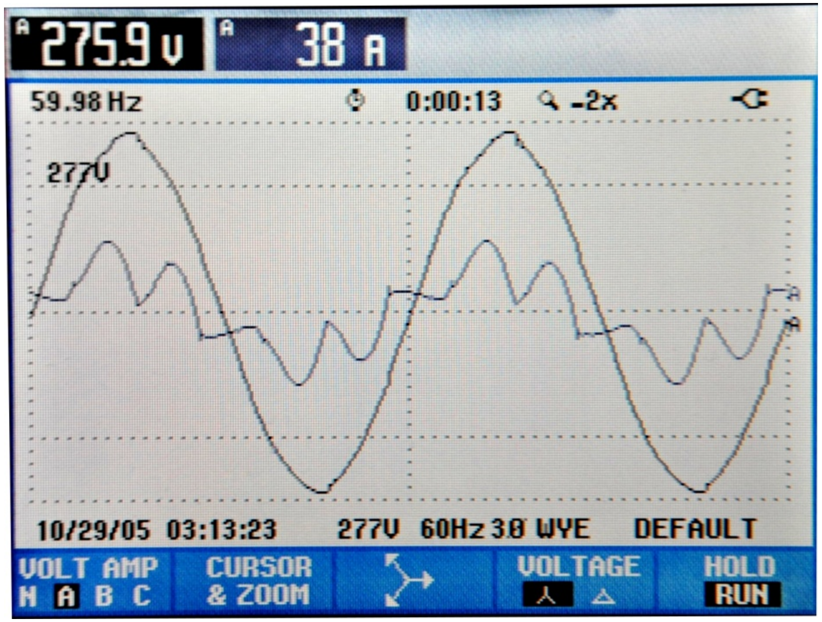


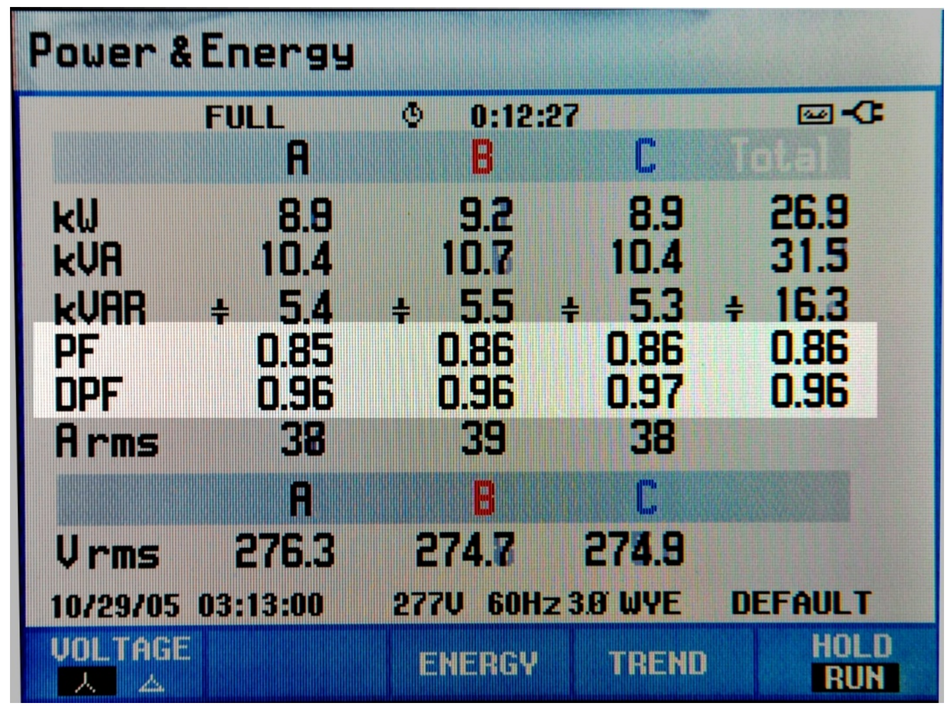
Non-Linear Loads Draw Power Unevenly

- Current is drawn in short “gulps” or pulses.
- Voltage and Current waveforms are irregular and don’t match – waveforms are said to be “DISTORTED”
- NON-LINEAR LOADS PRODUCE HARMONICS
- Harmonics cause mis-operation of equipment and WASTE ENERGY.



Distortive Power Factor





Harmonic Resonance

- Capacitors not only supply reactive power to the loads in an electrical distribution system they also change the resonance frequency of the system.
- Capacitors are also a “sink” for harmonic currents present in a system (**series resonance**).
- When the resonance frequency of a system with PF correction capacitors is close to the frequency of a harmonic current generating load **parallel resonance** can occur.

Why talk about - Harmonic Resonance

The "Self Correcting" Problem

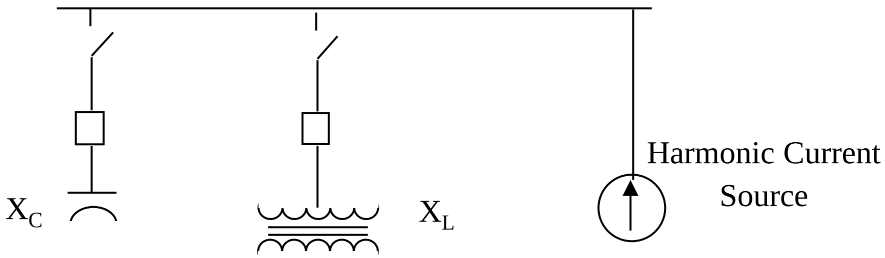
- Blown Fuses
- Failed Capacitors
- Damaged Transformer

Parallel Resonance

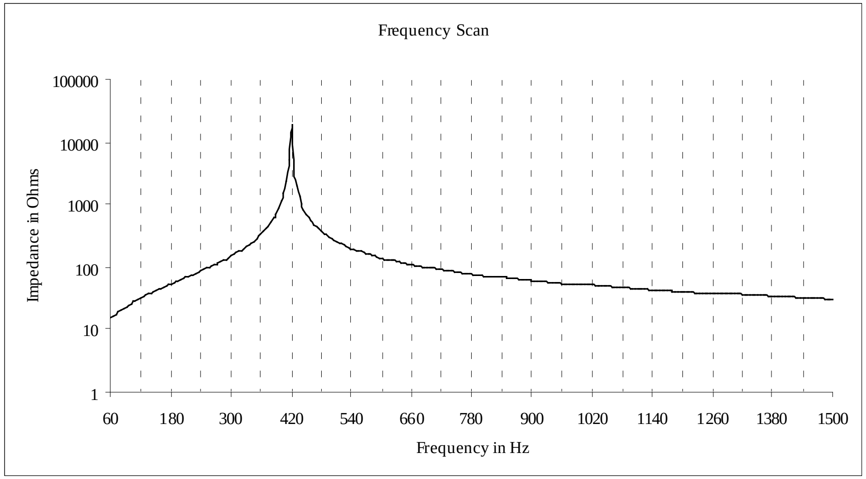
- The parallel combination of impedance is:

$$X_{EQUIVALENT} = \frac{jX_L \times (-j)X_C}{jX_L + (-j)X_C}$$

- Since XL and XC have opposite signs, the denominator can equal zero if XL = XC. In reality, the only limiting factor is the difference in resistance between the capacitor and reactor.



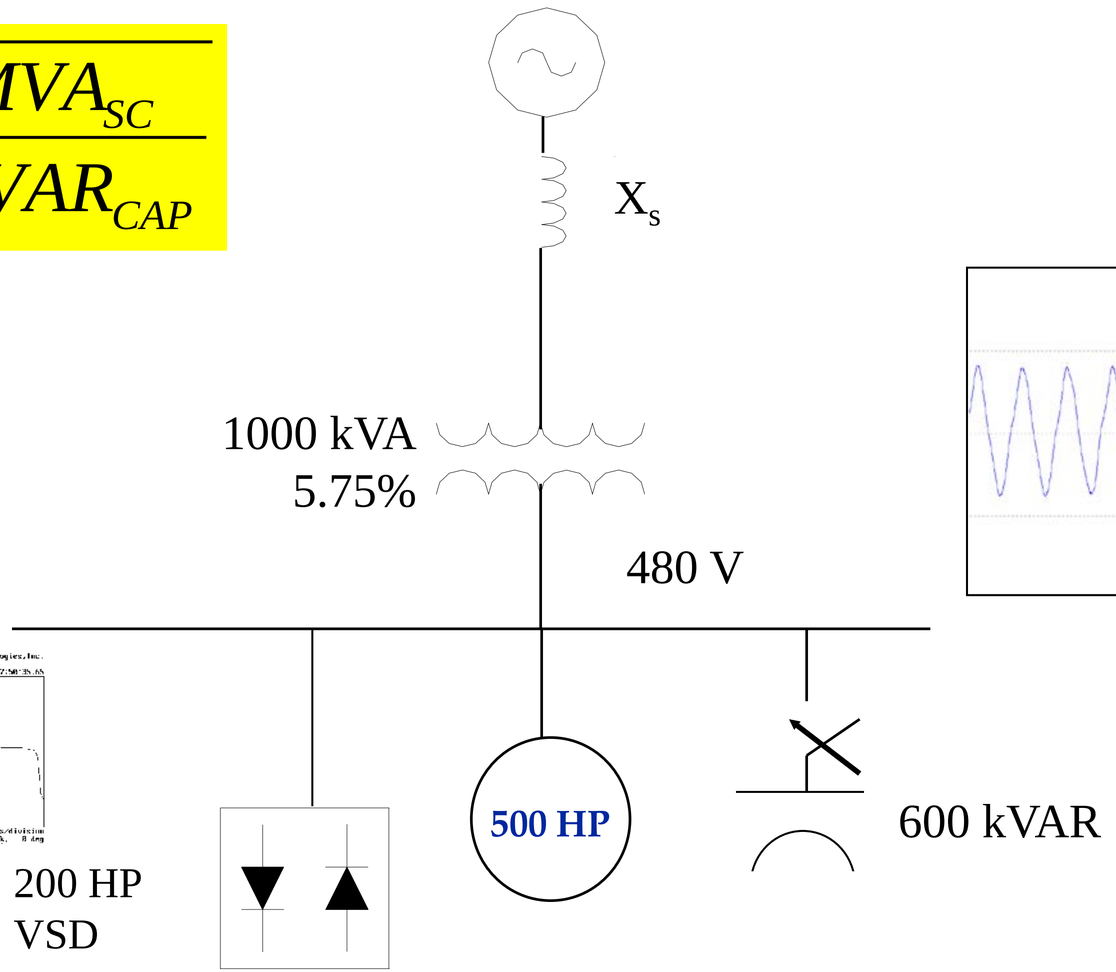
Equivalent Parallel Resonant Circuit

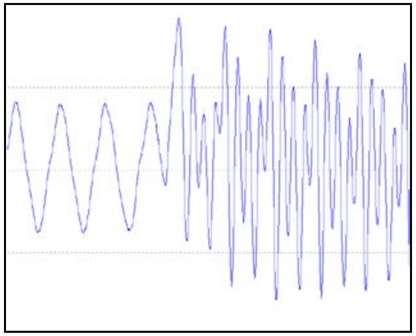


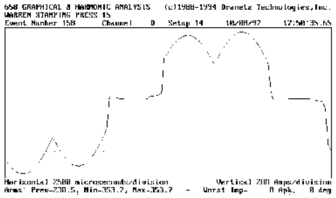
Frequency Scan for Parallel Resonant Circuit

Parallel Resonance

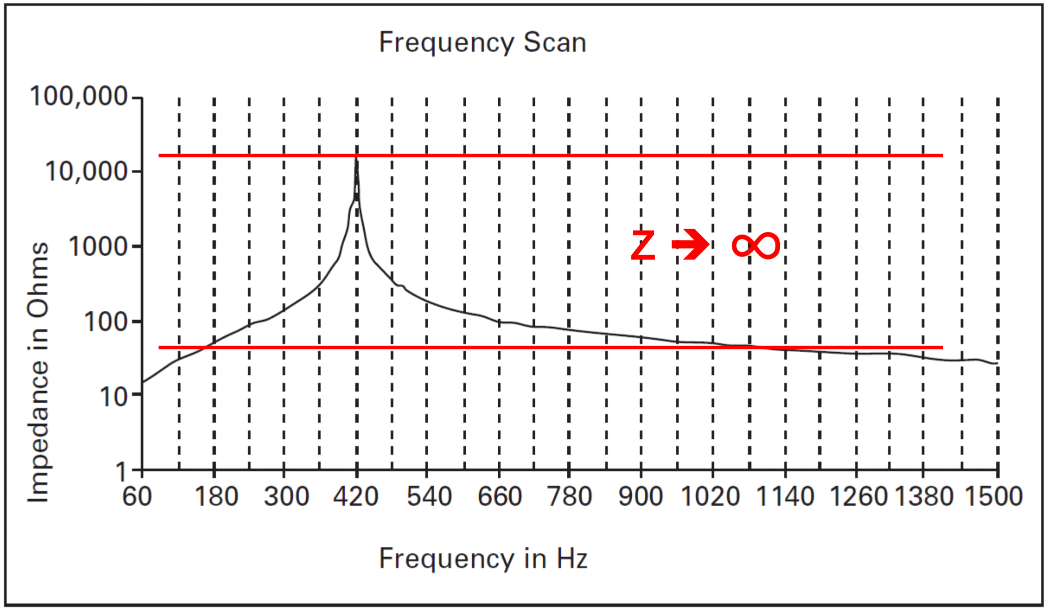
$$h_R = \sqrt{\frac{MVA_{SC}}{MVAR_{CAP}}}$$







Parallel Resonance – the Problem



At 420Hz (the 7th harmonic) the Z (impedance) of the circuit increases from around 80 ohms to 10,000 ohms

125 times increase!

Subsequently, harmonic voltage Increases 125 times!

Solution?

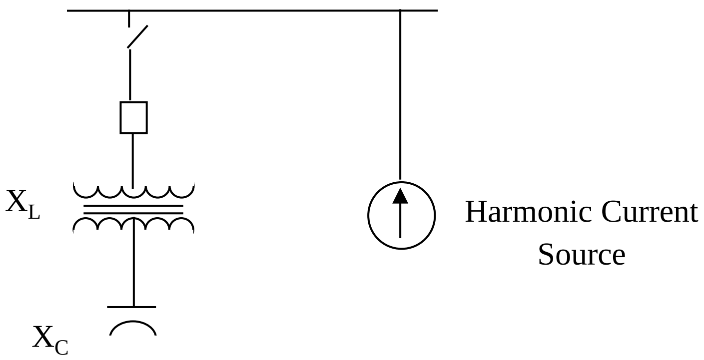
- Make sure you perform calculation
- Purchase Power Factor caps with detuned anti-resonance filter
- Use capacitor-less solutions (HCU & others)

Series Resonance

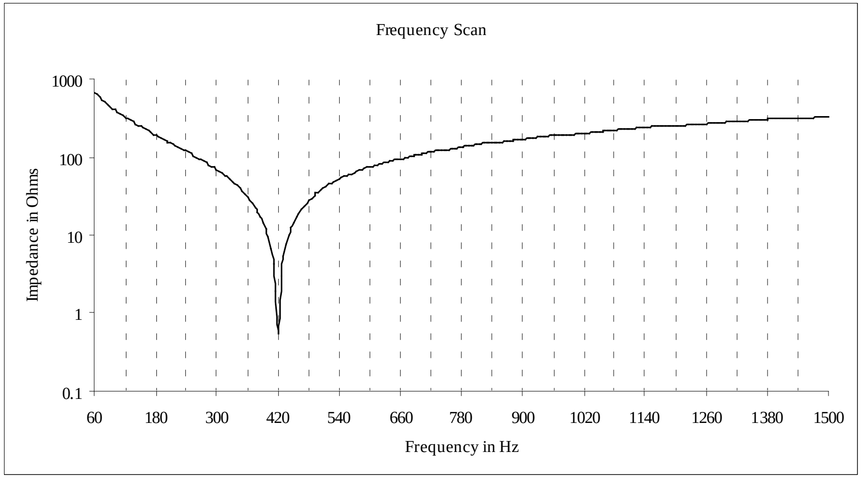
The series combination of impedance is:

$$X_{EQUIVALENT} = jX_L + (-j)X_C$$

Since XL and XC have opposite signs, the summation can equal zero if XL = XC. In reality, the only limiting factor is the difference in resistance between the capacitor and reactor.



Equivalent Series Resonant Circuit



Frequency Scan for Series Resonant Circuit

Expected Harmonics

Source	Typical Harmonics*
6 Pulse Drive/Rectifier	5, 7, 11, 13, 17, 19…
12 Pulse Drive/Rectifier	11, 13, 23, 25…
18 Pulse Drive	17, 19, 35, 37…
Switch-Mode Power Supply	3, 5, 7, 9, 11, 13…
Fluorescent Lights	3, 5, 7, 9, 11, 13…
Arcing Devices	2, 3, 4, 5, 7...
Transformer Energization	2, 3, 4

* Generally, magnitude decreases as harmonic order increases

H = NP+/-1

i.e. 6 Pulse Drive - 5, 7, 11, 13, 17, 19,…

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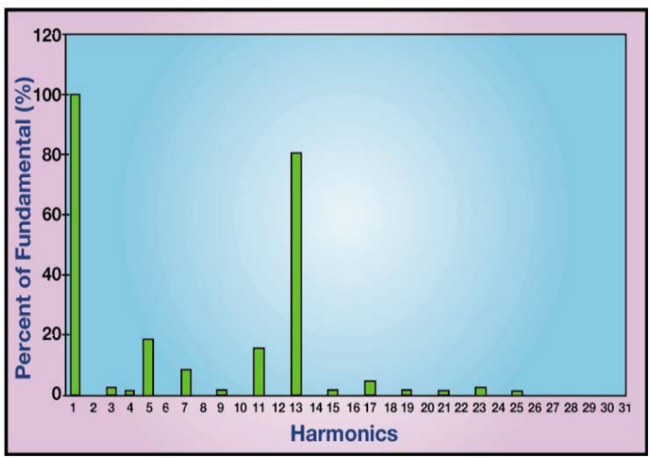
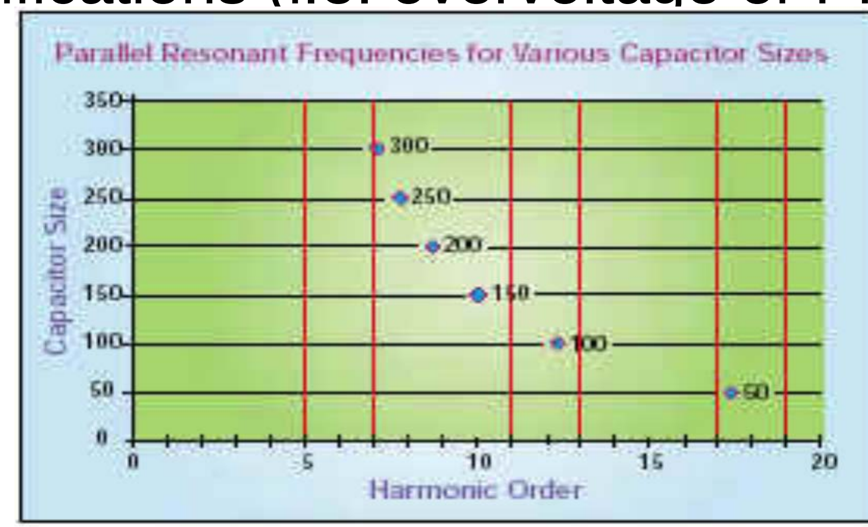
Harmonic Resonance - Solutions

1. **Change the method** of kvar compensation (harmonic filter, active filter, etc.)
2. **Change the size** of the capacitor bank to over-compensate or under-compensate for the required kvar and live with the ramifications (i.e. overvoltage or PF





Natural System frequency of oscillation typically at 5th to 13th harmonic

What type of PFC solution?

- Capacitors (standard/harmonically hardened)
- Harmonic Filters (Tuned or De-tuned)
- Active Filters
- LV or MV
- Fixed or Switched (contactor or thyristor)
- Active harmonic filter (PF and harmonic control)

Capacitor Selection

Capacitor selection issues (besides size)

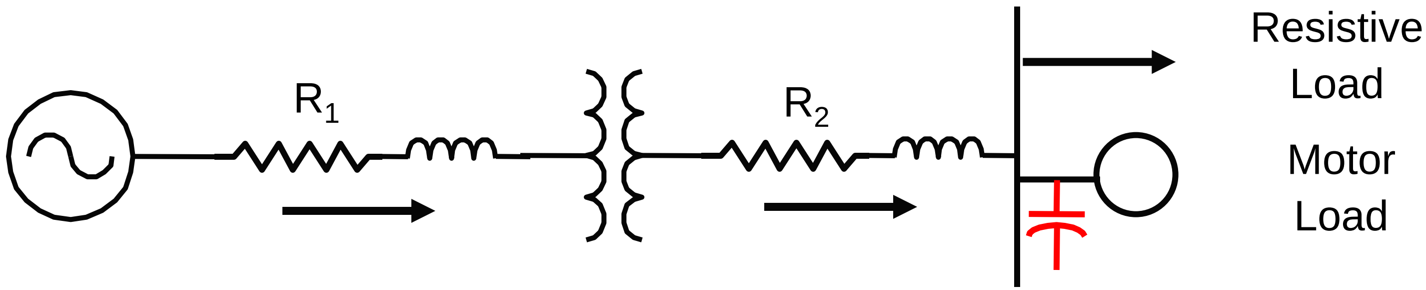
- Utility penalties
- Installed cost, payback of equipment, and NPV
- Load variability
- Voltage regulation
- Load requirements (Speed of changing PF)
- Harmonic resonance

Application Example – At the Load

At a motor
Group of Motors
Group of Motors w/ harmonics

Variable Load
Variable System
Variable System w/ harmonics
Rapidly changing load
Electronic VAR Injector

MV at a motor
MV variable load



Eaton Unipump

Advantages

- Auto-regulating, comes on and off with load
- Capacitor matched with load – reduces concern of overcorrection
- Relatively small in size – easy to locate, no additional distribution equipment required

When to Use

- Facility load fluctuates
- Many anticipated changes to plant system and loads

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Application Example – Group of Loads

At a motor

Group of Motors

Group of Motors w/ harmonics

Variable Load

Variable System

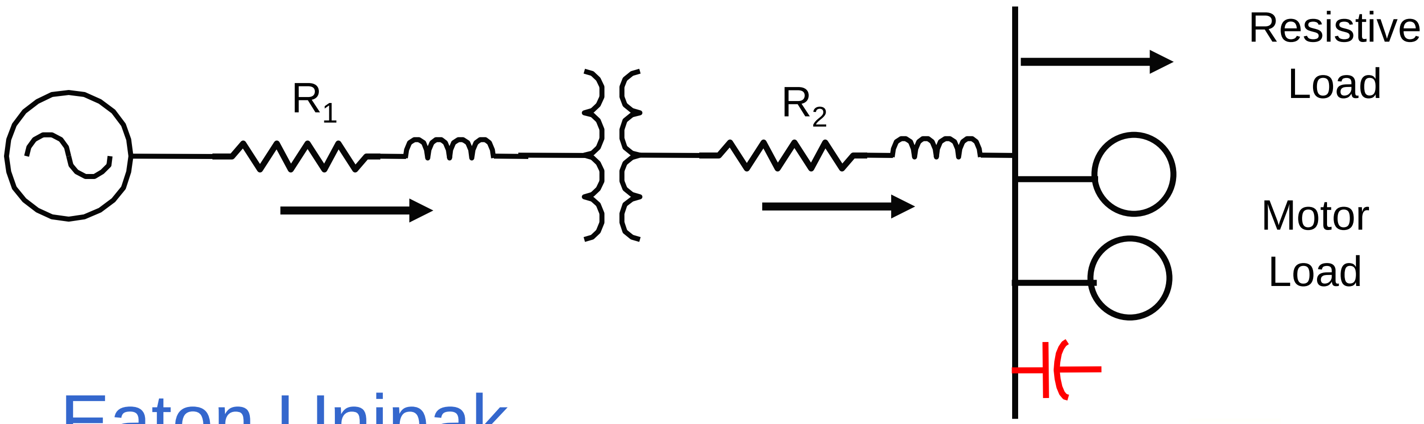
Variable System w/ harmonics

Rapidly changing load

Electronic VAR Injector

MV at a motor

MV variable load



Eaton Unipak

When to use

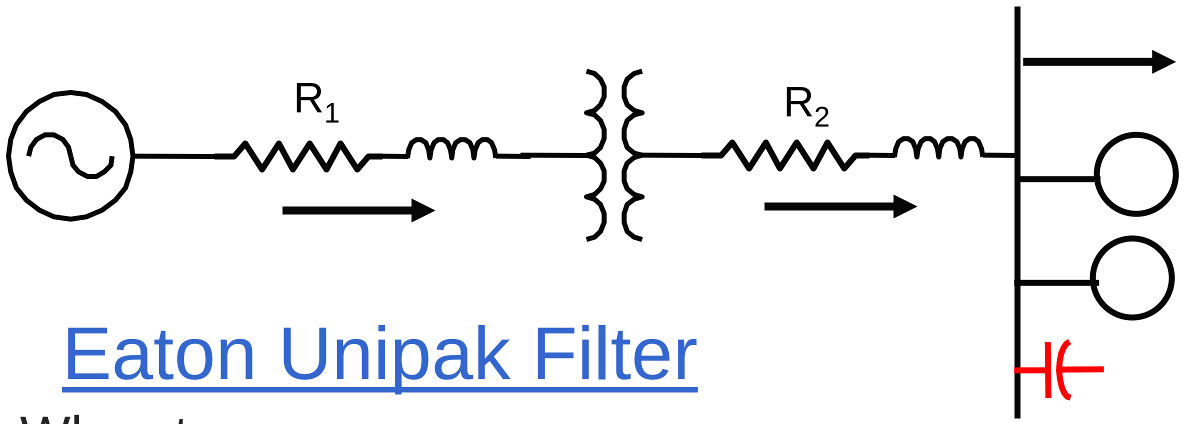
- Facility load is relatively constant – 24/7/365
- Few anticipated changes to plant system & loads

Considerations

- Possibility of “over-correcting” (leading power factor, increases current)
- Overvoltage can occur if load drops

Application Example – Group of Harmonic Loads

At a motor
Group of Motors
Group of Motors w/ harmonics
Variable Load
Variable System
Variable System w/ harmonics
Rapidly changing load
Electronic VAR Injector
MV at a motor
MV variable load



Eaton Unipak Filter

When to use

- Facility load is relatively constant – 24/7/365
- Few anticipated changes to plant system & loads
- Capacitors protected from harmonics through the use of a detuned, anti-resonance filter / reactors

Considerations

- Possibility of “over-correcting” (leading power factor, increases current)
- Overvoltage can occur if load drops

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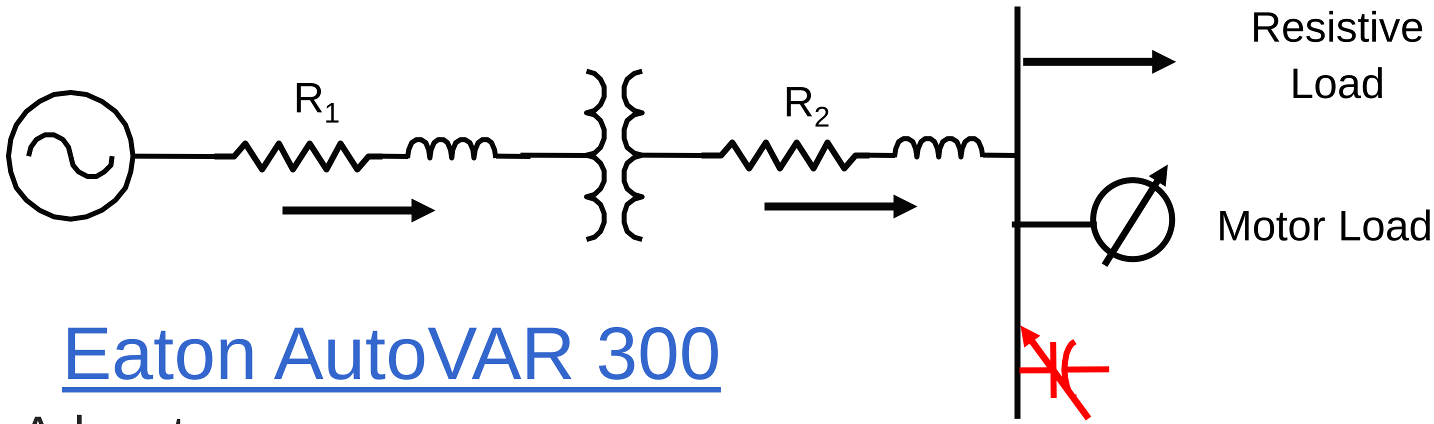
Application Example – Variable Load

- At a motor
- Group of Motors
- Group of Motors w/ harmonics
- **Variable Load**
- Variable System
- Variable System w/ harmonics
- Rapidly changing load
- Electronic VAR Injector
- MV at a motor
- MV variable load



Eaton AutoVAR 300

Advantages

- Single installation
- Load is monitored and brings individual capacitors in / out as required to meet power factor target value
- Wall mounted

When to use

- When load flexibility is required
- Facility loads turned off at night
- Future load expected to change

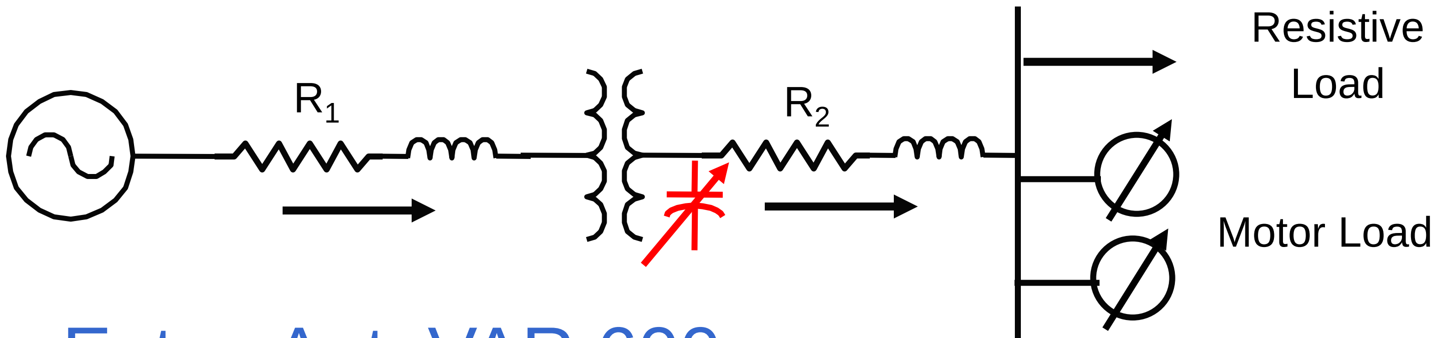
Powering Business Worldwide

Application Example – Variable System

At a motor
Group of Motors
Group of Motors w/ harmonics

Variable Load
Variable System
Variable System w/ harmonics
Rapidly changing load
Electronic VAR Injector

MV at a motor
MV variable load



Eaton AutoVAR 600

Advantages

- Single installation
- System is monitored and brings individual capacitors in / out as required to meet power factor target value
- Floor mount

When to use

- When system flexibility is required
- Facility loads turned off at night
- Future load expected to change

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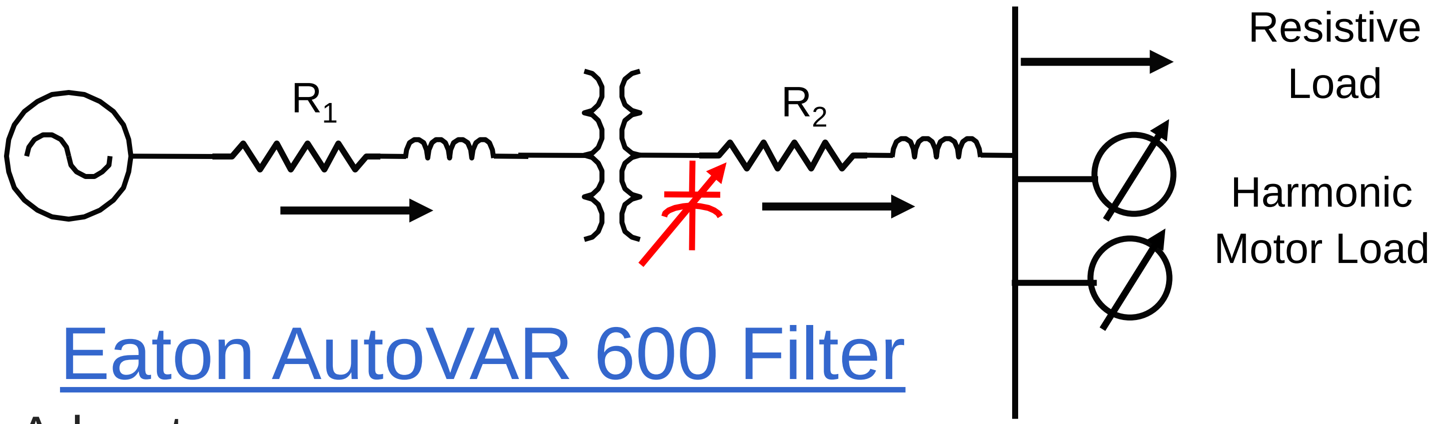
Application Example – Variable System with harmonics

At a motor
Group of Motors
Group of Motors w/ harmonics
Variable Load
Variable System
Variable System w/ harmonics
Rapidly changing load
Electronic VAR Injector
MV at a motor
MV variable load



Eaton AutoVAR 600 Filter

Advantages

- Single floor mount installation
- System is monitored and brings individual capacitors in / out as required to meet power factor target value
- Floor mount

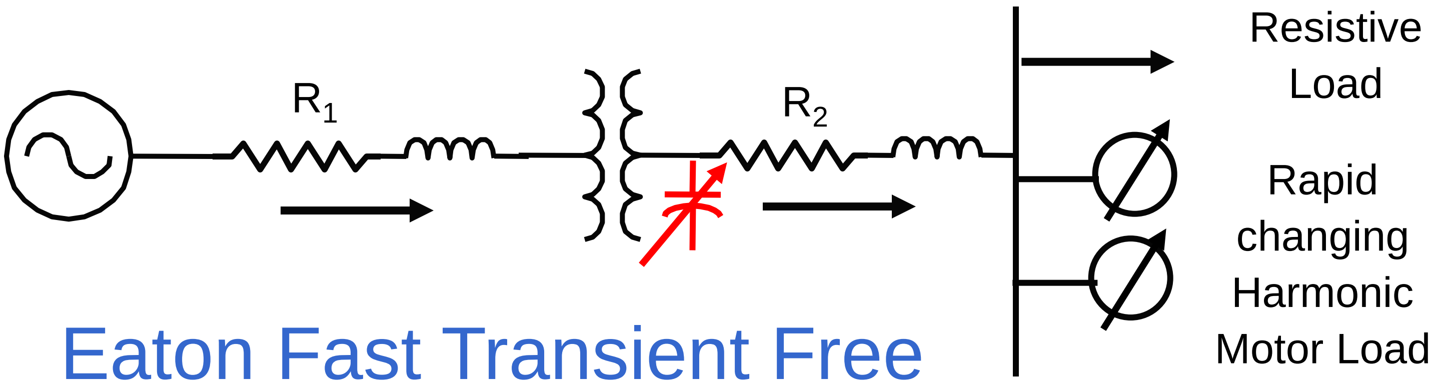
When to use

- When system flexibility is required
- Facility loads turned off at night
- Future load expected to change

Powering Business Worldwide

Application Example – Rapidly Changing Load

At a motor
Group of Motors
Group of Motors w/ harmonics
Variable Load
Variable System
Variable System w/ harmonics
Rapidly changing load
Electronic VAR Injector
MV at a motor
MV variable load



Eaton Fast Transient Free

Advantages

- Switches at zero-crossing – no transients
- Can correct Power Factor within:
  - FTA Model – 3 to 4 s
  - FTE Model – 5 to 20 ms
- Includes detuned, anti-resonance filtering

When to use

- Rock crushing or other rapidly changing loads that require power factor correction

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Application Example – Electronic VAR Injector

At a motor

Group of Motors

Group of Motors w/ harmonics

Variable Load

Variable System

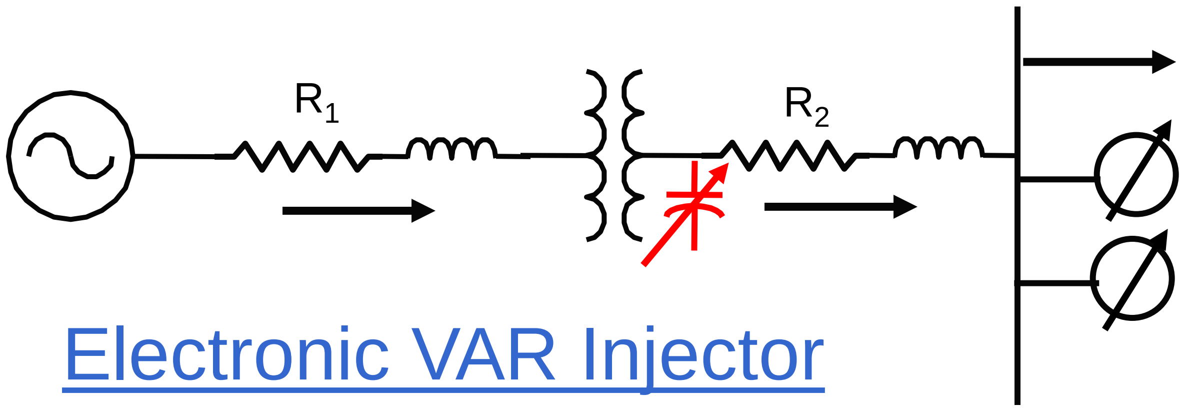
Variable System w/ harmonics

Rapidly changing load

Electronic VAR Injector

MV at a motor

MV variable load



Electronic VAR Injector

Advantages

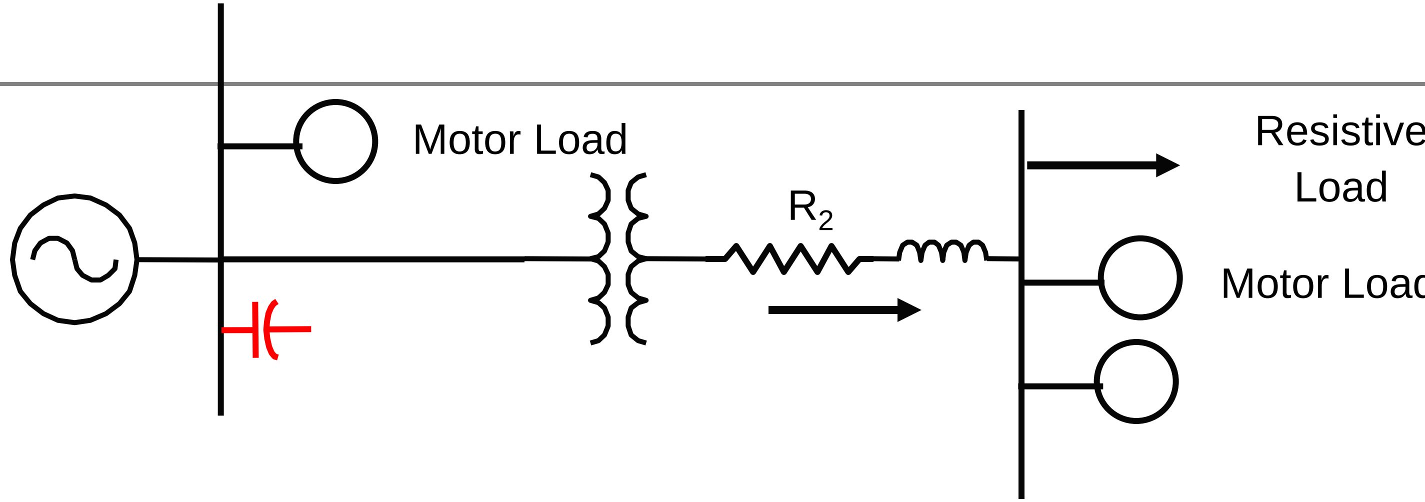
- Power electronics – no capacitors
- Provide VARs in non-standard harmonic environment
- 2 cycle response

When to use

- Most demanding of all electrical environments (208-480V, 45 to 65 Hz)

Application Example – Medium Voltage at Motor

At a motor
Group of Motors
Group of Motors w/ harmonics
Variable Load
Variable System
Variable System w/ harmonics
Rapidly changing load
Electronic VAR Injector
MV at a motor
MV variable load



Eaton MV UniVAR & MV

Advantages

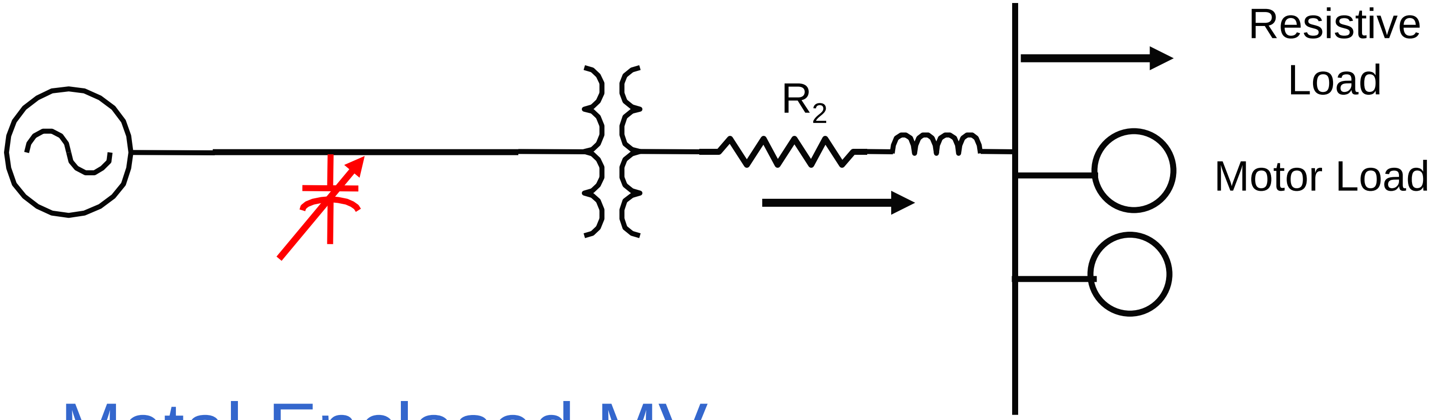
- Designed for industrial and commercial power systems with their own substations
- UniVAR XV: 2.4kV to 4.8kV
- UniVAR MV: 6.6kV to 13.8kV
- Available from 25 kVAR to 900 kVAR

Application Example – Medium Voltage Variable load

At a motor
Group of Motors
Group of Motors w/ harmonics

Variable Load
Variable System
Variable System w/ harmonics
Rapidly changing load
Electronic VAR Injector

MV at a motor
MV variable load



Metal-Enclosed MV

Advantages

- Built in detuning, anti-resonance filtering to protect the capacitors
- Up to 15 MVAR of compensation
- Top of Bottom Cable Entry
- Up to 12 automatic switched capacitor/reactor stages

Powering Business Worldwide

Power Quality Experience Center and Lab

- Overview of Lab and Capabilities
  - Purpose
    - To demonstrate and Test PQ Problems and Solutions
    - Power Quality solutions, especially harmonic solutions, are difficult to understand

    - Demystify solutions – mis-information and confusion regarding PQ and energy savings
  - Equipment (Harmonic Related)
    - 18 Pulse Drives
    - HMT's
    - Active Filters
    - Broadband Filters
    - Passive (Fixed) Filters
    - Passive (Switched) Filters
    - Active Rectifier (UPS)
    - Reactors
- Link:http://www.eaton.com/EatonCom/Markets/Electrical/ServicesSupport/Experience/index.htm – Simply search on Google for Eaton Experience Center

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Eaton Power Factor Correction Tool™ - Resonance

Step 1

Bus Voltage	480	
Existing Load	1150	kW
	0.89	PF
Target PF	0.95	
Required kvar	211	kvar

Enter Quantities in Blue

Quantities in Orange are Calculated

Step 2

Select Cap/Filter Size	200	kvar
Penalty per Year	$ 12,000	

Estimated Installed Cost for		Estimated Payback
Fixed Cap and Breaker	$ 5,000	5 Months
Switched Cap and Breaker	$ 10,000	10 Months
Fixed Harmonic Filter and Breaker	$ 11,000	11 Months
Switched Harmonic Filter and Breaker	$ 15,000	15 Months
Actual Total Equipment Cost	$ 6,000	6 Months

Instructions

Step 1: Calculate required capacitance.

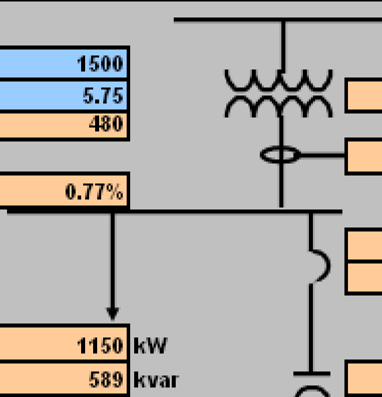
Step 2: Select a standard capacitor or harmonic filter size (refer to price list for standard sizes) and penalty per year to calculate return on investment (ROI).

Step 3: Input system data and calculate potential overvoltage, harmonic resonance, kva reduction, and breaker or fuse size

For more information or assistance in using this tool, please contact the Power Quality Hotline at (800) 809-2772 Option 1, Sub-option 2.

Step 3

Transformer kVA	1500	
Transformer %Z	5.75	
Bus Voltage	480	
Maximum % bus voltage rise at this bus - no load with the full capacitor	0.77%	
	1150	kW
	589	kvar



6%	Load Reduction (kVA) with Addition of Selected Capacitor Bank	
0.95	Actual Corrected PF	
325	Amp	Breaker or Fuse Size @ 135% Rating
400	Amp	Typical Breaker or Fuse Size or Setting @ 135% Rating for Selected Capacitor Bank
11.42	Estimated Parallel Resonant Harmonic Order (Based on Selected Capacitor)	

Check Harmonics

Note: For estimating harmonic resonance, check every STEP of a multi-step capacitor bank

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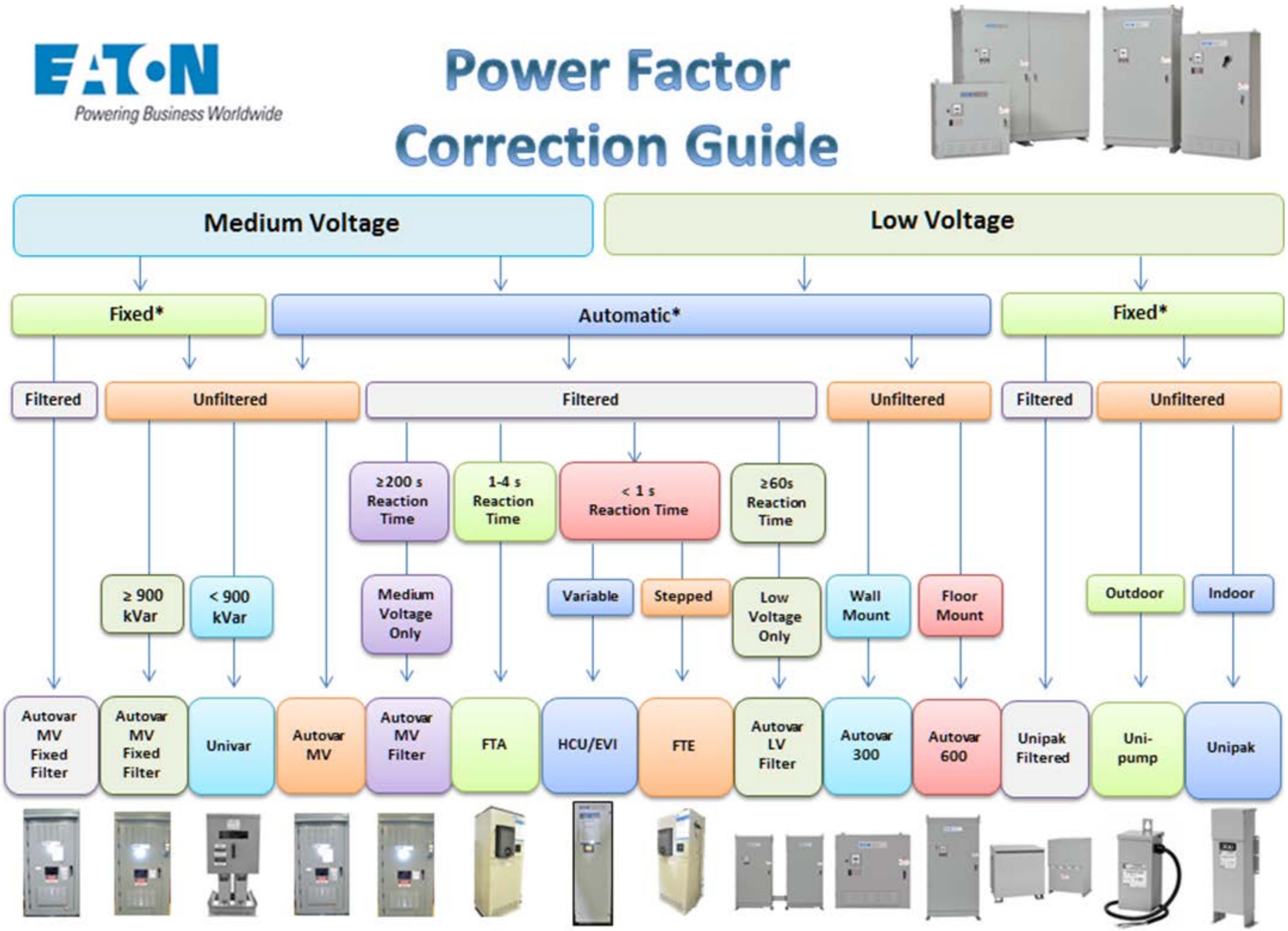
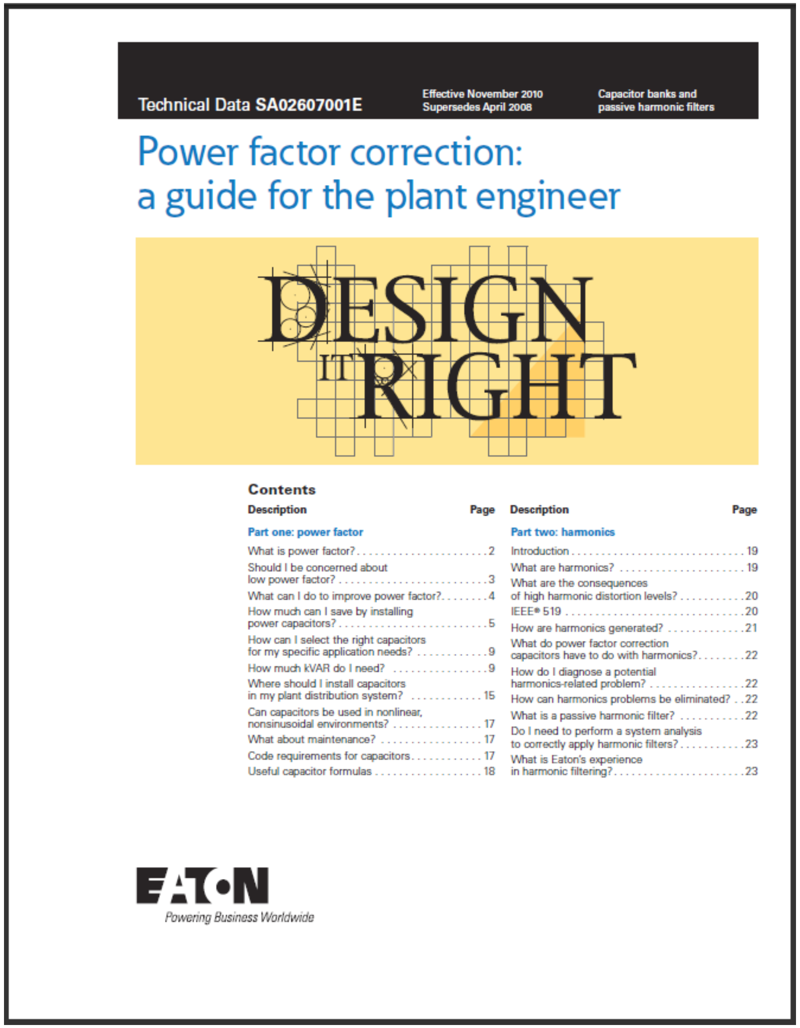
PFC Tools – PFC Selection Chart



PFC Literature – Design it Right Guide


Technical Data SA02607001E
Effective November 2010
Supersedes April 2008
Capacitor banks and
passive harmonic filters

Power factor correction:
a guide for the plant engineer

DESIGN IT RIGHT

Contents

Description	Page	Description	Page
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Should I be concerned about low power factor?	3	What are harmonics?	19
What can I do to improve power factor?	4	What are the consequences of high harmonic distortion levels?	20
How much can I save by installing power capacitors?	5	IEEE® 519	20
How can I select the right capacitors for my specific application needs?	9	How are harmonics generated?	21
How much kVAR do I need?	9	What do power factor correction capacitors have to do with harmonics?	22
Where should I install capacitors in my plant distribution system?	15	How do I diagnose a potential harmonics-related problem?	22
Can capacitors be used in nonlinear, nonsinusoidal environments?	17	How can harmonics problems be eliminated?	22
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Code requirements for capacitors	17	Do I need to perform a system analysis to correctly apply harmonic filters?	23
Useful capacitor formulas	18	What is Eaton's experience in harmonic filtering?	23

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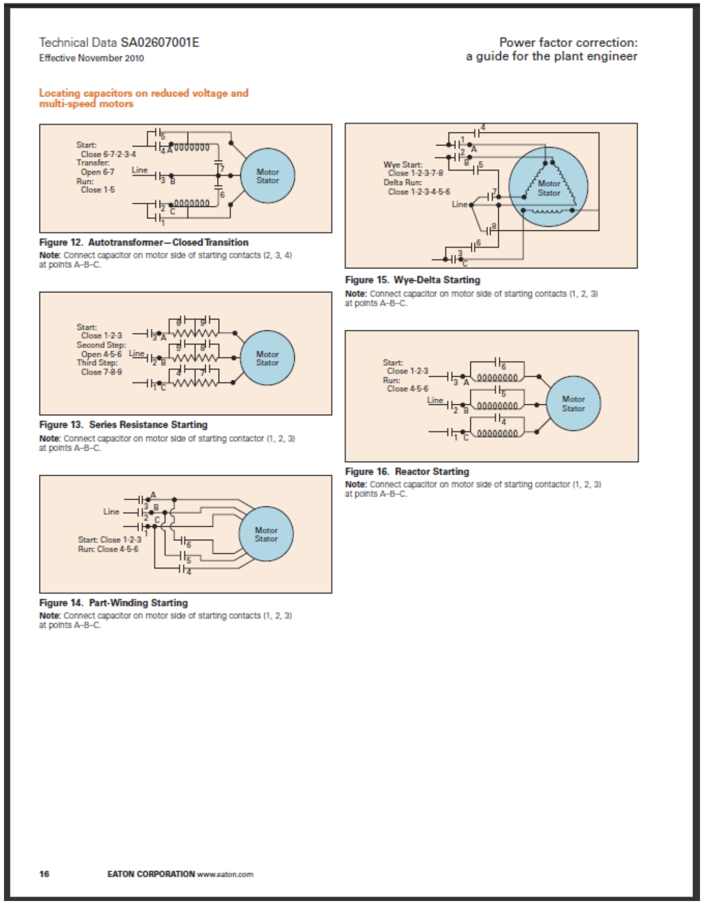
Application Examples


Technical Data SA02607001E
Effective November 2010

Power factor correction:
a guide for the plant engineer

Locating capacitors on reduced voltage and multi-speed motors

Figure 12. Autotransformer—Closed Transition

Note: Connect capacitor on motor side of starting contacts (2, 3, 4) at points A–B–C.

Figure 13. Series Resistance Starting

Note: Connect capacitor on motor side of starting contactor (1, 2, 3) at points A–B–C.

Figure 14. Part-Winding Starting

Note: Connect capacitor on motor side of starting contacts (1, 2, 3) at points A–B–C.

Figure 15. Wye-Delta Starting

Note: Connect capacitor on motor side of starting contacts (1, 2, 3) at points A–B–C.

Figure 16. Reactor Starting

Note: Connect capacitor on motor side of starting contactor (1, 2, 3) at points A–B–C.

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PFC Literature – Design it Right Guide

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Capacitor banks and passive harmonic filters

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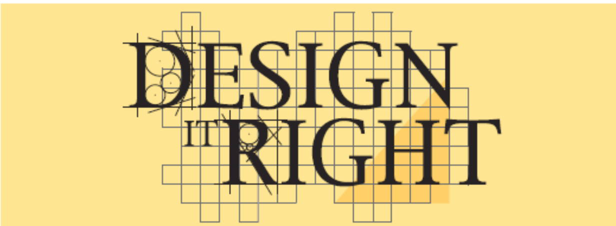

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Sizing Charts

Table 3. Suggested Maximum Capacitor Ratings

Induction Motor hp Rating	Number of Poles and Nominal Motor Speed in RPM											
	2–3600 RPM		4–1800 RPM		6–1200 RPM		8–900 RPM		10–720 RPM		12–600 RPM	
	Capacitor kVAR	Current Reduction %	Capacitor kVAR	Current Reduction %	Capacitor kVAR	Current Reduction %	Capacitor kVAR	Current Reduction %	Capacitor kVAR	Current Reduction %	Capacitor kVAR	Current Reduction %
Used for High-Efficiency Motors and Older Design (Pre "T-Frame") Motors ①												
3	1.5	14	1.5	15	1.5	20	2	27	2.5	35	3	41
5	2	12	2	13	2	17	3	25	4	32	4	37
7.5	2.5	11	2.5	12	3	15	4	22	5	30	6	34
10	3	10	3	11	3	14	5	21	6	27	7.5	31
15	4	9	4	10	5	13	6	18	8	23	9	27
20	5	9	5	10	6	12	7.5	16	9	21	12.5	25
25	6	9	6	10	7.5	11	9	15	10	20	15	23
30	7	8	7	9	9	11	10	14	12.5	18	17.5	22
40	9	8	9	9	10	10	12.5	13	15	16	20	20
50	12.5	8	10	9	12.5	10	15	12	20	15	25	19
60	15	8	15	8	15	10	17.5	11	22.5	15	27.5	19
75	17.5	8	17.5	8	17.5	10	20	10	25	14	35	18
100	22.5	8	20	8	25	9	27.5	10	35	13	40	17
125	27.5	8	25	8	30	9	30	10	40	13	50	16
150	30	8	30	8	35	9	37.5	10	50	12	50	15
200	40	8	37.5	8	40	9	50	10	60	12	60	14
250	50	8	45	7	50	8	60	9	70	11	75	13
300	60	8	50	7	60	8	60	9	80	11	90	12
350	60	8	60	7	75	8	75	9	90	10	95	11
400	75	8	60	6	75	8	85	9	95	10	100	11
450	75	8	75	6	80	8	90	9	100	9	110	11
500	75	8	75	6	85	8	100	9	100	9	120	10
"T-Frame" NEMA® "Design B" Motors ❶												
2	1	14	1	24	1.5	30	2	42	2	40	3	50
3	1.5	14	1.5	23	2	28	3	38	3	40	4	49
5	2	14	2.5	22	3	26	4	31	4	40	5	49
7.5	2.5	14	3	20	4	21	5	28	5	38	6	45
10	4	14	4	18	5	21	6	27	7.5	36	8	38
15	5	12	5	18	6	20	7.5	24	8	32	10	34
20	6	12	6	17	7.5	19	9	23	10	29	12.5	30
25	7.5	12	7.5	17	8	19	10	23	12.5	25	17.5	30
30	8	11	8	16	10	19	15	22	15	24	20	30
40	12.5	12	15	16	15	19	17.5	21	20	24	25	30
50	15	12	17.5	15	20	19	22.5	21	22.5	24	30	30
60	17.5	12	20	15	22.5	17	25	20	30	22	35	28
75	20	12	25	14	25	15	30	17	35	21	40	19
100	22.5	11	30	14	30	12	35	16	40	15	45	17
125	25	10	35	12	35	12	40	14	45	15	50	17
150	30	10	40	12	40	12	50	14	50	13	60	17
200	35	10	50	11	50	11	70	14	70	13	90	17
250	40	11	60	10	60	10	80	13	90	13	100	17
300	45	11	70	10	75	12	100	14	100	13	120	17
350	50	12	75	8	90	12	120	13	120	13	135	15
400	75	10	80	8	100	12	130	13	140	13	150	15
450	80	8	90	8	120	10	140	12	160	14	160	15
500	100	8	120	9	150	12	160	12	180	13	180	15

❶ For use with three-phase, 60 Hz NEMA Classification B Motors to raise full load power factor to approximately 95%.

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PFC Literature – Technical Data –LV & MV

Cutler-Hammer

Low Voltage Power Factor Correction Capacitor Banks and Harmonic Filters

Technical Data TD02607001E

Effective July 2008
Supersedes TD02607001E, Pages 1 – 32, Dated September 2007

Low Voltage Power Factor Correction Capacitor Banks and Harmonic Filters

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Active-Harmonic Filter-Harmonic Correction Units 25

Note:

Images contained in this document may be shown with optional components and features not included as part of the base offering.

Power Factor Correction Capacitors

Eaton® introduces Cutler-Hammer® power factor correction capacitor banks and harmonic filters. Power factor correction capacitors and harmonic filters are an essential part of modern electric power systems. Power factor correction capacitors are the simplest and most economical means of increasing the capacity of any power system, minimizing energy losses and correcting load power factor. In addition, power factor penalties can be reduced and power quality can be greatly enhanced.

There are several reasons to correct poor power factor. The first is to reduce or eliminate a power factor penalty charged by the utility. Another reason is that your existing transformer is, or shortly will be, at full capacity and installing power factor correction capacitors can be a very cost-effective solution to installing a brand new service. Depending on the amount of power factor correction (kvar that needs to be injected into the electrical system to improve the power factor) and the dynamic nature of the load, a fixed or switched capacitor bank may be the best solution. When capacity becomes a problem, the choice of a solution will be dependent upon the size of the increase needed. Like all power quality solutions, there are many factors that need to be considered when determining which solution will be best to solve your power factor problem.

Harmonic Filtering

As the world becomes more dependent on electric and electronic equipment, the likelihood that the negative impact of harmonic distortion increases dramatically. The efficiency and productivity gains from these increasingly sophisticated pieces of equipment have a negative side effect…increased harmonic distortion in the power lines. The difficult thing about harmonic distortion is determining the cause. Once this has been determined, the solution can be easy. Passive and active harmonic filtering equipment will mitigate specific harmonic issues, and correct poor power factor as well.

Metal-Enclosed Medium Voltage Power Factor Correction and Harmonic Filter Systems

Technical Data TD02607011E

Effective November 2008
Supersedes August 2005

Metal-Enclosed Medium Voltage Power Factor Correction System

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Product Description

Eaton's Cutler-Hammer® metal-enclosed medium voltage capacitors, systems and harmonic filters are designed for indoor or outdoor commercial, industrial and utility power systems requiring motor start support, power factor correction, harmonic filtering, IEEE 519 compliance, and increased system capacity. Fixed motor start capacitors are available to assist in motor starting applications. Engineered designs are available with a host of options and accessories to fit the requirements and desired configurations of virtually any installation. Single-stage and multi-stage, tuned or de-tuned filter banks can be supplied. Metal-enclosed medium voltage capacitor banks are designed for industrial, commercial and utility power systems involving motors, feeder circuits, and transmission and distribution lines where power factor improvement is required.

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PFC Literature – Customer Survey Sheet

PFC survey

Power factor correction capacitor bank survey sheet

Date: ____________

General

Customer: ____________

Customer contact: ____________

Address: ____________

E-mail: ____________

Phone: ____________

Eaton contact: ____________

Preliminary information for budgetary estimate

Name of utility* ____________

Current billed demand* (kW/kVA) ____________

Present power factor (known/calculated)* (lagging) ____________

Desired power factor* (lagging) ____________

kVA of service transformer (kVA) ____________

Transformer primary and secondary voltages (V) ____________

Impedance of transformer (if known) (%Z) ____________

Nonlinear loads present (Y/N) ____________

Approximate ratio of nonlinear load to total load (%) ____________

*If information is unknown, please provide the following:

- ☐ Rate sheet attached/rate structure ____________
- ☐ Past 12 months of billing information attached (if not available, at least 3 months summer and 3 months winter bills)

Additional information required for a quote

Intent: ____________

(Reduce or eliminate PF penalty, release plant/transformer/cable capacity, assist in voltage regulation, filter or correct harmonics, fault ride-through, bus voltage support, or other).

- ☐ Plant one-line drawing attached (if not available, a hand sketch of the distribution system) showing major distribution levels (HV, MV, LV and distribution panels and PF expected/observed at each distribution level)

Distribution and utilization voltage (HV/MV/LV) ____________

Additional source of generation (co-gen, diesel generators, etc.) ____________

Total connected load (kVA/kW/hp) ____________

Total demand load (kVA/kW/hp) ____________

Largest motor size (kW/hp) ____________

Largest non-motive load (kVA/kW/hp) ____________

Type of nonlinear load ____________

- ☐ Adjustable speed drives type (DC drives, 6 pulse, 12 pulse, 18 pulse) ____________
- ☐ Soft starters
- ☐ Arc furnaces
- ☐ Welders
- ☐ UPS
- ☐ UV equipment
- ☐ DC–DC, AC–DC converters (electrolysis cells, etc.)
- ☐ Others (please describe) ____________

Type of production facility: (cement, chemical, sawmill, underground mine, etc.) ____________

Type of environment: (dusty, conductive metallic dust, hazardous, very hot, marine, chemically reactive, etc.) ____________

Short-circuit capacity of the system on the primary side (MVA) ____________

Are there PF capacitors currently present? (Y/N) ____________

(Preferably collect information on utility bulk correction capacitors for the line)

If yes, kVAR capacity and voltage (kVAR) ____________

(volts) ____________

Eaton Corporation
Electrical Sector
1000 Cherrington Parkway
Moon Township, PA 15108
United States
TRC 800-809-2772 (Option 4, then 2)
pfc@Eaton.com

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What to do next?

- Contact Eaton – GSF, Manufacturing Representative, Technical Resource Center (TRC) and our website
  - Website: www.eaton.com/pfc
    - Calculators, data sheets, presentations, site surveys
  - TRC: 800-809-2772, Option 4, Option 2
    - Answered during business hours Eastern Time. Typical response turnaround 24 hours or less.

The Hidden Threat

Quick introduction to Surge Protection

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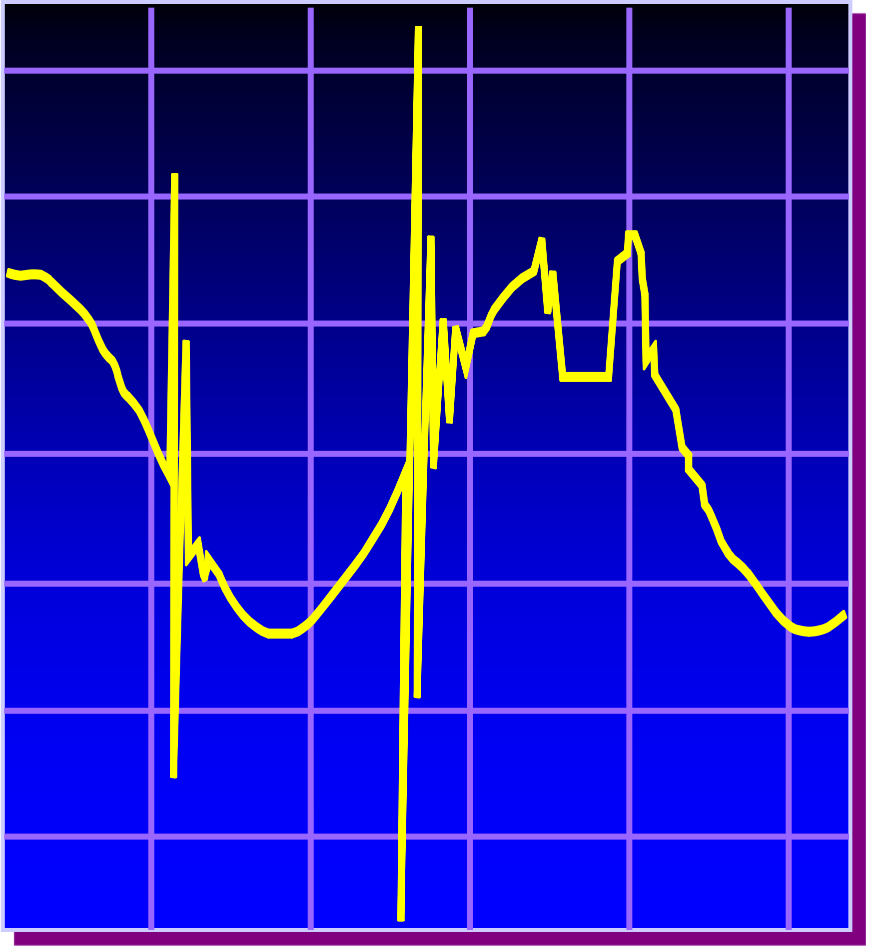
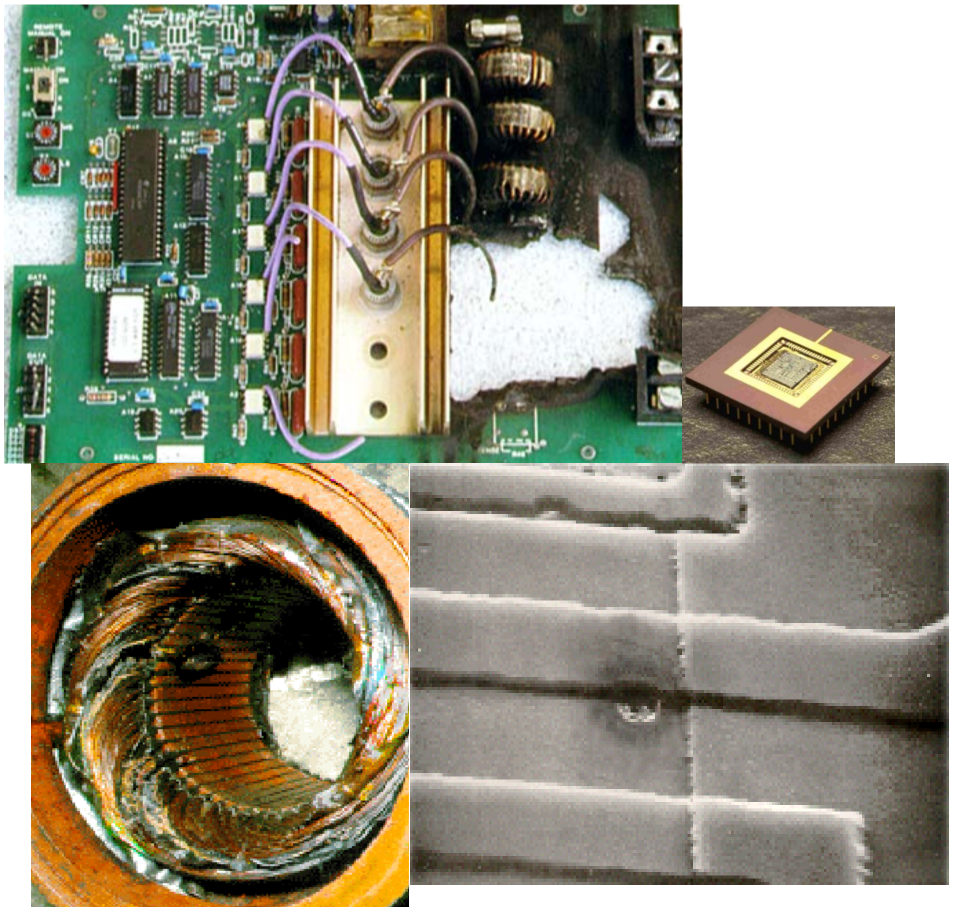
Voltage Transients (Surge)



Definition

A high rising voltage condition which lasts 2 ms or less and can produce up to 20 kV!

What is the Threat?



- Equipment damage
- Insulation breakdown
- Premature aging
- Process interruption
- Data loss

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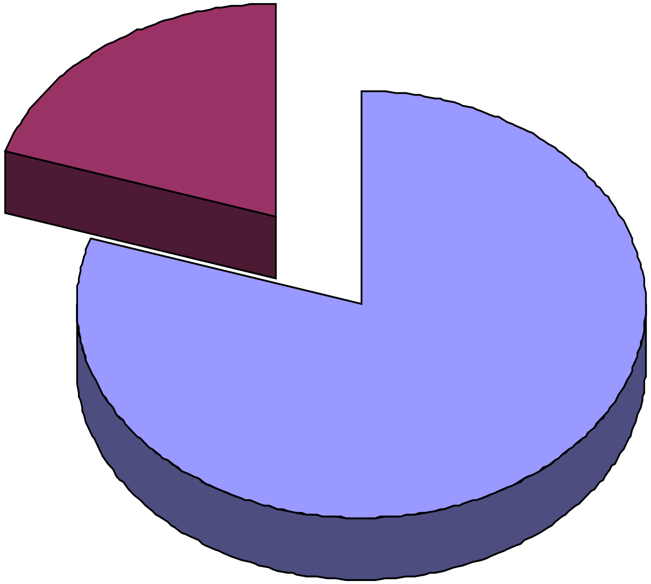
What are the Causes?



20% External

- Lightning
- Capacitor switching
- Utility load switching

80% Internal

- Load switching
- Short circuits
- Manufacturing Equipment
- VS Drives

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SPD Design

Design Tips

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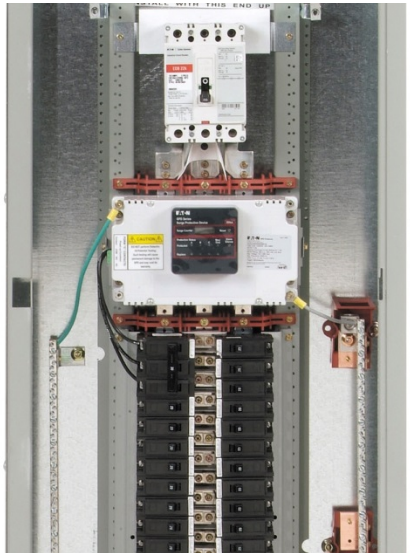
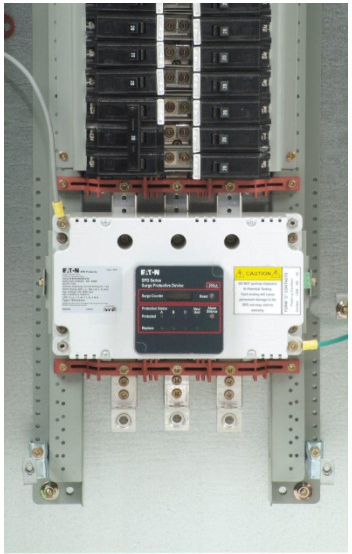
Independent tests confirm better performance with integrated SPDs

Good → **Better** → **Best**





Side Mount

Good let-though if leads are short.

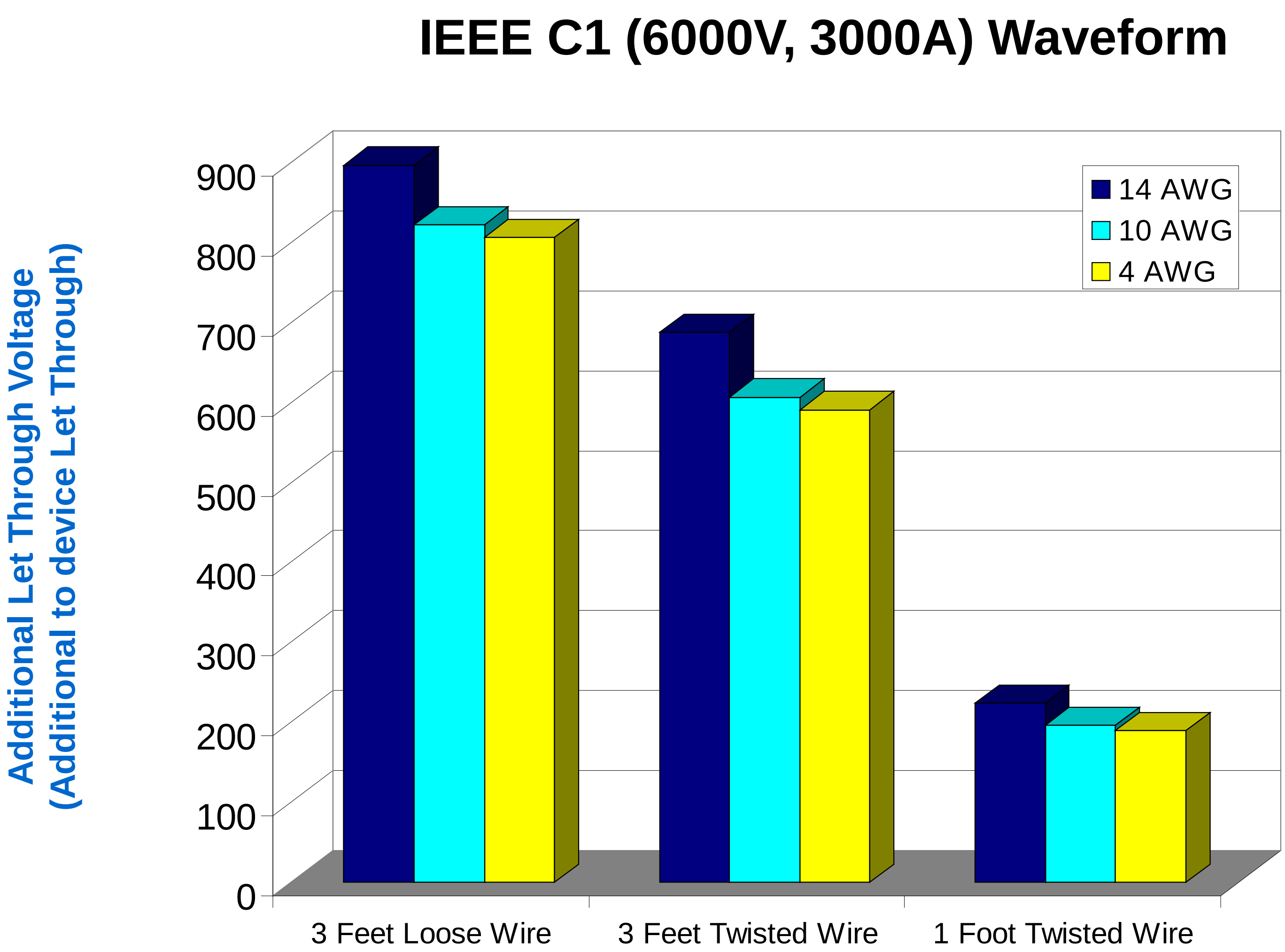
Wired Connection

Better than side mount.

Direct Bus Connected

Best Protection

Performance/Application - Affect of Lead Length on Let-through Voltage



Nameplate Data - Peak surge current rating

- The peak surge current is a predictor of how long an SPD will last in a given environment
  - The higher the kA, the longer the life of the MOVs
- Similar to the tread on a tire
  - The thicker the tread, the longer the tire will last

IEEE Emerald Book facts

Panelboards are available that contain integrally mounted SPDs that minimize the length of the SPD conductors, thus **optimizing the effectiveness** of the device.

"Why is my SPD Not Protecting Me?"

Biggest News in Surge Protection

2014 NEC Article 700.8 **requires** surge protection for emergency circuits. Eaton has produced Sales Aid SA158003EN to describe this code change and impact. The document is available on literature fulfillment and the website.

Surge protection

NEC surge protection requirement for emergency power systems

New requirement within 2014 National Electrical Code® (NEC®): Code change NEC 700.8—Surge protection required for emergency power panels

The 2014 National Electrical Code, Article 700.8, states: "A listed SPD shall be installed in or on all emergency systems switchboards and panelboards." The change requires surge protection to be installed on all emergency electrical equipment to improve the reliability of emergency power systems. The NEC defines emergency power systems as systems legally required to automatically supply power to designated loads upon loss of normal power. Protection of emergency systems is achieved by installing surge protection on panelboards, switchboards and other critical equipment.

Typical applications

Article 700.8 requires surge protection to ensure reliability of critical emergency systems such as:

- Medical care facilities
- Emergency lighting panels
- Emergency communication systems
- Fire control systems
- Elevators used for evacuation
- All other emergency panels, circuits and equipment

Recommended solutions

For new construction applications, integrating surge products into panelboards and switchboards provides the most reliable solution with superior performance.

Eaton's SPD series of surge protection products provides maximum surge protection with superior reliability. For existing installations, Eaton makes a complete line of products to meet your risk exposure needs.

Healthcare

Industrial

Data centers

Commercial

To contact an Eaton salesperson or local distributor, please visit:
Eaton.com/spd

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Eaton
1000 Eaton Boulevard
Cleveland, OH 44122
United States
Eaton.com

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