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We are glad you are here, its almost time to *"Sharpen the Saw"*.

While you are waiting, subscribe to our Podcast channel, The Power Grid.





PQU Online

Providing an educational environment for training, testing, and evaluation of today's power quality and data center solutions and equipment.

P3 leads Customer Education through Power Quality University (PQU):

- Highly Qualified, Expert Instructors
- Practical, Relevant Topics
- Continuing Education Credits (CEU's)

Upcoming Events

Surge Protection Devices – Thursday, July 23 – 12 PM – 1 PM CDT.
Generator Docking Station – Friday, August 7 – 9 AM – 11 AM CDT.

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Power Factor Correction



Presented by



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Presenter: Andy Angrick
Host: Amy Strong
Karah Butac

Program

- Power Factor Related Definitions
- Industry & Utility Standards
- Effects on a Facility
- Power Factor Correction Sizing

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P3 is the industry's trusted and respected advisor for critical power, cooling and energy solutions.



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Providing industry knowledge, product expertise, & technological innovation over a broad portfolio of products and services to our customers across a wide range of industries and applications.

To achieve zero downtime, scale the data center to meet ever changing requirements, and reduce energy costs, you need the most reliable and efficient power and cooling infrastructure available.

Modular & Scalable Data Center Equipment
Systems that grow and change with your modern Data Center.

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Modular / Scalable and Traditional
Data Center Equipment



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INDUSTRIAL POWER SOLUTIONS

Power Quality Specialists with expertise in your Power Quality needs.

Industrial Power Quality, doesn't just happen. It takes technical expertise, investment in products and facility coordination to achieve the desired levels of Power Quality. With experience in both new construction and retrofit installations, P3 can help you select and install the correct products.

We provide Industrial Power Quality Solutions





Surge Protection Devices

Harmonic Mitigating Transformers

Power Factor Correcting Capacitors

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System analysis and evaluation of power quality issues to provide solution recommendations for the best possible performance from your existing power system.

The ability to quickly identify and remedy power quality problems will lengthen the life of electrical equipment and improve power system availability.

Our engineering technicians will help you understand your unique facility power system.



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Service plans and support services that provide maintenance, parts, & service necessary to ensure the best possible performance from your existing power system.

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- Energy Management Services
- Power & Cooling Analysis
- Data Center Assessments
- Project Management
- Battery Replacement



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How P3 Operates



We use core values to guide us

Core Values

Blaze The Trail

Do the Right Thing

Be Humble and Honest

Create a Positive Influence



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Power Factor Correction



PQU seminars brought to you by
P3 gives you the information you
need to build confidence and
reliability in your electrical system.

Power Factor Correction is a complicated journey without a lot of direction and guidance but with the proper tools and people in place, a positive result is possible.



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Power Factor



The
POWER
GRID

- What is Power Factor?
- What is a good Power Factor?
- What is a Bad Power Factor?
- What problems are caused by a bad Power Factor?
- How to correct for a bad Power Factor.

This is the beginning of a long journey



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POWER QUALITY
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What is Power Factor?



The
POWER
GRID

- Power Factor is the ratio of **Active Power** to **Total Power**

$$\frac{\text{Active Power}}{\text{Total Power}} = \text{Power Factor}$$

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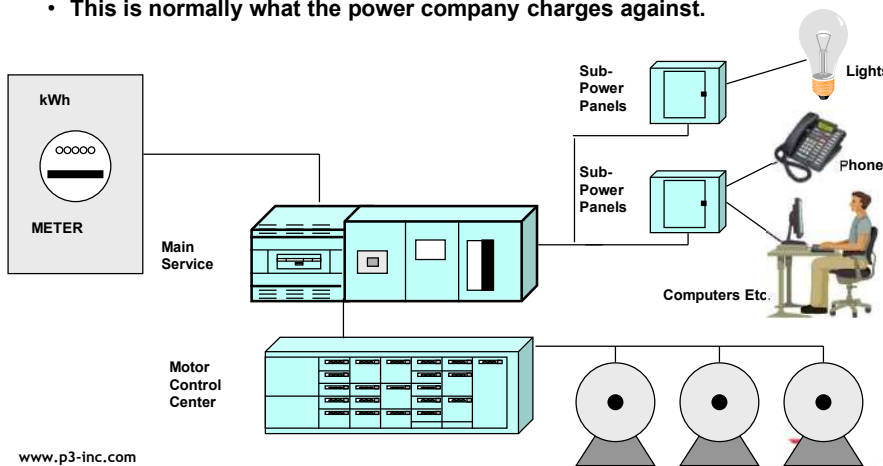
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Active Power



- Active power** is what we normally see as the electricity used in our facility.
- Measured in kW (Kilowatts).
- This is normally what the power company charges against.



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Total Power



- Total power** is what our equipment needs to be sized for in our facility.
- Measured in KVA (Kilo-voltamps).
- The power company may charge extra money (penalties) for a large KVA.
- The large KVA is usually stated in **Power Factor**.

Total Power is a combination of **Active Power** and something called **Reactive Power**.

$$\frac{\text{Active Power}}{\text{Total Power}} = \text{Power Factor}$$

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Reactive Power



Measured in Kvar

- **Reactive Power** takes into consideration the energy needed to build all the magnetic fields in a facility.
- Your facilities equipment must be sized large enough to handle the extra energy needed to produce these magnetic fields.
- Magnetic fields are produced in ALL current carrying equipment in a facility. This includes Switchboards, Panelboards, Busway, wiring, all equipment, and especially MOTORS. Motors have thousands of feet of wire which add greatly to a facilities **Reactive Power**

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Magnetic Fields



Produced in your Facility

- In a AC (Alternating Current) system, current flow changes direction 60 times every second. This is called 60 Hertz (Hz).
- Each time the current changes direction a magnetic field is developed around ALL current carrying parts of a circuit.
- This includes all the wire in your facility, all Motors and all transformers.

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Magnetic Fields



Produced in your Facility

680V

0V

680V



Section of Wire





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Magnetic Fields

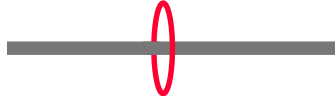


Produced in your Facility

680V

0V

680V



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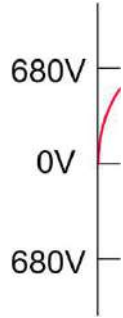
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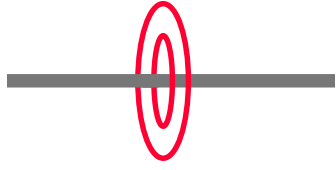


Magnetic Fields



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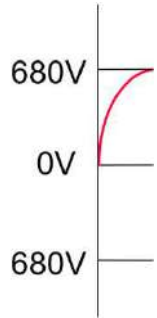
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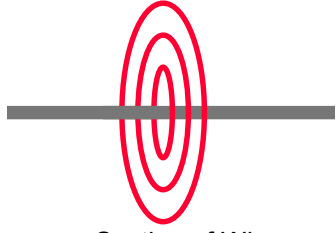


Magnetic Fields



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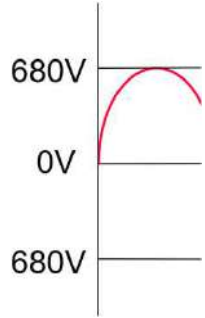
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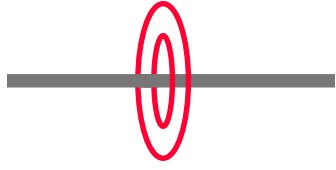


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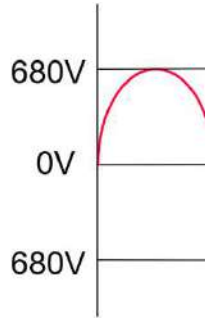
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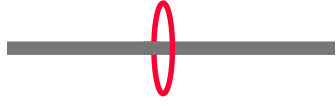


Magnetic Fields



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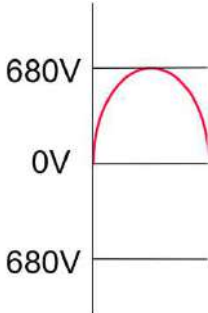
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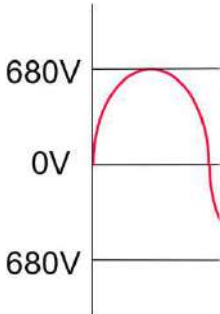
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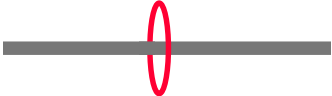


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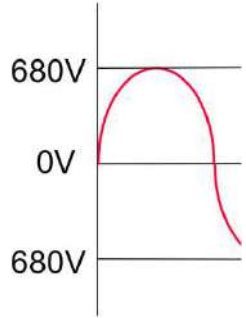
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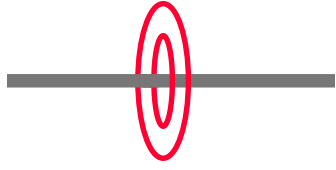


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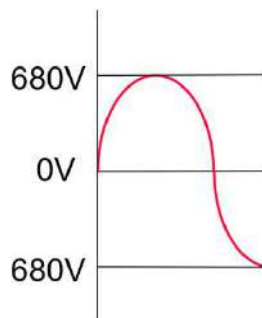
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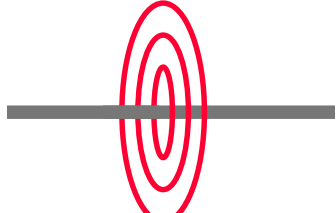


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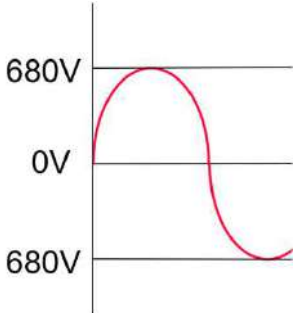
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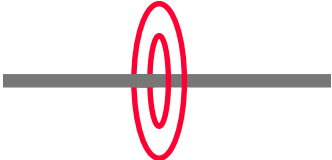


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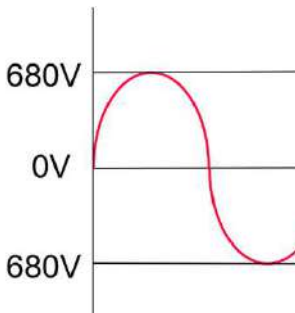
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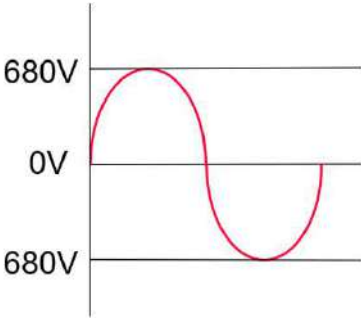
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Magnetic Fields

The POWER GR/D

Produced in your Facility





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Reactive Power

The POWER GR/D

- The energy needed to produce this Magnetic Field is real.
- You don't see it on your energy bill because the power is given back to the circuit in each quarter cycle.
- The extra current flow is there. Therefore, you and your power company must size equipment large enough to handle the extra energy needed to produce these magnetic fields.
- This is why many Power Companies add an extra charge (penalty) to facilities with a large amount of reactive power.

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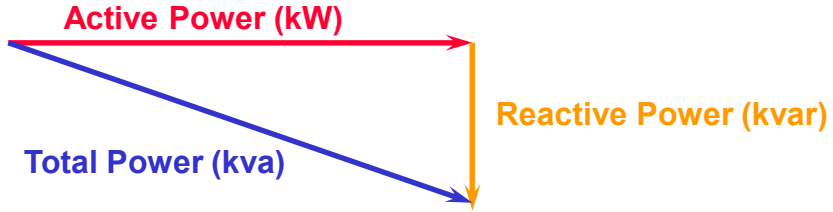
Power Factor



Remember...

Total Power is a combination of Active Power and Reactive Power.

This is how they combine:



$\text{Active Power (kW)}^2 + \text{Reactive Power (kvar)}^2 = \text{Total Power (kva)}^2$

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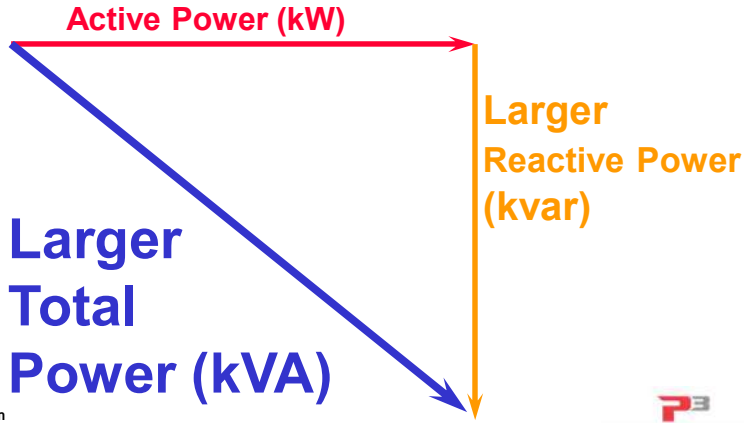
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Power Factor



As **Reactive Power** increases
Active Power stays the same however
Total Power increases greatly.



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Remember



- Power Factor is the ratio of **Active Power** to **Total Power**.
- When **Reactive Power** is large **Total Power** increases.
- With the formula below we now see that when **Total Power** increases the **Power Factor** decreases.

$$\frac{\text{Active Power}}{\text{Total Power}} = \text{Power Factor}$$

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Power Factor



$$\frac{\text{Active Power}}{\text{Total Power}} = \text{Power Factor}$$

- When **Total Power** increases the **Power Factor** decreases.

$$\frac{1000 \text{ kW}}{1050 \text{ kVA}} = .95 \text{ Power Factor}$$

$$\frac{1000 \text{ kW}}{1500 \text{ kVA}} = .6 \text{ Power Factor}$$

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Power Factor



$$\frac{1000 \text{ kW}}{1050 \text{ kVA}} = .95 \text{ Power Factor}$$

- .95 to 1 is considered a good power factor.

$$\frac{1000 \text{ kW}}{1500 \text{ kVA}} = .6 \text{ Power Factor}$$

- Anything less than .9 can be considered a bad **Power Factor**
- Your Power Company may charge you or you may have internal problems in your facility with **Power Factors** less than .9.

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Power Factor Solution



- The best way solve a low Power Factor problem is to install Power Factor Correction Capacitors.
- These Power Factor Correction Capacitors capture the energy from the collapsing magnetic field and give the energy back on the next Quarter cycle.

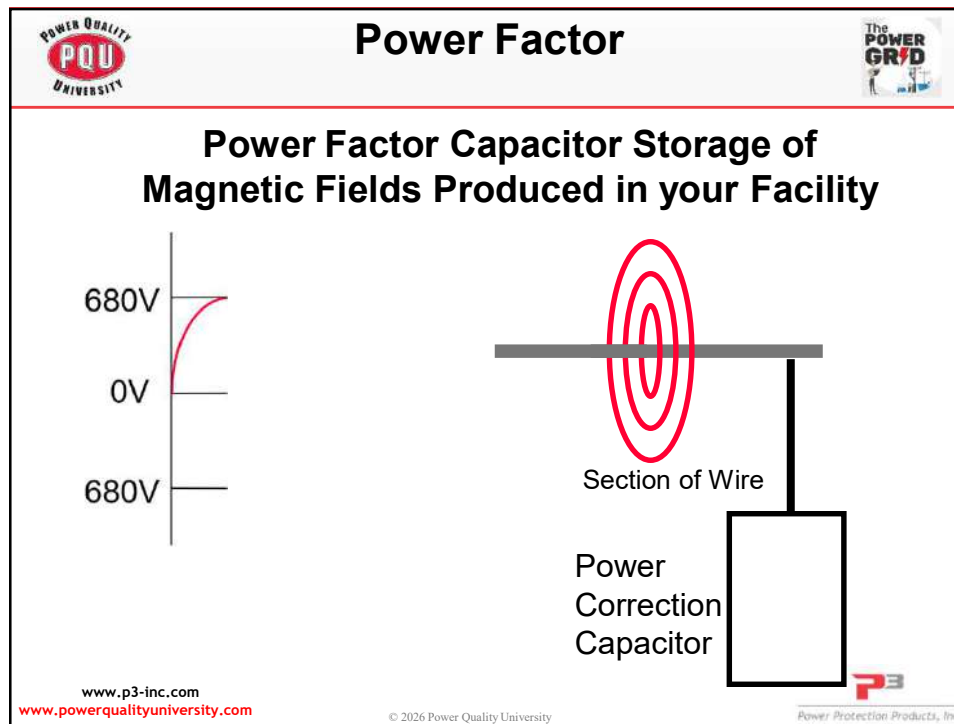
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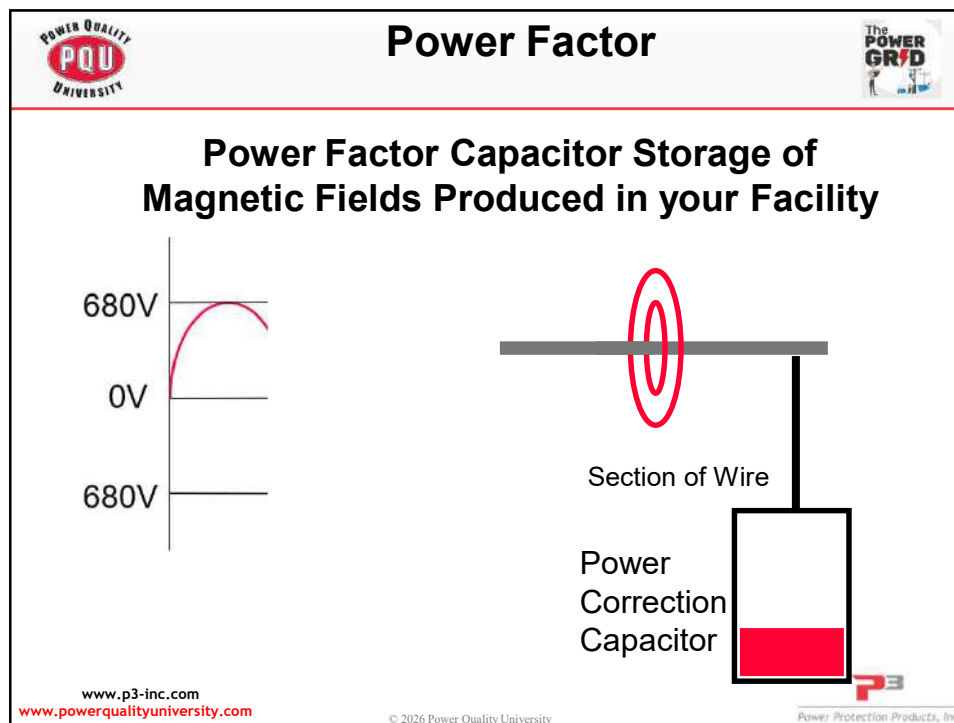


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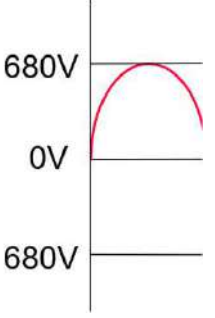
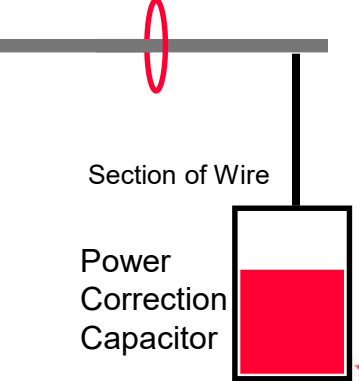
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Power Factor



Power Factor Capacitor Storage of Magnetic Fields Produced in your Facility

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Power Correction Capacitor

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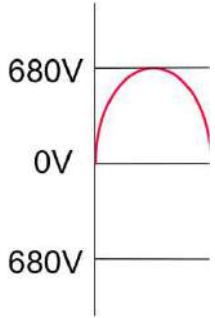
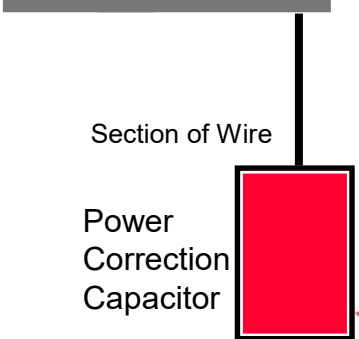
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Power Factor



Power Factor Capacitor Storage of Magnetic Fields Produced in your Facility

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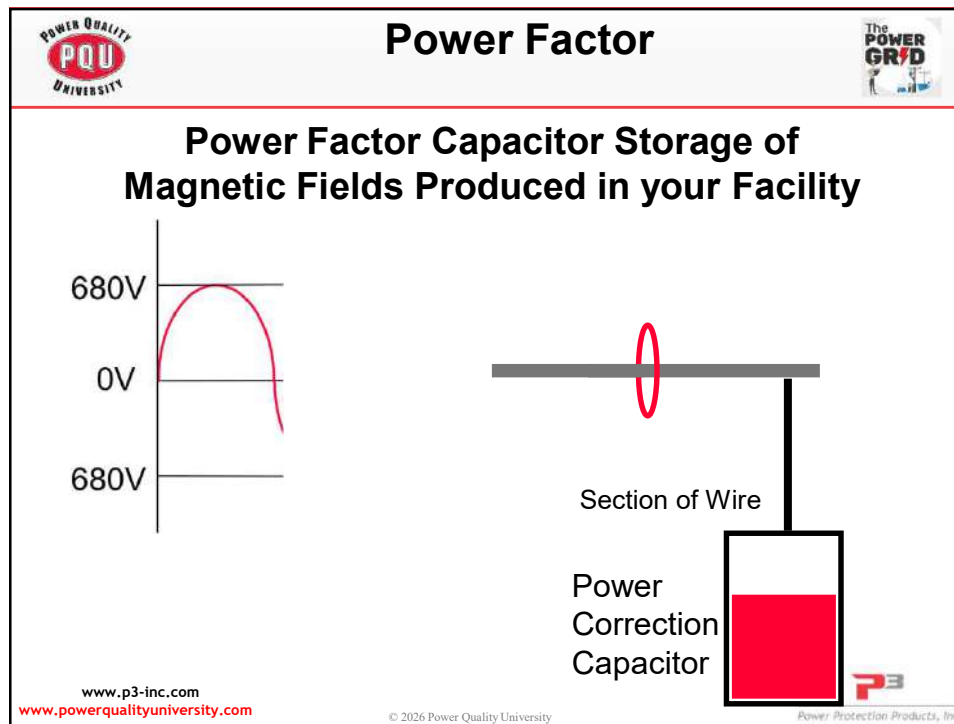
Power Correction Capacitor

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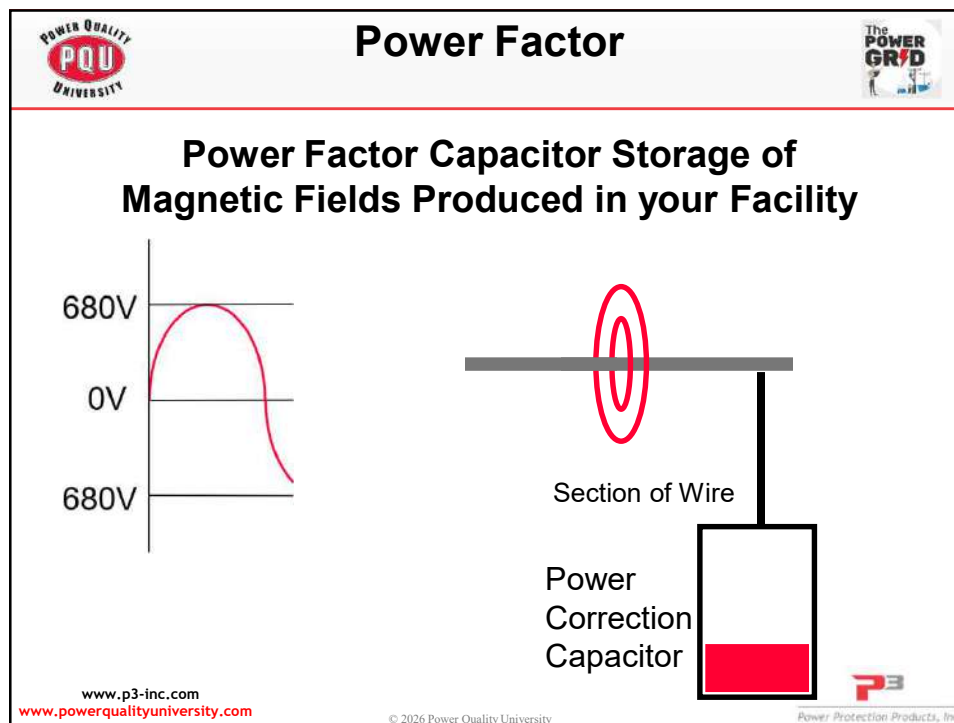
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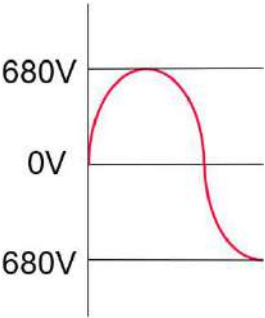
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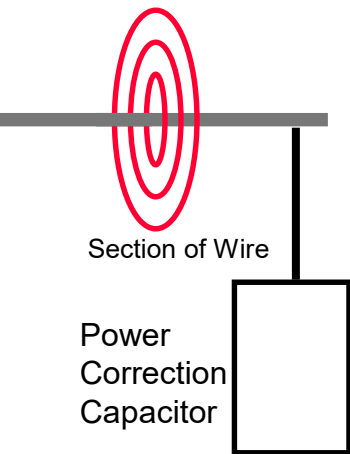


Power Factor



Power Factor Capacitor Storage of Magnetic Fields Produced in your Facility





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Power
Correction
Capacitor

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Power Factor



Why install Power Correction Capacitors?

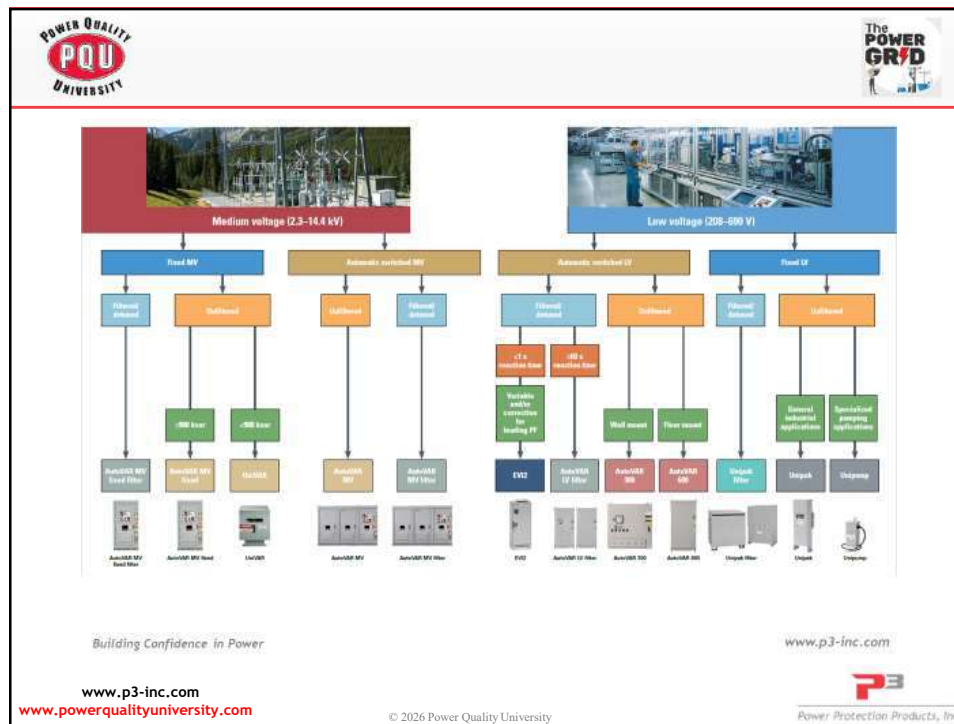
- With capacitors storing the energy from the magnetic fields the Power Company does not have to supply extra power, therefore, you do not get penalized.
- With proper placement of these Power Factor Correction Capacitors you can control your facilities power needs and reduce the costs of equipment to handle large Reactive Power Loads.
- Capacitors will raise the voltage in your system. It is rarely economical to install them for this purpose alone. The increase is usually less than 3%. It does have to be taken into account if it raises your voltage level to high.
- By installing capacitors and lowering KVA you can reduce energy losses in the form of heat in all system equipment.

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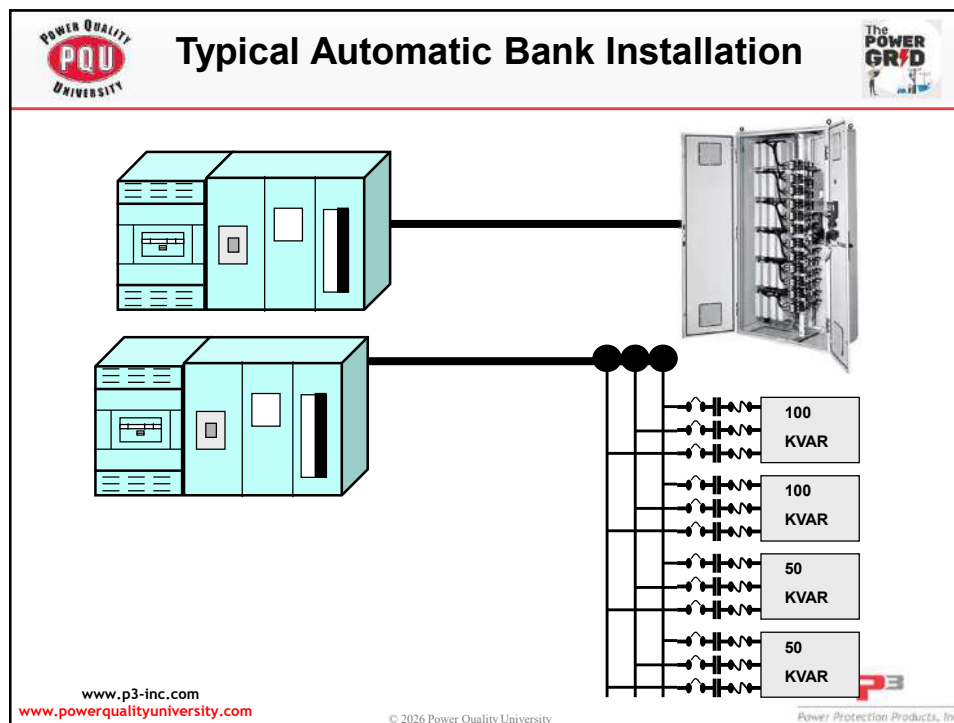
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Gaining Capacity with Power Factor Capacitors



$$\frac{1000 \text{ kW}}{1500 \text{ kVA}} = .6 \text{ Power Factor}$$

If we increase Power Factor, what happens to KVA?

$$\frac{1000 \text{ kW}}{1050 \text{ kVA}} = .95 \text{ Power Factor}$$





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Gaining Capacity with Power Factor Capacitors



1500 kVA on a 480 3 phase system is **1800 AMPS**

1050 kVA on a 480 3 phase system is **1200 AMPS**

Could we use this gain of 600 amps?

Absolutely!

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Power Factor: The above rate schedule is based on a power factor of 90% or higher. Where the power factor is less than 85%, the net demand charges will be increased by 1/10% for each 1/10% the power factor is below 90%; likewise where the power factor is higher than 95%, the demand charges will be decreased by 1/10% for each 1/10% the power factor is above 90%. The power factor shall be determined by suitable recording instruments. A power factor of 100% will be used in the event the Customer is providing kilovars to the IPL system at the time the billing demand is set.



.85 (or less) to .90 - Penalty Area

.90 to .95 No Penalty No Credit

.90 to .99 Full Credit (above .95)

Most Industrial Customers with poor power factor can reduce penalties plus increase credits by adding kvar

.85 (or less) to .99 No Penalty plus Full Credit

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Proper Power Factor Installation



PFCs do not generate harmonics, but their connection to a power system can change that system's ability to transmit harmonic currents.

If the changes are severe enough to send the power system into *resonance*, equipment protective and control system mis-operation and damage can result.

Harmonic resonance can be avoided by installing harmonic filters with the capacitors. Filter/capacitor units provide power factor correction, but are also designed to remove specific harmonic currents from causing damage to the system.

**How can you determine if harmonics will be a problem?
With any sizable kvar PFC installation (more than about 15% of the transformer rating in kVA) a harmonic assessment should be conducted.**

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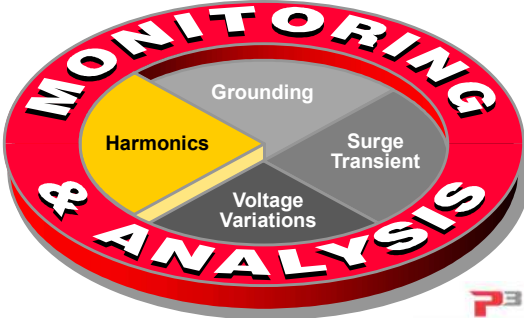
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- Harmonic problems are becoming more apparent because more equipment that produce harmonics are being applied to power systems





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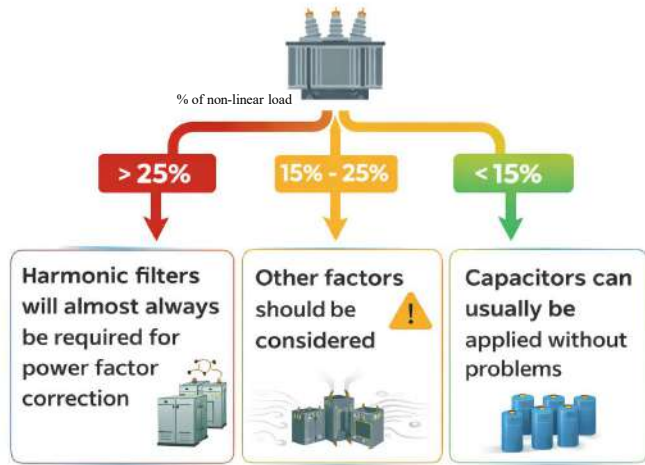

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Power Factor





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Which came first?.....

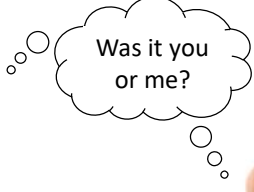




Voltage Distortion



Current Distortion



- In this case...the Egg!
 - Current distortion causes Voltage distortion
 - Voltage distortion is created by pulling distorted current through an impedance
 - Amount of voltage distortion depends on:
 - System impedance
 - Amount of distorted current pulled through the impedance
 - If either increases, V_{THD} will increase

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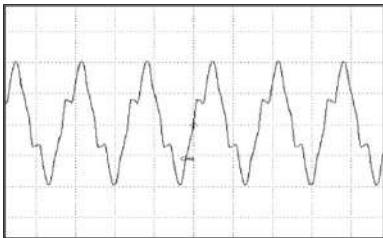


Harmonics



Total Harmonic Distortion (THD) –
 (voltage or current) represents a ratio of the root-mean-square of the harmonic content to the fundamental quantity, expressed as a percent of the fundamental.

$$\%THD_I = \frac{\sqrt{I_2^2 + I_3^2 + I_4^2 + \dots}}{I_1} \times 100\%$$



100%, 60 Hz
20%, 180 Hz
12%, 300 Hz
4%, 420 Hz
2%, 660 Hz
2%, 780 Hz

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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

$H = NP \pm 1$

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

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Harmonic Sources - VFD's



- The input side (AC) of all AC or DC drives are usually very similar. For most drives today, the input is a 6-pulse rectifier circuit.
- The harmonic current produced is related to the drive pulse number by the formula:

$$h = Np \pm 1$$
 - where h = the harmonic number
 - N = an integer multiplier beginning with 1
 - p = the pulse number.
- Theoretically, for a 6-pulse drive, the harmonic current produced would include
 - 5th, 7th, 11th, 13th, 17th, 19th, 23rd, 25th, etc.
 - Called the drive characteristic harmonics, and for the most part, their magnitudes decrease as their harmonic number increases
 - No even harmonics would be generated.

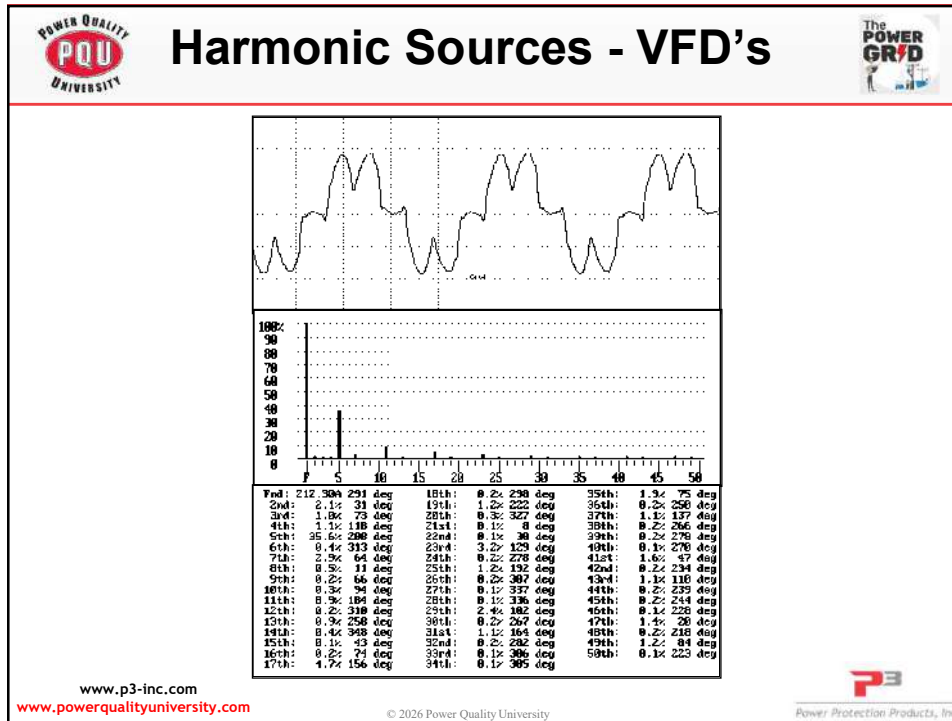
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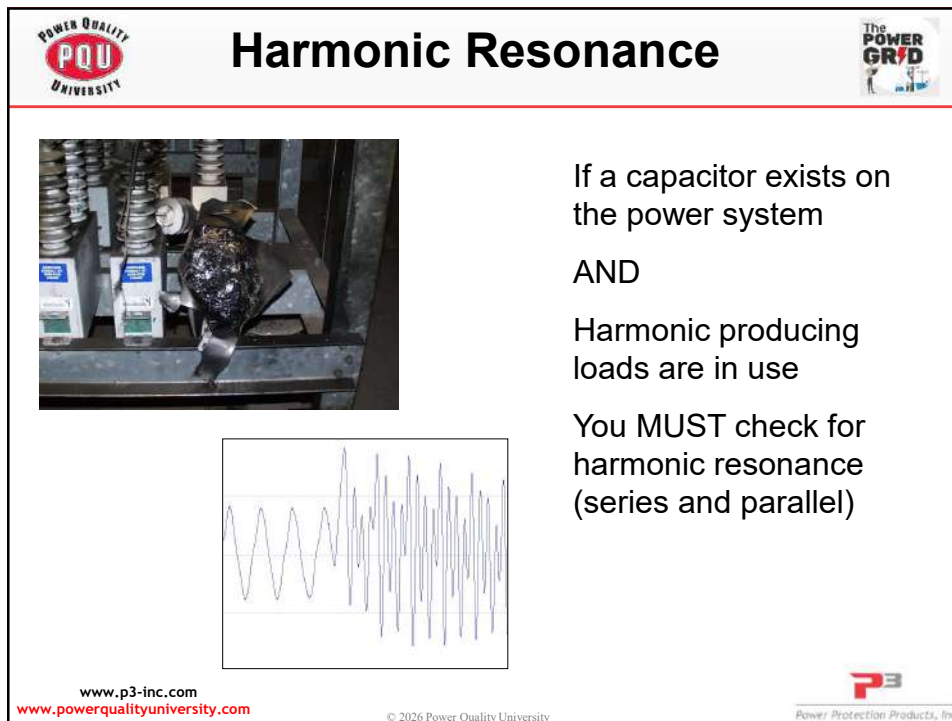


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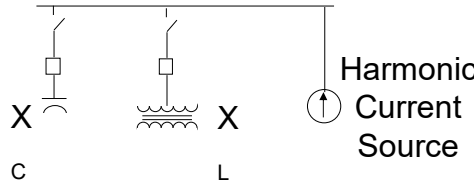
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Parallel Resonance



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- The parallel combination of impedance is:
$$X_{EQUIVALENT} = \frac{jX_L \times (-j)X_C}{jX_L + (-j)X_C}$$
- Since X_L and X_C have opposite signs, the denominator can equal zero if $X_L = X_C$. In reality, the only limiting factor is the difference in resistance between the capacitor and reactor.



Equivalent Parallel Resonant Circuit

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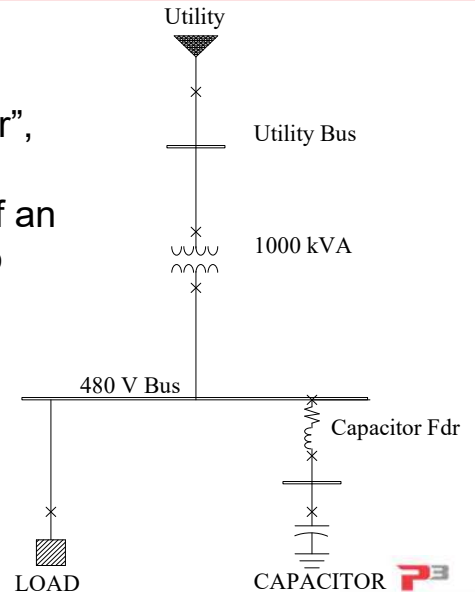
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Harmonic Modeling - Example



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If other loads on the system are “Non-Linear”, consider installing a harmonic filter in lieu of an “unfiltered” capacitor to avoid *RESONANCE*



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IEEE 519-Current



Maximum Harmonic Current Distortion

I_{sc} / I_L	TDD
1-20	5%
20-50	8%
50-100	12%
100-1000	15%
1000+	20%

I_{sc}=Maximum short circuit current
I_L= Maximum demand load
TDD= Total Demand Distortion

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IEEE 519-Voltage



Maximum Harmonic Voltage Distortion

Voltage	TVD
69kV and below	5%

TVD=Total Voltage Distortion

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Future of IEEE 519



- More concise document
- PCC clarified
- New voltage range
 - 1.0 kV and below
 - 8% THD_V
 - 5% individual voltage harmonics

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IEEE Std 519-2014



IEEE Std 519-2014 is “*The IEEE Recommended Practice and Requirements for Harmonic Control in Electrical Power Systems*” and is the most recent standard for harmonic regulations. This update (2014) superseded the IEEE Std 519-1992 recommended practice. Surprisingly, the standard reduced the scope and details of the earlier version and now the standard is a much more concise document. The original IEEE Std 519-1992 was 93 pages and the updated 2014 document is only 17 pages. This is rare for standards to reduce scope and content to clarify the message but the authors of this paper are convinced that this is the most significant change to help users of the standard understand its meaning and content. The major changes between the 1992 and 2014 are highlighted in **Table 2**.

Table 2. IEEE 519 1992 vs 2014 standard

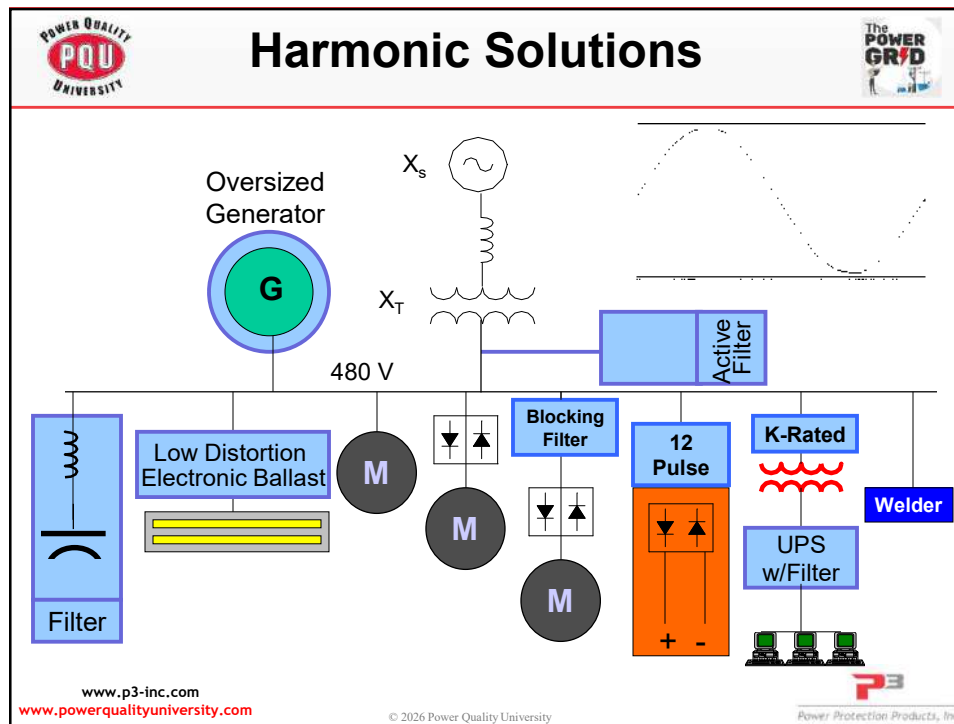
IEEE Std 519-1992	IEEE Std 519-2014
Detailed	Concise
Focused on teaching where harmonics come from, effects of harmonics, resonance and issues	Focused on recommended limits
Steady-state focus for limits	Limits based on statistical information (based on duration of excessive levels)
Voltage limit (for <1000 V)	Voltage limit (for <1000 V)
= 5% THD	= 8% THD
93 pages	17 pages

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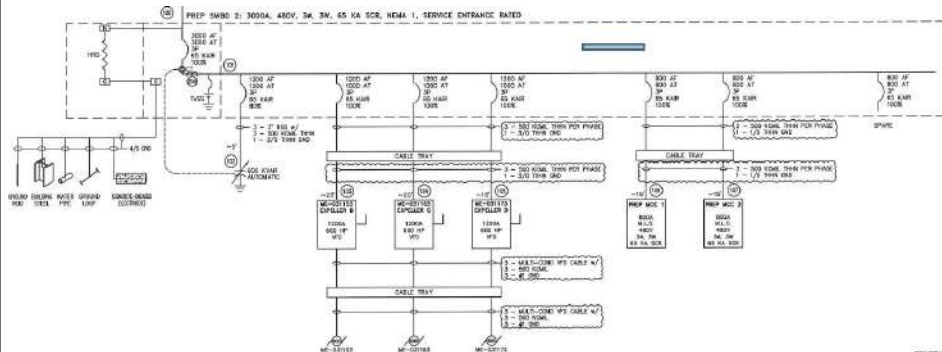


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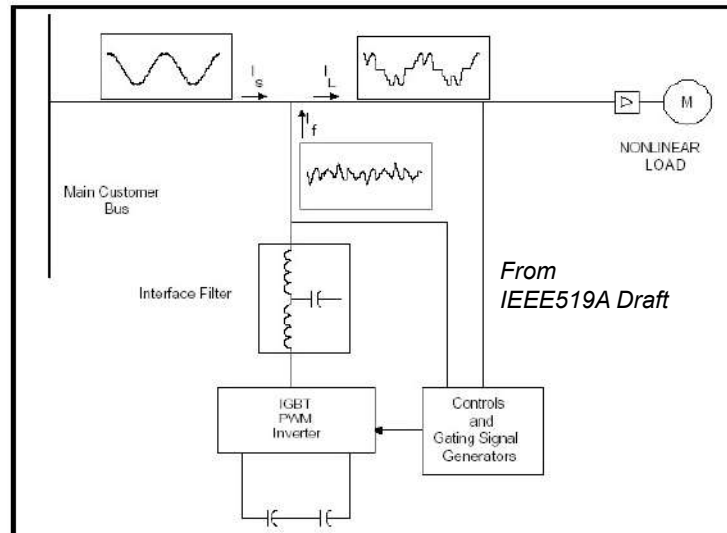
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Active Filters



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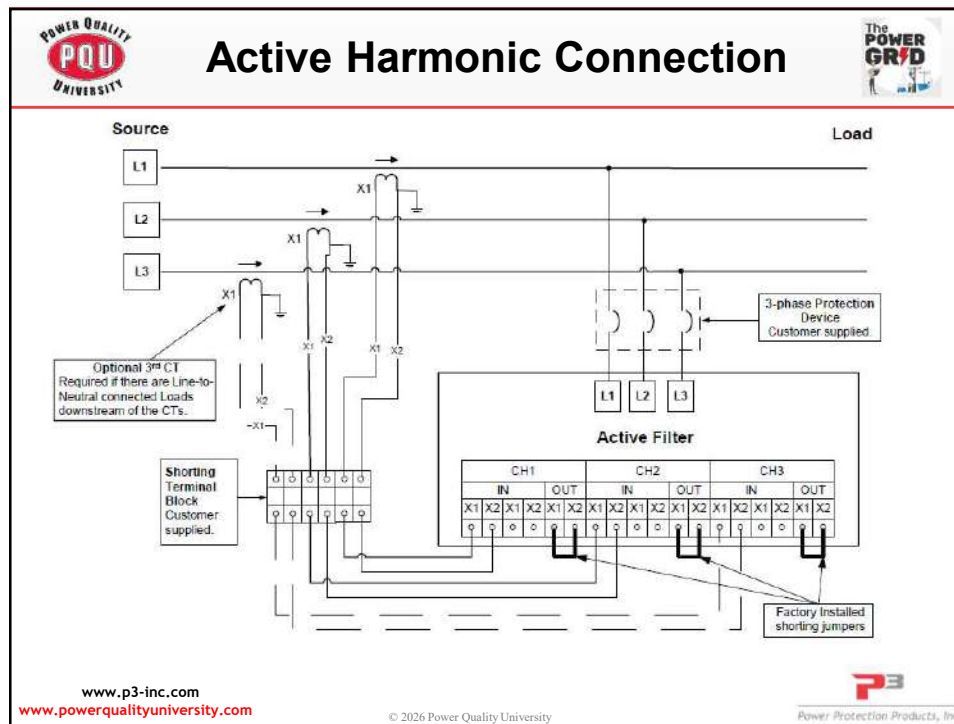
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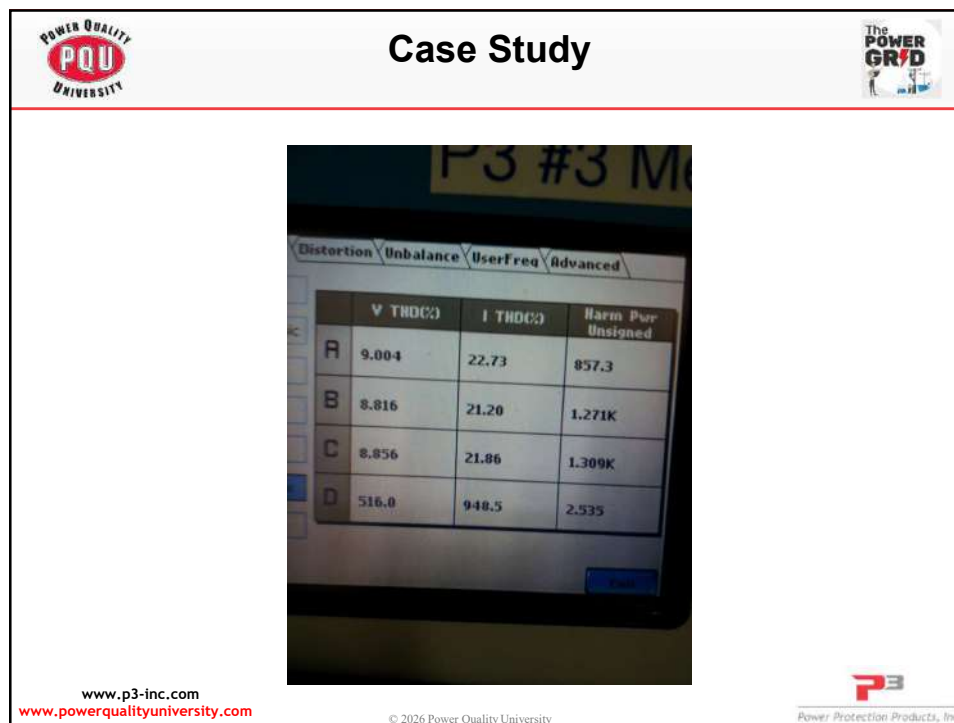
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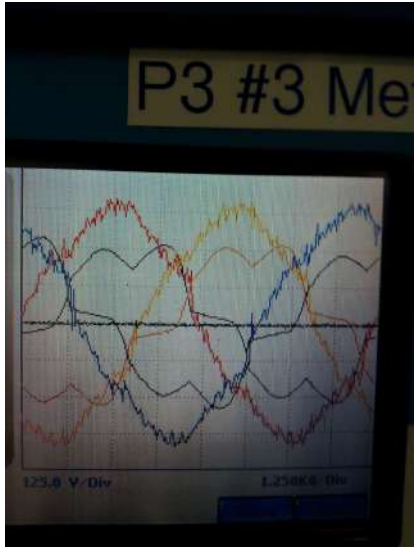


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	Watts	VA	VAR	TPF	DPF
A	452.4K	493.3K	136.5K	0.913	0.945
B	482.7K	525.1K	159.4K	0.919	0.950
C	462.7K	512.2K	178.7K	0.903	0.933
D	4.797	61.11	0.066	-0.078	-0.112
Tot	1.398M	1.482M	494.6K	0.943	0.929

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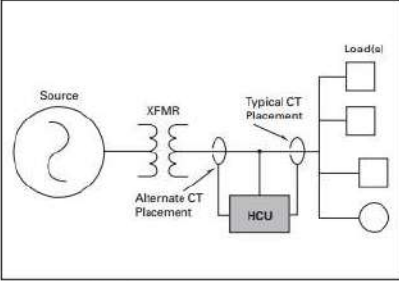

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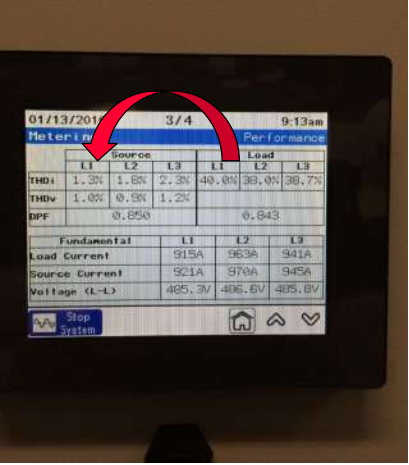
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Active Harmonic Correction







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HC Units Scalable





Up to 15 units



example

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Proper Power Factor Installation



Any Power Factor Capacitor installation should be accompanied by a Power Quality Study:

Size?
Type?
Location?
Harmonics?
Transients?
Growth?

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Power Factor Penalty



Some different ways of charging a Power Factor Penalty:

- KVA Billing
- KVA Demand Billing
- KW Demand Billing
- KVAR Demand Billing

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Sample Utility Bill



THANK YOU FOR BEING OUR CUSTOMER

Page 1 of 2 Statement date: July 1

Account #	Due Date	Amount Due
1399795246	July 20, 2016	\$8,621.12

SUMMARY

Previous balance \$3,708.86

Payments - Thank you -3,708.86

Balance forward 0.00

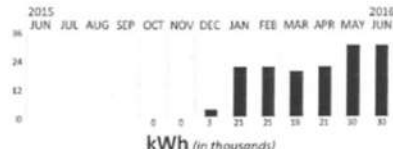
Current charges 8,133.13

City franchise fee 487.99

Total due by July 20, 2016 \$8,621.12



9 MONTH USAGE



kWh (in thousands)

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Sample Utility Bill



Page 2 of 2

Account #: 1399795246

Meter #: 04388699 Rate code: 370

CURRENT CHARGES

Basic service fee	\$100.00
Energy use	555.97
Demand	5,480.94
Fuel used in power generation	646.30
Property tax surcharge	66.48
Transmission	1,276.45
Energy efficiency	6.99
Total current charges	\$8,133.13
Average cost per day	\$254.16

BILLING FACTORS

Present meter read	01210
Previous meter read	00962
Billing multiplier	120
Energy use kWh	29,760
Actual demand kW	185
Power factor %	47.5
Adjusted demand kW	351
Summer peak kW	351
50% of summer peak kW	176
Peak demand month	June 2016
Tariff minimum demand kW	200
Billing demand kW	351
Cost of fuel per kWh	\$0.021717

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Sample Utility Bill

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Account #: 1399795246

Meter #: 04388699

Rate code: 370

Medium General Service

CURRENT CHARGES

Basic service fee	\$100.00
Energy use	555.97
Demand	5,480.94
Fuel used in power generation	646.30
Property tax surcharge	66.48
Transmission	1,276.45
Energy efficiency	6.99
Total current charges	\$8,133.13
Average cost per day	\$254.16

BILLING FACTORS

Present meter read	01210
Previous meter read	00962
Billing multiplier	120
Energy use kWh	29,760
Actual demand kW	185
Power factor %	47.5
Adjusted demand kW	351
Summer peak kW	351
50% of summer peak kW	176
Peak demand month	June 2016
Tariff minimum demand kW	200
Billing demand kW	351
Cost of fuel per kWh	\$0.02171

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Utility Bill Math

Actual usage in Kw charges:

$$\text{\$}555.97 + 646.30 + 1,276.45 + 487.99 = \text{\$}2,966.71$$

$$\text{\$}2,966.71 / 29760\text{kWh} = 10 \text{ cents per kW}$$

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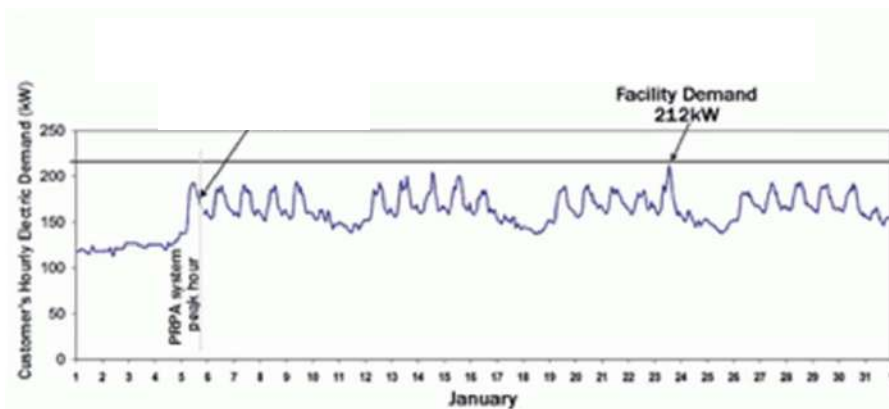
Utility Bill Math



- Demand charges **WITH** a LOW Power Factor
 - Actual kilowatt demand (kWD) = 185kWD
 - Adjusted kilowatt demand (kWD) = 351kWD
 - Demand charge on bill = \$5,480
1. Where does this Adjusted kilowatt demand come from?
 2. What is Kilowatt Demand (kWD)?



What is Kilowatt Demand (kWD)?





Where Does This Adjusted Kilowatt Demand Come From?



- This customer has a \$15.61 per kWD Demand charge
- If they were only charged for this demand, the bill would show:
 $185 \times \$15.61 = \$2,887$
- However, this utility has an additional charge for a low power factor.
- The Adjusted kW Demand is calculated by:
 Actual kW Demand divided by the actual Power Factor
 $185 \text{ divided by } .475 = 390\text{kWD}$
 $390\text{kWD} \times .9 = 351 \text{ kWD}$ (this utility only requires correction to 90%)
- $351 \times \$15.61 = \$5,480$ charge on the utility bill

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Why Install Power Factor Correction Capacitors?



- If we install Power Factor Correction capacitors and remove the Adjusted kW Demand charge:
 $\$5,480 - \$2,887 = \$2,593$ per month reduction in the utility bill
- For this facility we need a 300kVAR AUTOVAR unit to correct above a .9 power factor.
- A 300kVAR AUTOVAR costs approximately \$35,000 installed.
 $\$35,000 \text{ divided by } \$2,593 = \text{A 14 month payback for your customer.}$

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Call to Action



Power Factor Correction can be a challenging task

Consider all the Factors

- Equipment needs to be Sized for Your Facility
- Power Factor Correction Equipment Correctly Installed
- Power Quality Study Conducted
- Verify Meter Data Collection
- Interpret the Data
- Present the results
- Recommend a solution



ARE **YOU** UP FOR
THE CHALLENGE

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At the end of long power factor correction journey is the beginning of solution implementation and obtaining desired results.





is here to guide you on this journey.

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Building Confidence in Power

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Power factor correction offers a valuable benefit beyond just reducing utility penalties. It can significantly extend the lifespan of your electrical equipment, particularly transformers.

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