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Upcoming Events

Surge Protection Devices– Thursday, November 19 – 12 PM – 1 PM CST.

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Power Factor Correction

Presented by

Presenter: Barry Wallace
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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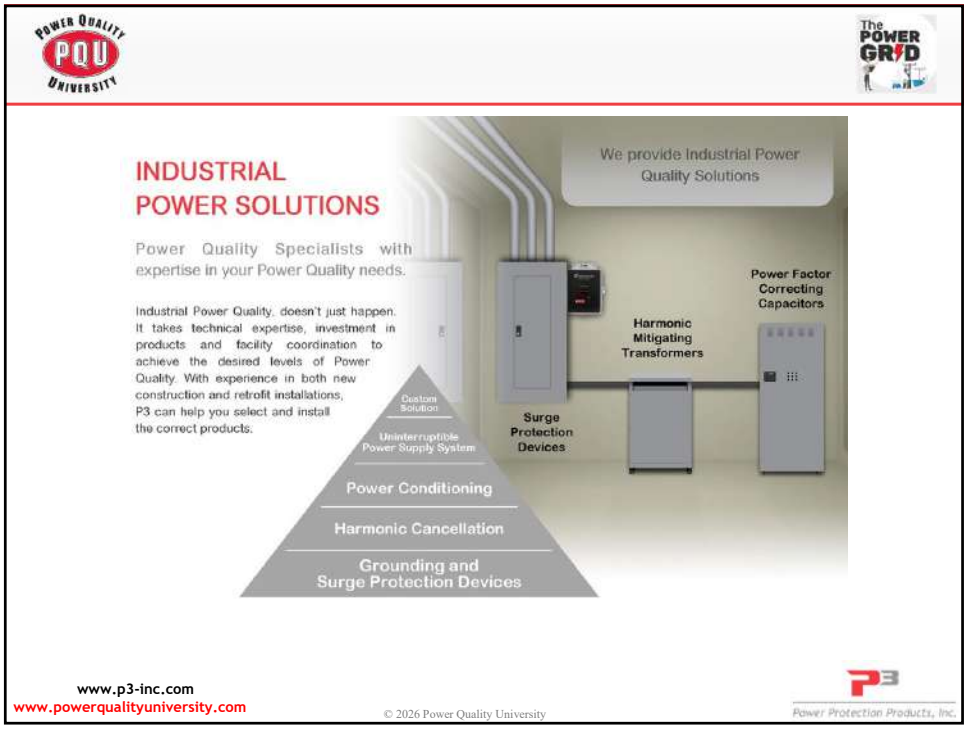
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Power Quality Specialists with expertise in your Power Quality needs.
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- Battery Replacement



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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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This webinar will be recorded

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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

- 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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What is Power Factor?

• Power Factor is the ratio of Active Power to Total Power

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

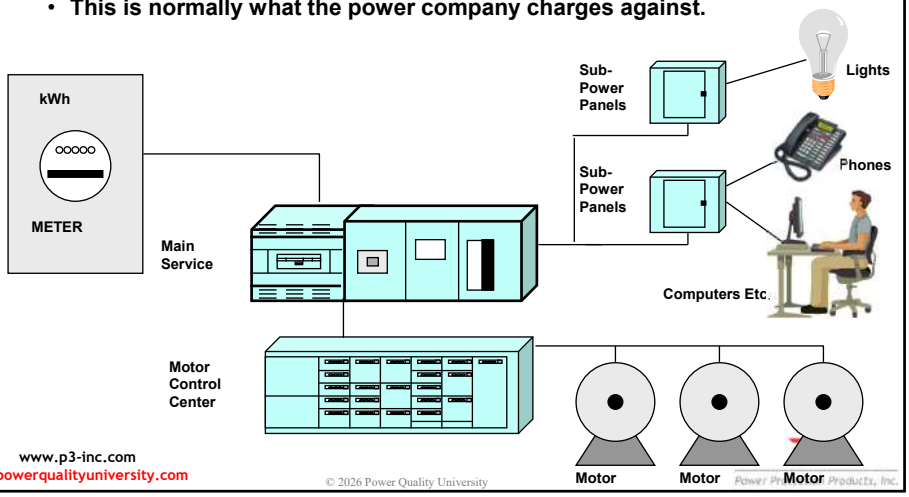
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Active Power

- **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

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Magnetic Fields

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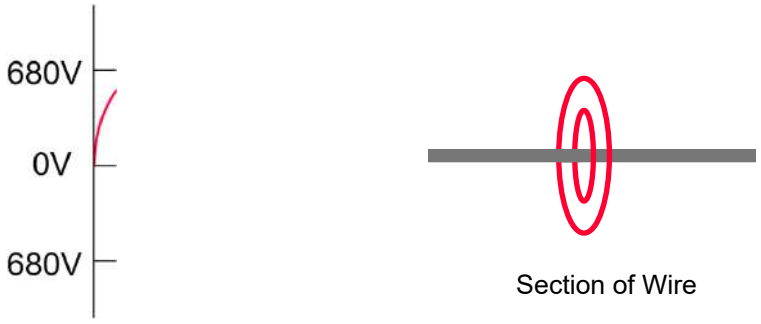
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Magnetic Fields

Produced in your Facility

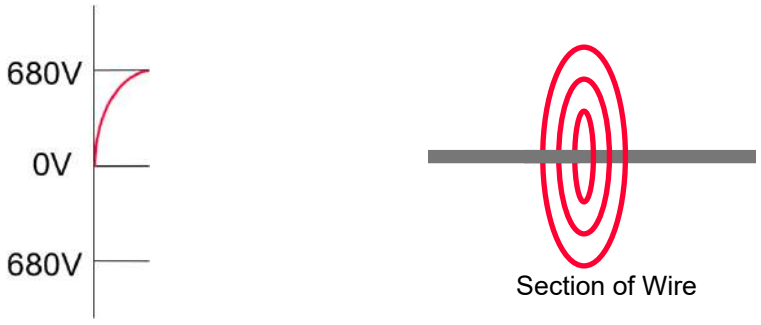


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Magnetic Fields

Produced in your Facility

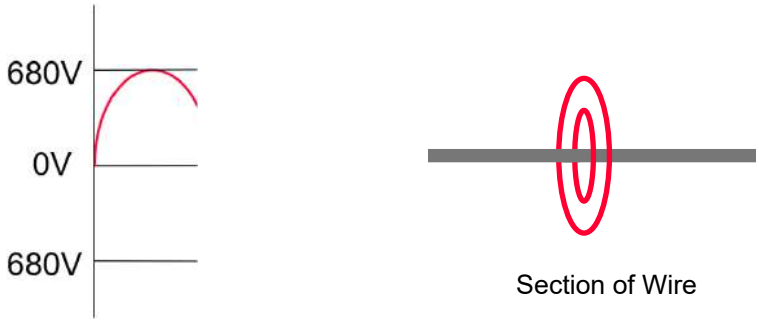


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Magnetic Fields

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Magnetic Fields

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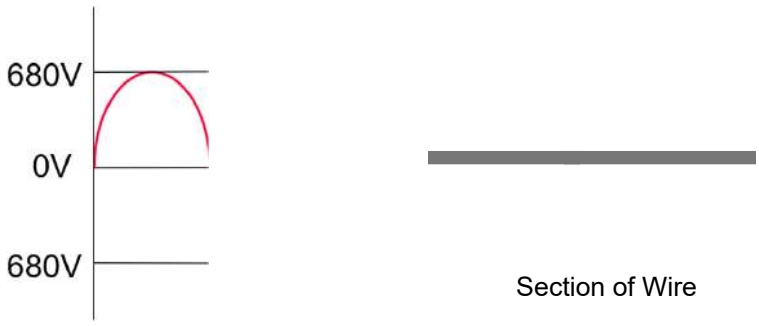


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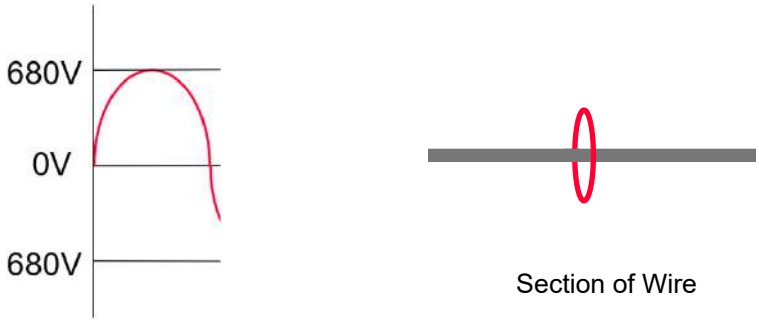


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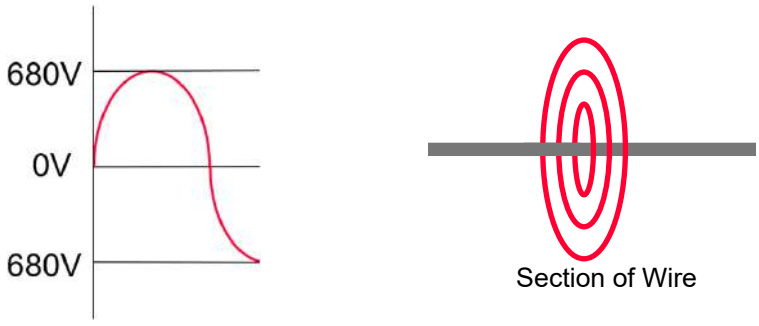


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Magnetic Fields

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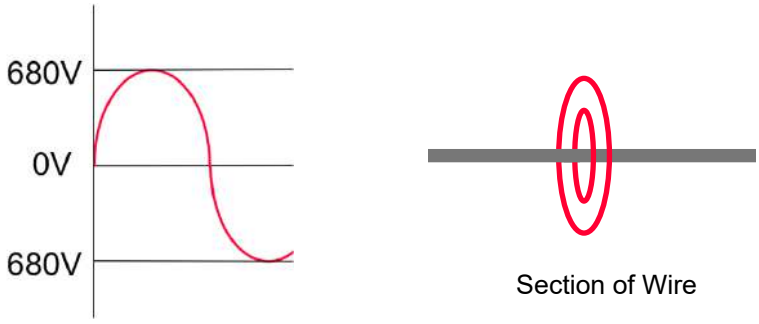


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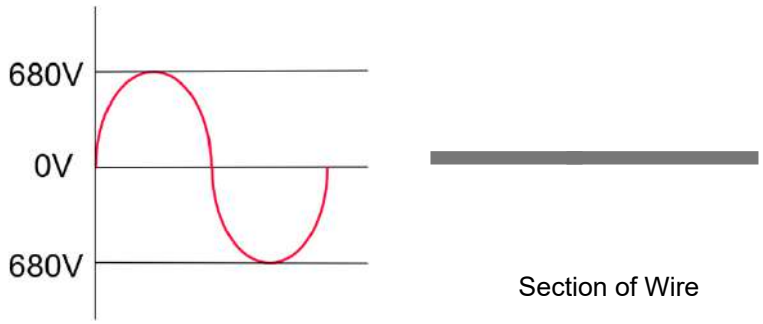


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Magnetic Fields

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Reactive Power

- 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.

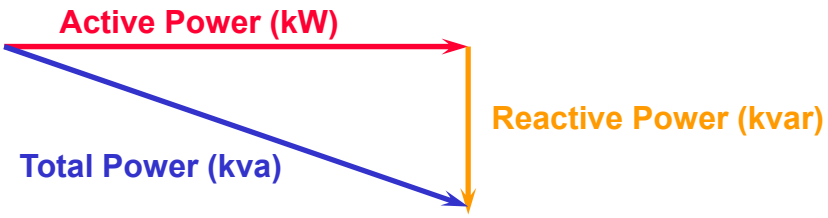
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Power Factor

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

This is how they combine:



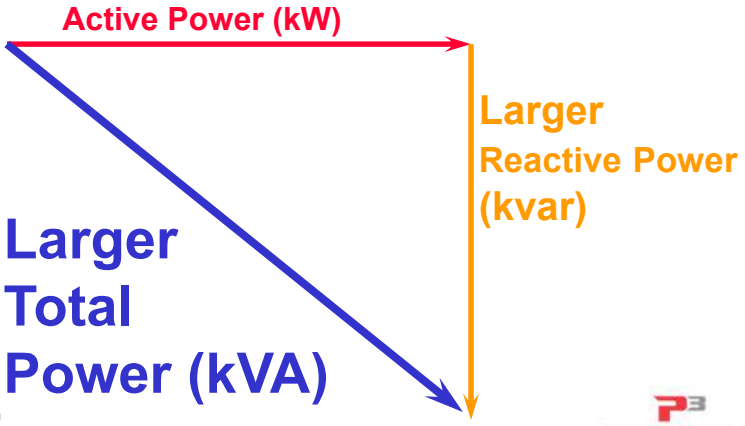
$$\text{Active Power (kW)}^2 + \text{Reactive Power (kvar)}^2 = \text{Total Power (kva)}^2$$

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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.

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

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

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Power Factor

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

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

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

- **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

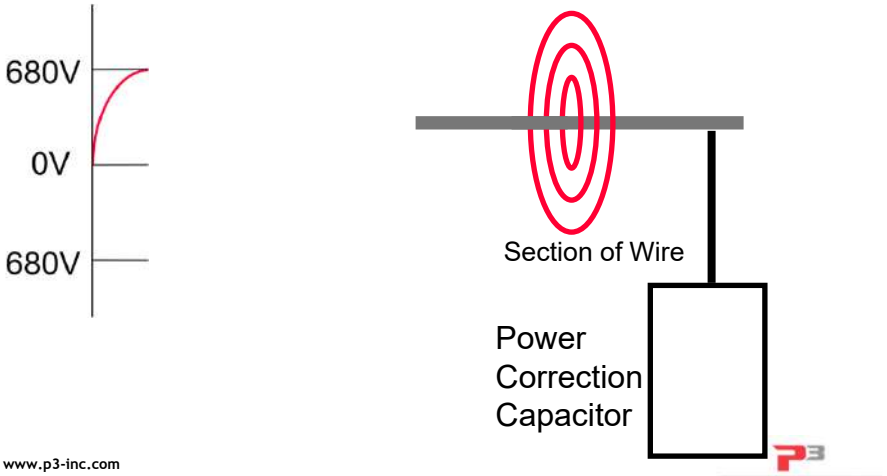
- **The best way solve a low Power Factor problem is to install Power Factor Correction Capacitors.**
- **These Power Factor Correction Capacitors capture the energy from the collapsing magnetic field and give the energy back on the next Quarter cycle.**

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Power Factor

Power Factor Capacitor Storage of Magnetic Fields Produced in your Facility

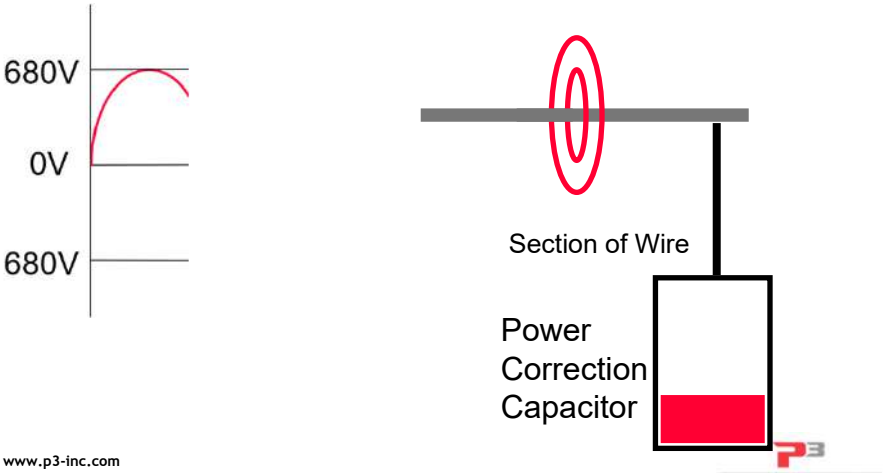


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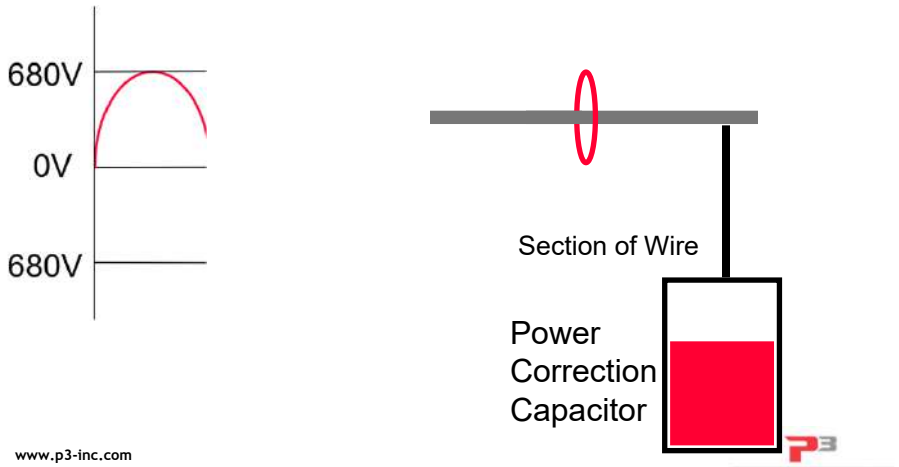


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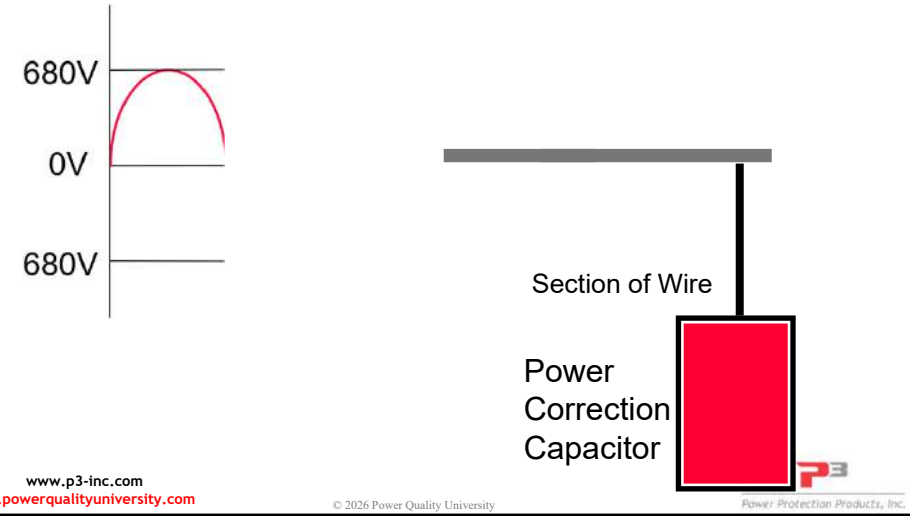
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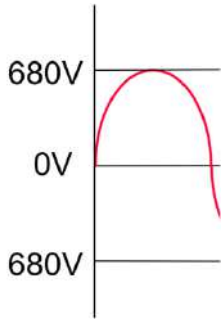
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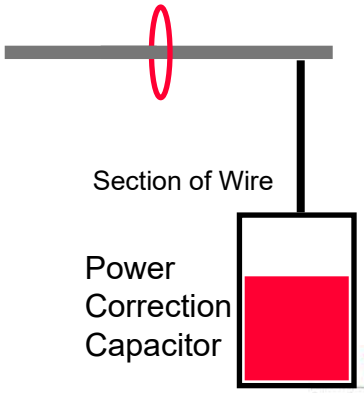
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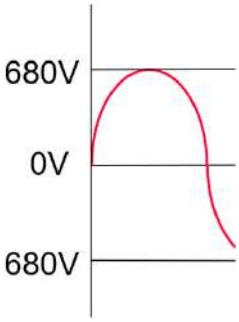
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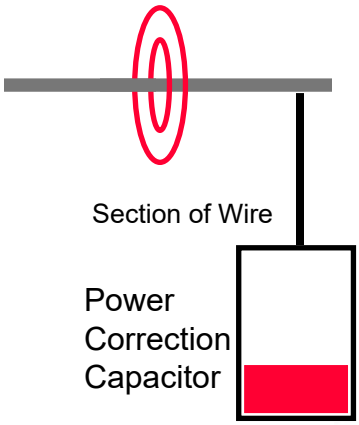
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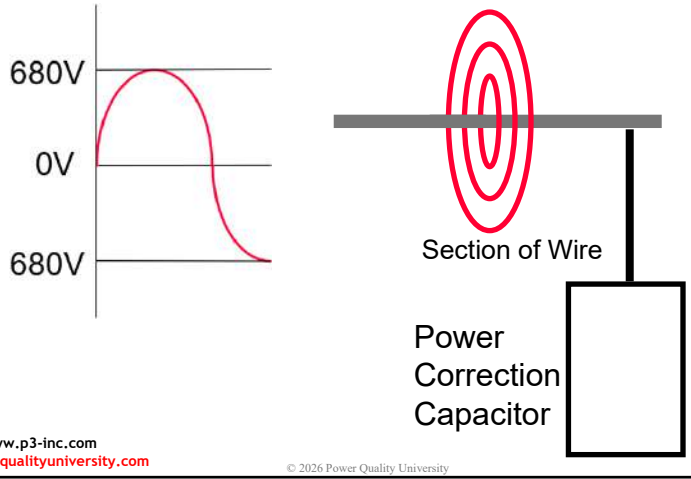
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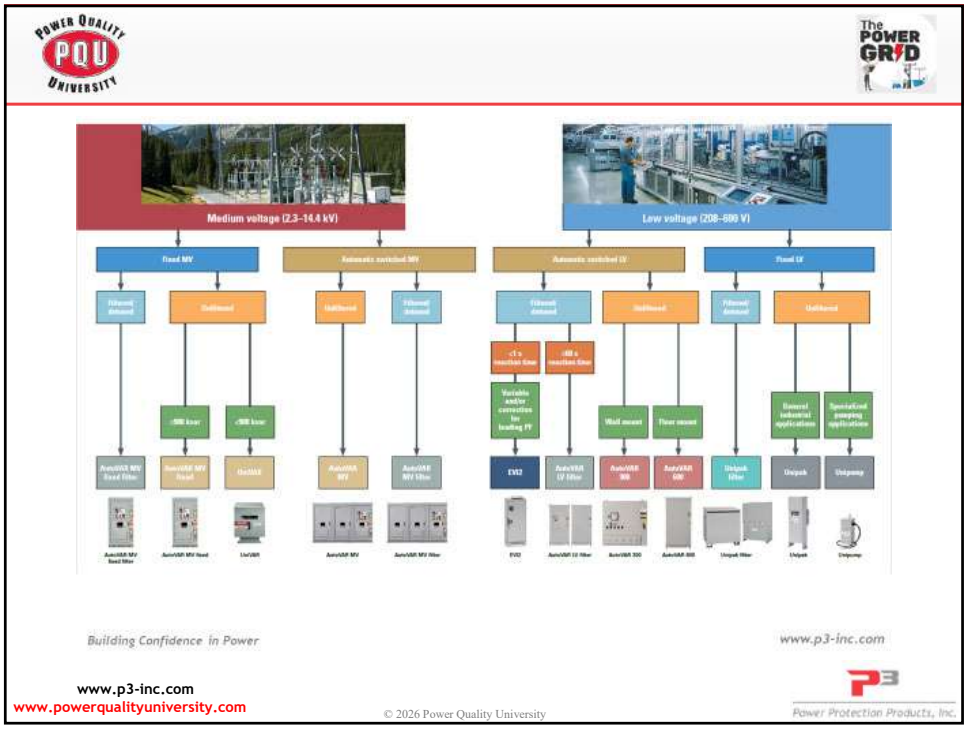
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Why install Power Correction Capacitors?

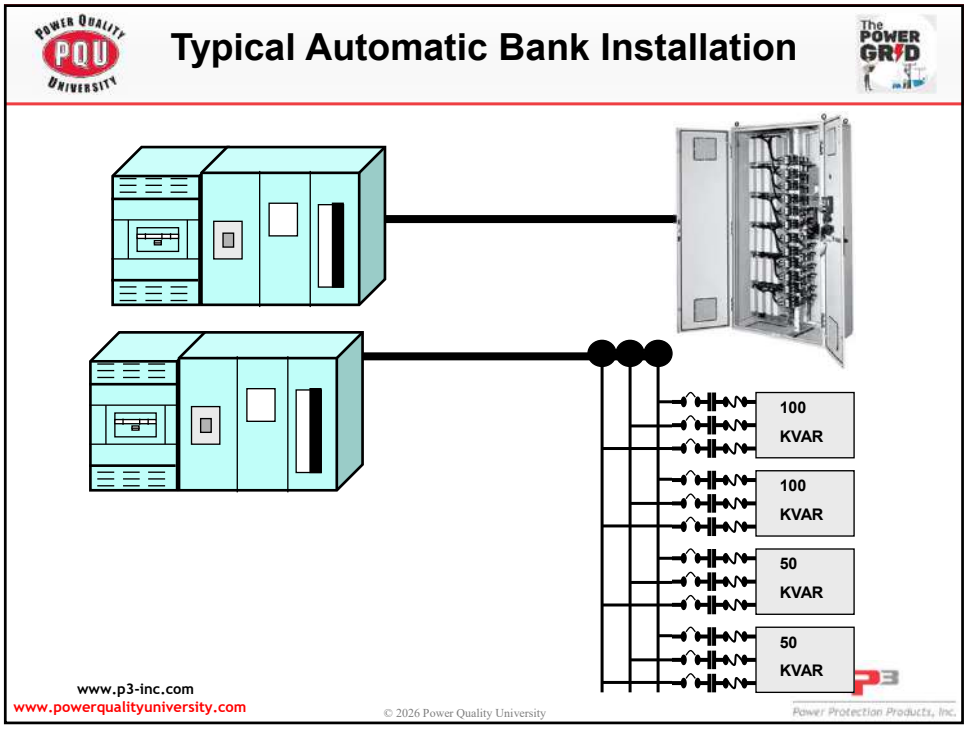
- With capacitors storing the energy from the magnetic fields the Power Company does not have to supply extra power, therefore, you do not get penalized.
- With proper placement of these Power Factor Correction Capacitors you can control your facilities power needs and reduce the costs of equipment to 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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Medium voltage (2.3–14.4 kV)
Low voltage (208–690 V)
Building Confidence in Power
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Typical Automatic Bank Installation
100 KVAR
100 KVAR
50 KVAR
50 KVAR
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Gaining Capacity
with Power Factor Capacitors

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

If we increase Power Factor, what happens to KVA?

$\frac{1000\ kW}{1050\ kVA}$ = .95 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 FACTORS FOR VARIOUS INDUSTRIES

Typical Unimproved Power Factor Values, by Industries	
Industry	**Power Factor**
Auto Parts	75 – 85
Brewery	75 – 85
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
Metalworking	65 – 70
Office Building	80 – 90
Oil-Field Pumping	40 – 60
Paint Manufacturing	55 – 65
Plastic	75 – 80
Stamping	60 – 70
Steel Works	65 – 80
Textile	65 – 75
Tool, Die, Jig	60 - 65

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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.

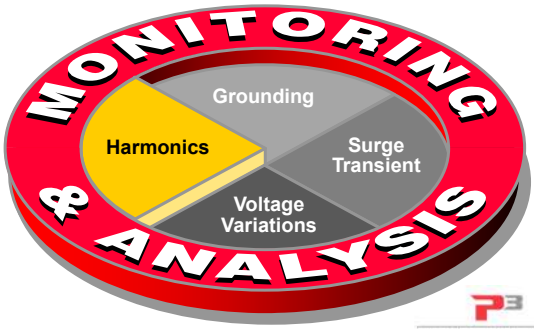
How can you determine if harmonics will be a problem? With any sizable kvar PFC installation (more than about 15% of the transformer rating in kVA) a harmonic assessment should be conducted.

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

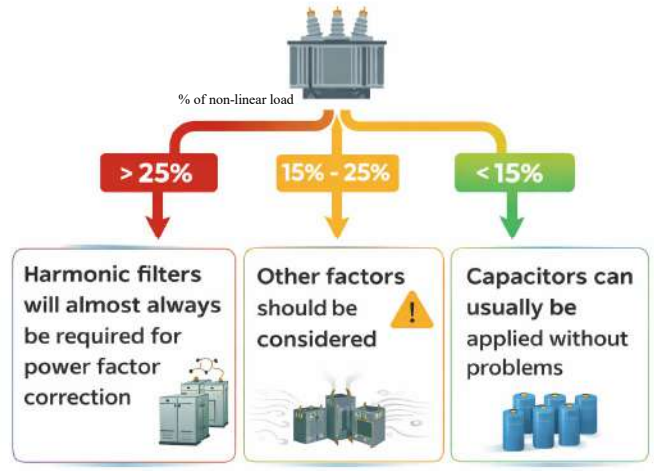




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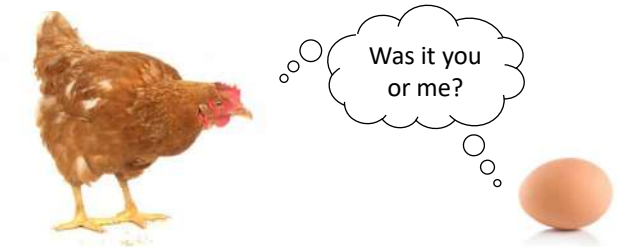
Power Factor



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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

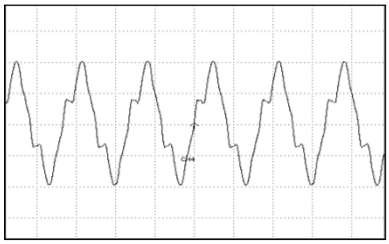
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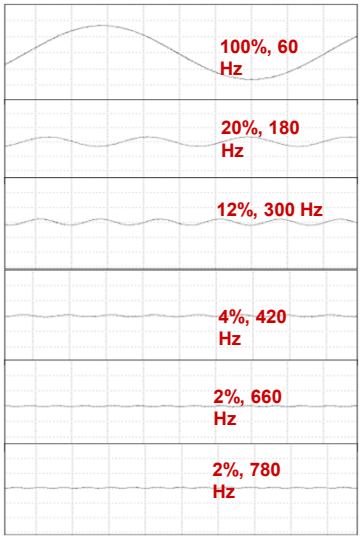
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Harmonics

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.

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





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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+/-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:

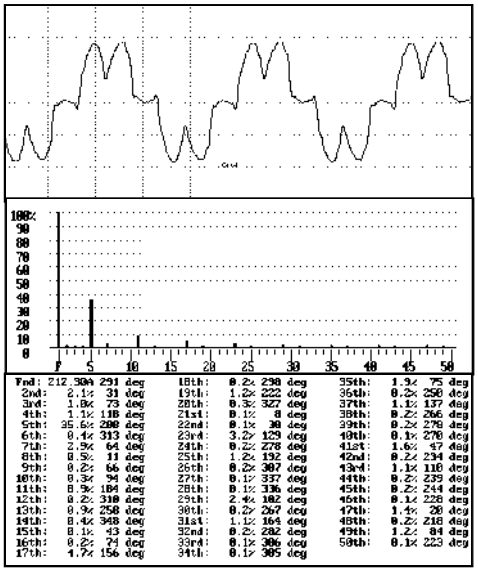
$$h = Np \pm 1$$

  - 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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Harmonic Sources - VFD's

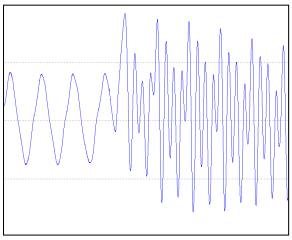


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Harmonic Resonance





If a capacitor exists on the power system

AND

Harmonic producing loads are in use

You MUST check for harmonic resonance (series and parallel)

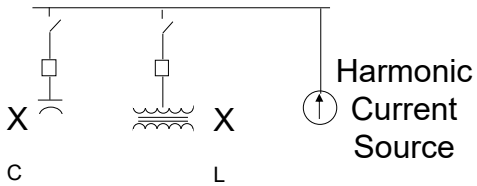
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Parallel Resonance

- 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.



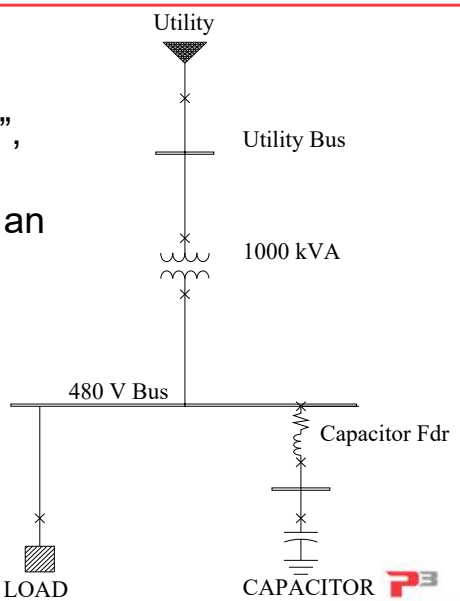
Equivalent Parallel Resonant Circuit

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Harmonic Modeling - Example

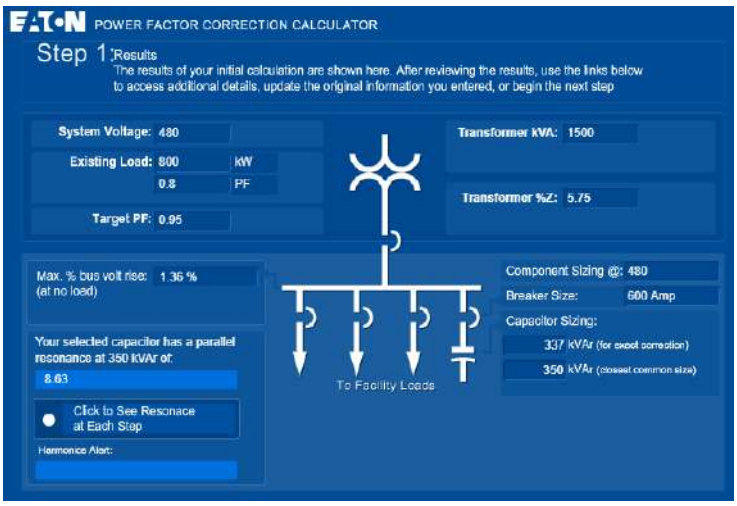
If other loads on the system are “Non-Linear”, consider installing a harmonic filter in lieu of an “unfiltered” capacitor to avoid *RESONANCE*



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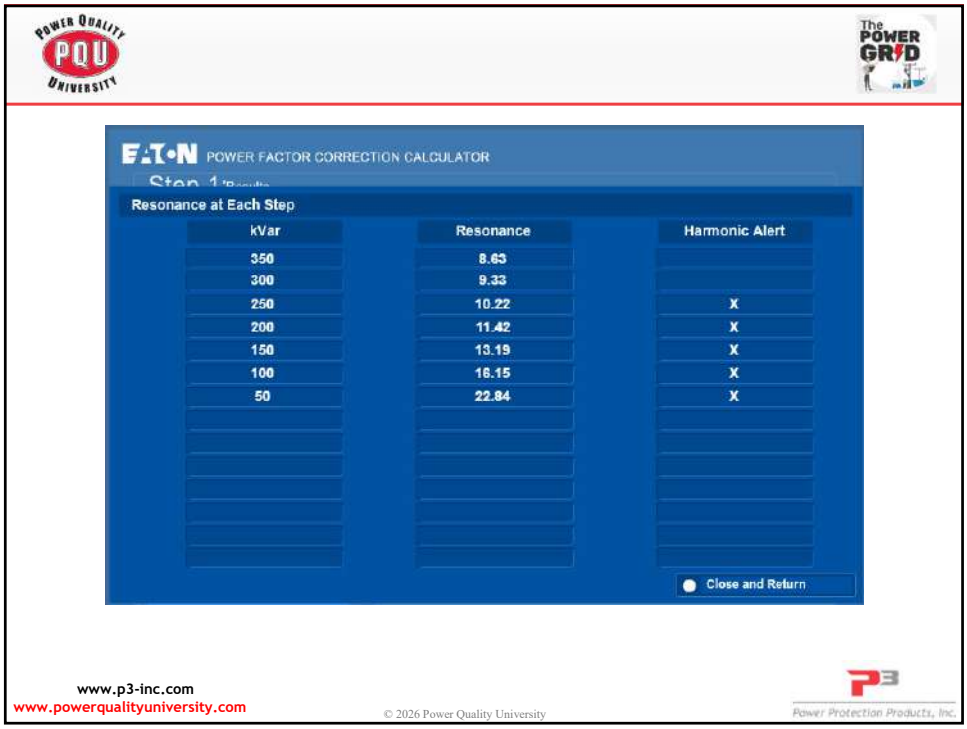
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Configuring a Solution



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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**.

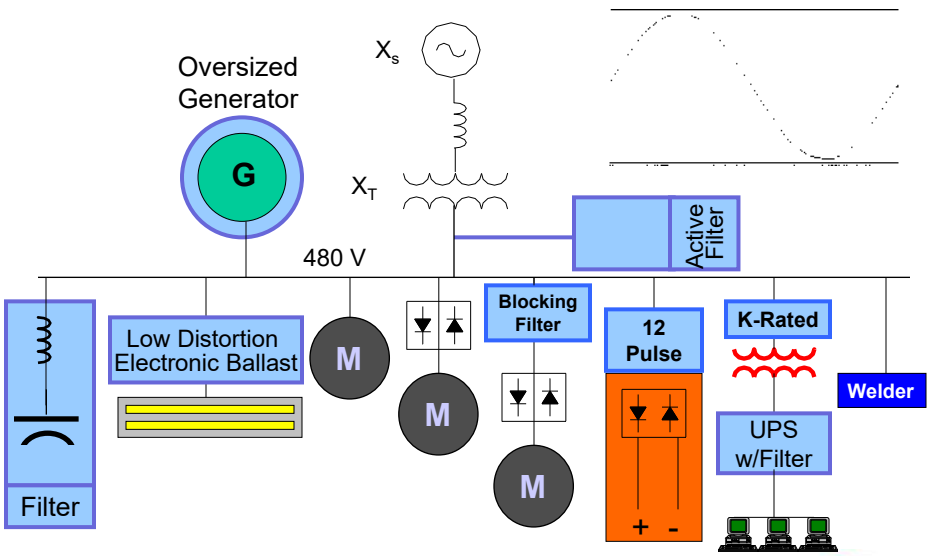
Table 2. IEEE 519 1992 vs 2014 standard

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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Harmonic Solutions

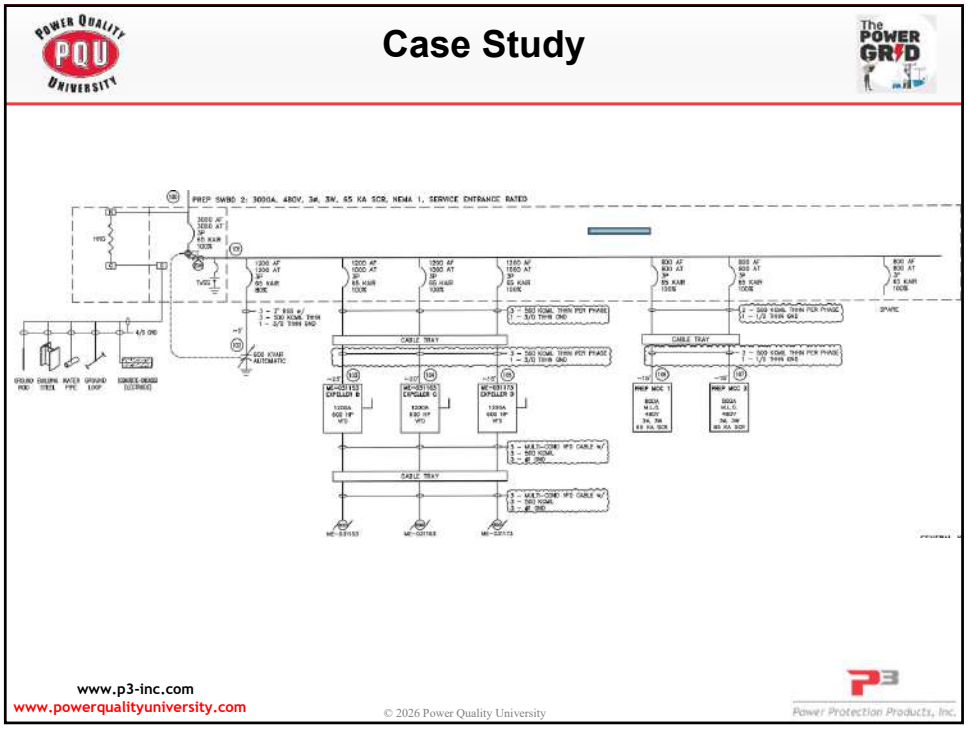


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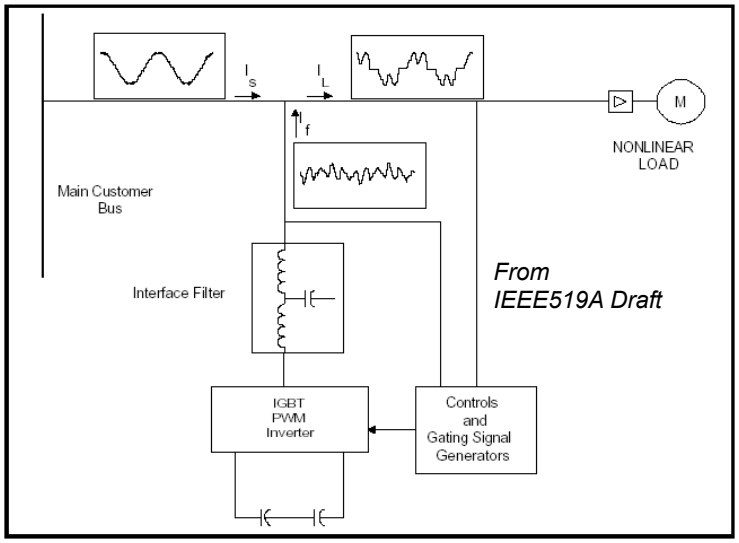

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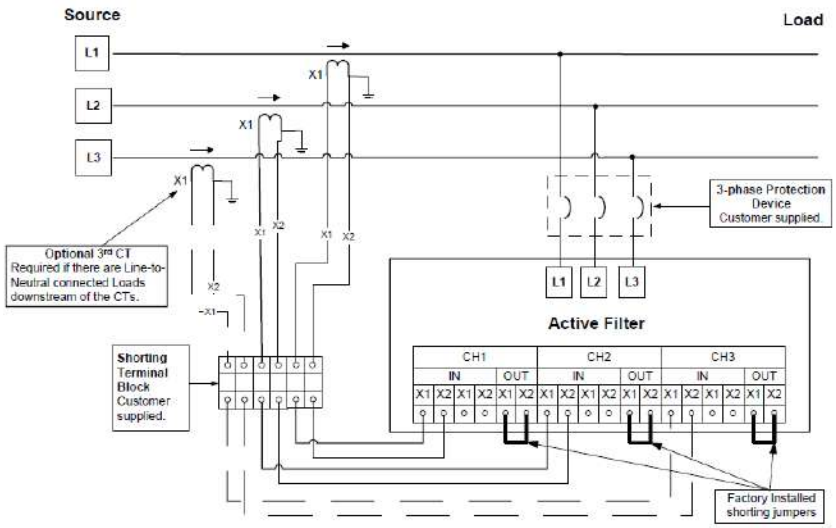
Active Filters



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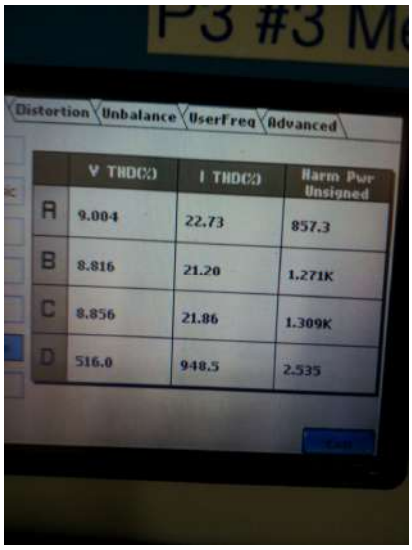
Active Harmonic Connection



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Case Study

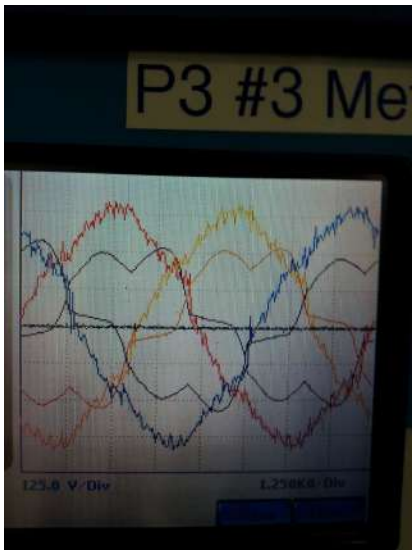


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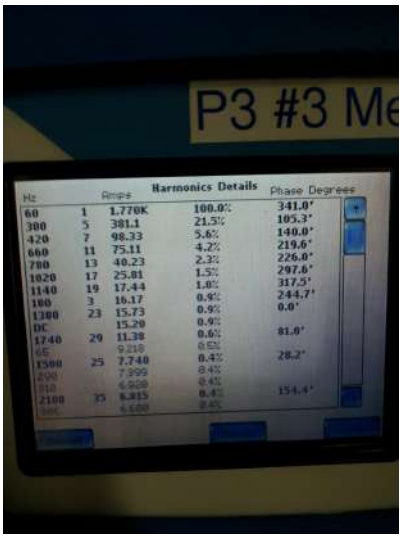


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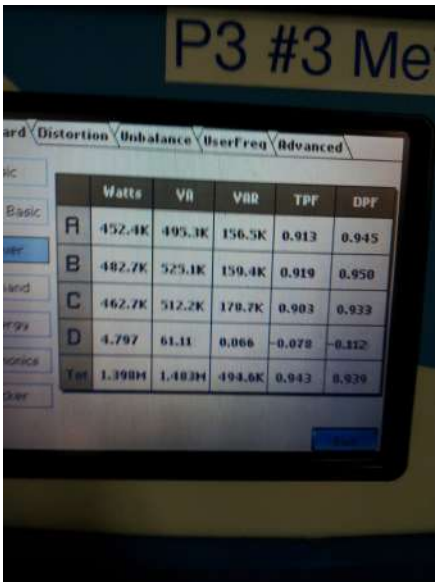


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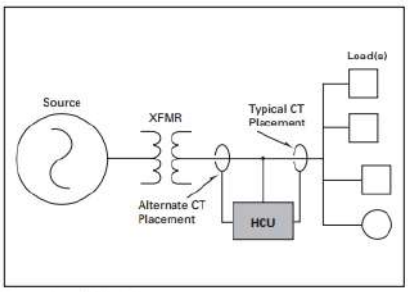


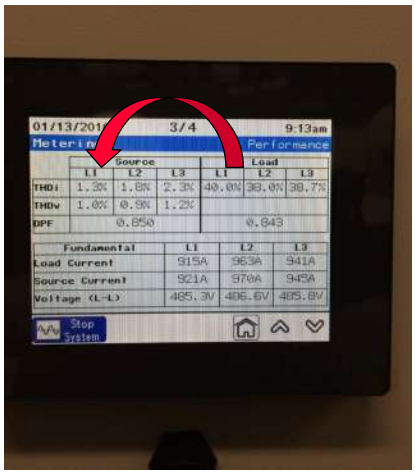
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Active Harmonic Correction





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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

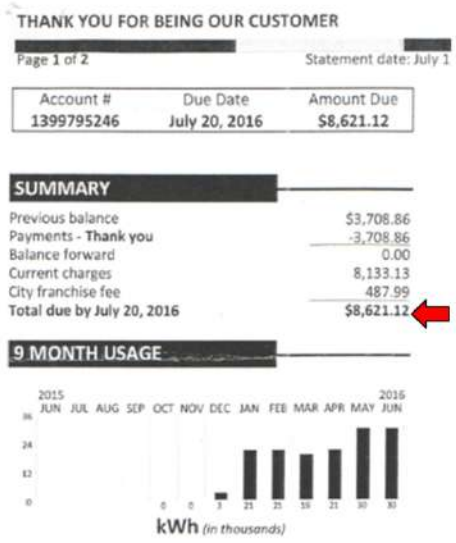
Some different ways of charging a Power Factor Penalty:

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

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Sample Utility Bill



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Sample Utility Bill

Page 2 of 2

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	$0.021717

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Sample Utility Bill

Page 2 of 2

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Utility Bill Math

Actual usage in Kw charges:

$555.97 + 646.30 + 1,276.45 + 487.99 = $2,966.71

$2,966.71 / 29760kWh = 10 cents per kW

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Utility Bill Math

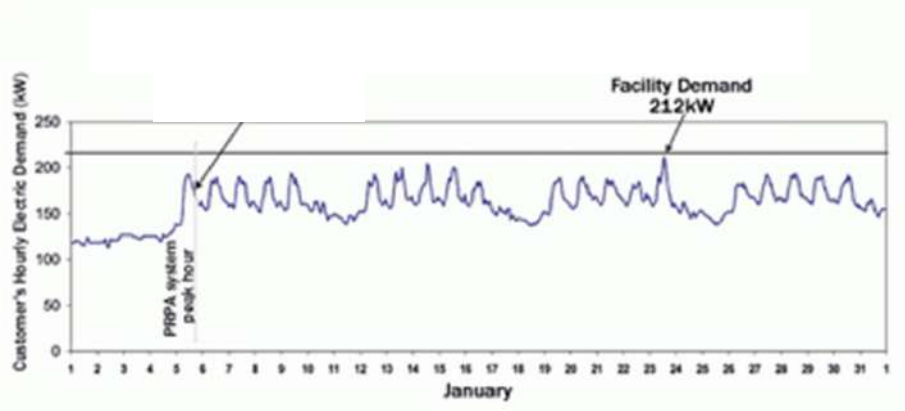
- **Demand charges WITH a LOW Power Factor**
- **Actual kilowatt demand (kWD) = 185kWD**
- **Adjusted kilowatt demand (kWD) = 351kWD**
- **Demand charge on bill = $5,480**

1. **Where does this Adjusted kilowatt demand come from?**
2. **What is Kilowatt Demand (kWD)?**

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What is Kilowatt Demand (kWD)?



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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 x $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 divided by .475 = 390kWD
  390kWD x .9 = 351 kWD (this utility only requires correction to 90%)
- 351 x $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 divided by $2,593= 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

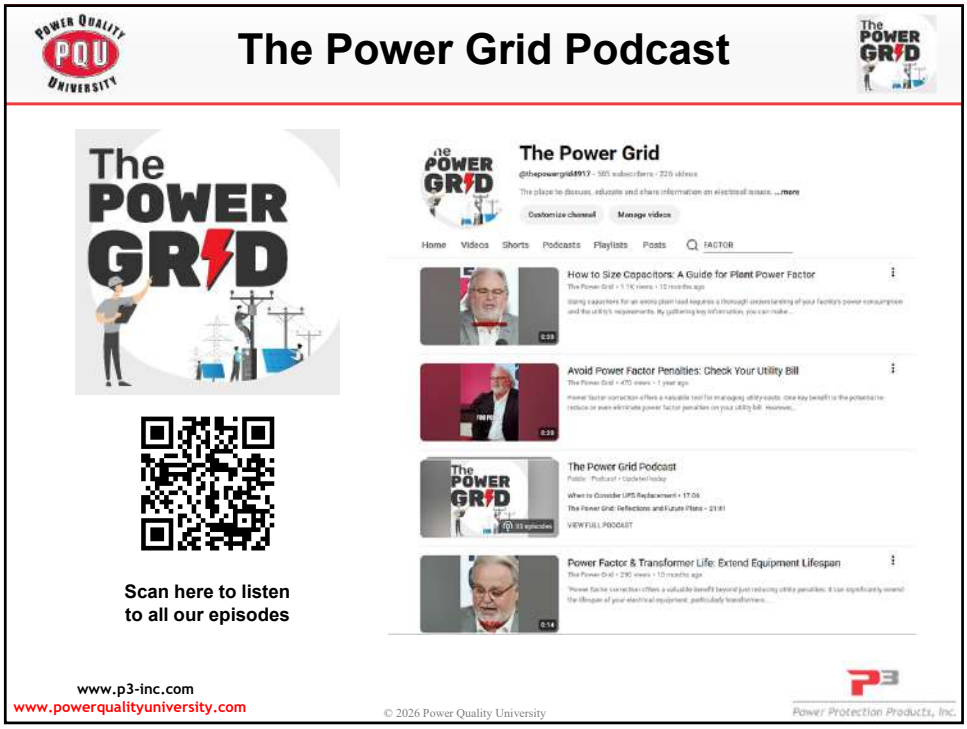
- Equipment needs to be Sized for Your Facility
- Power Factor Correction Equipment Correctly Installed
- Power Quality Study Conducted
- Verify Meter Data Collection
- Interpret the Data
- Present the results
- Recommend a solution

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CHALLENGE ACCEPTED
At the end of long power factor correction journey is the beginning of solution implementation and obtaining desired results.
Success
JUST AHEAD
is here to guide you on this journey.
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