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

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Harmonics

Agenda

Introductions to P3 Hosts

Speaker: Andy Angrick
Host: Karah Butac

Program

- Linear and non-linear power and relationship to harmonics
- Equipment causing harmonic issues
- Equipment and facility infrastructure potentially damage by harmonics
- Power usage inefficiency
- Mitigating or eliminating harmonics
- Harmonic mitigating equipment
- Energy savings
- IEEE/ANSI standards related to harmonics

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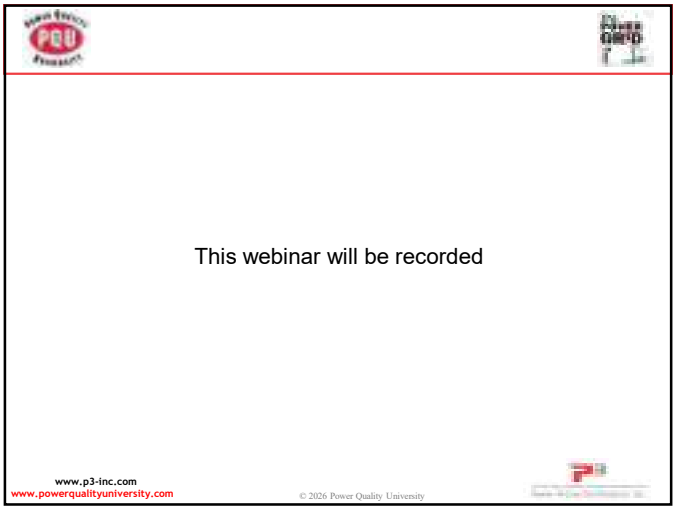
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What is a Harmonic?

A harmonic is the term used for current flow on your facilities power system at frequencies other than 60Hertz.

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Harmonic Problems

Over heating and failure of:



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Harmonic Problems

- **Electrical and Electronic damage.**
- **Control System errors due to Electrical noise caused by harmonics.**
- **Blown Fuses for no APPARENT reason.**
- **Nuisance tripping of Circuit Breakers.**

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Understanding Linear & Nonlinear Power

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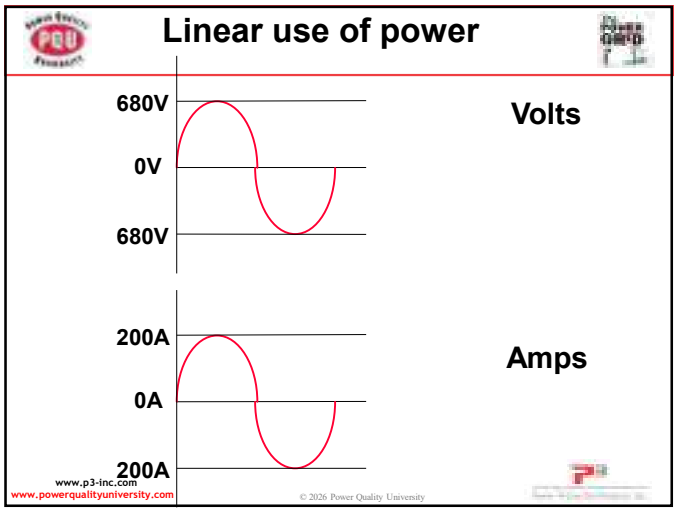

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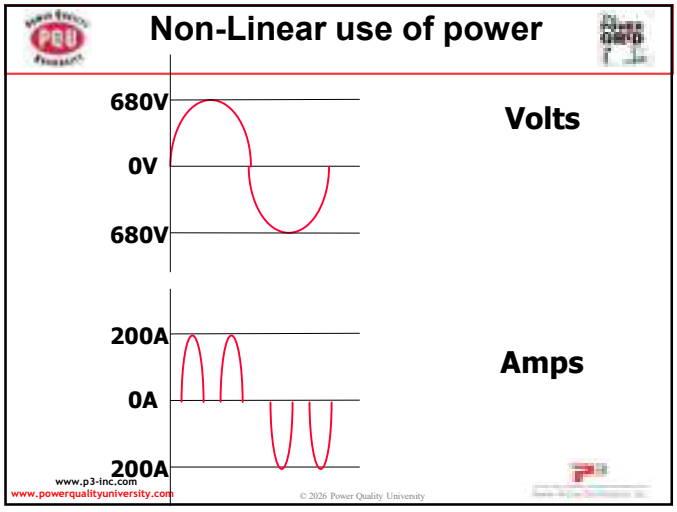

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Typical Non-Linear frequencies that cause problems:

3 x 60 = 180HZ
5 x 60 = 300HZ
7 x 60 = 420HZ
9 x 60 = 540HZ
11 x 60 = 660HZ

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Why does Non-Linear current flow cause problems in my facility?

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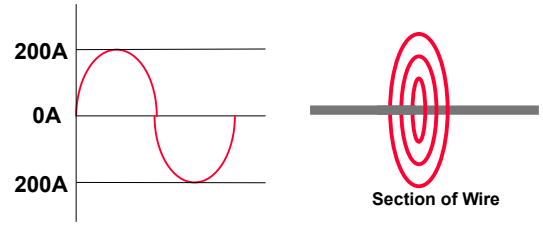
Magnetic field produced around wire



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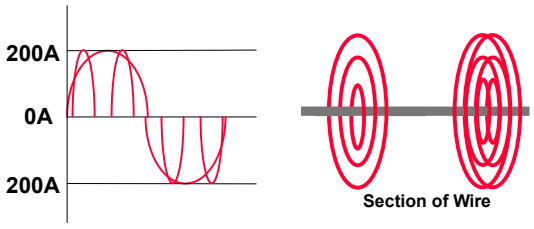
Combination of Linear & Non-Linear power



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Harmonic currents flow on your power system neutral

Why?

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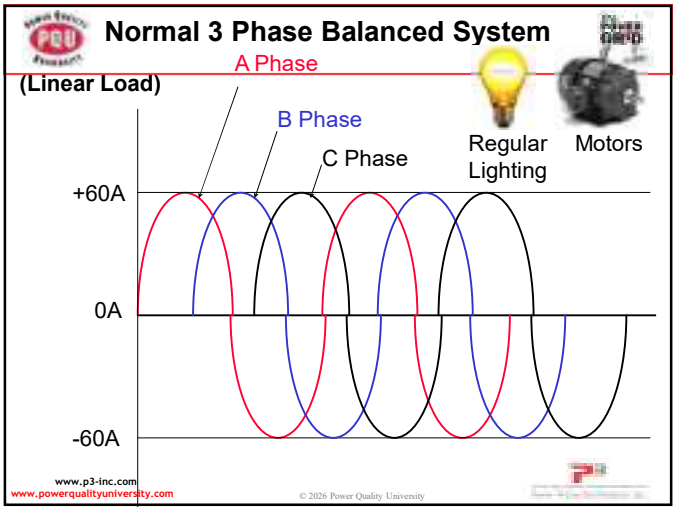

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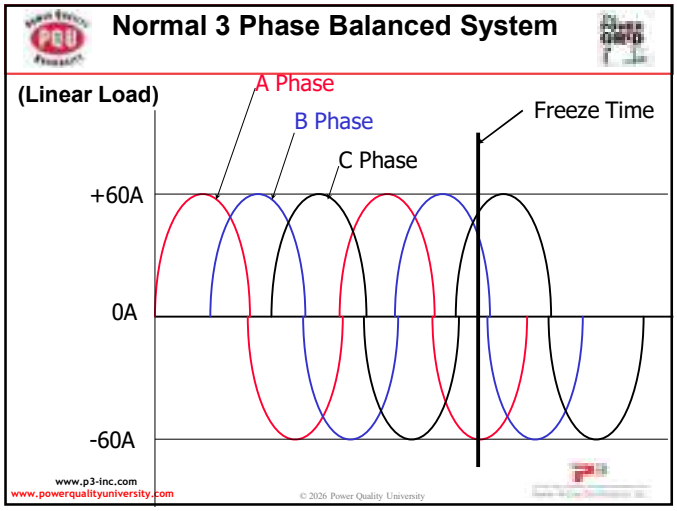

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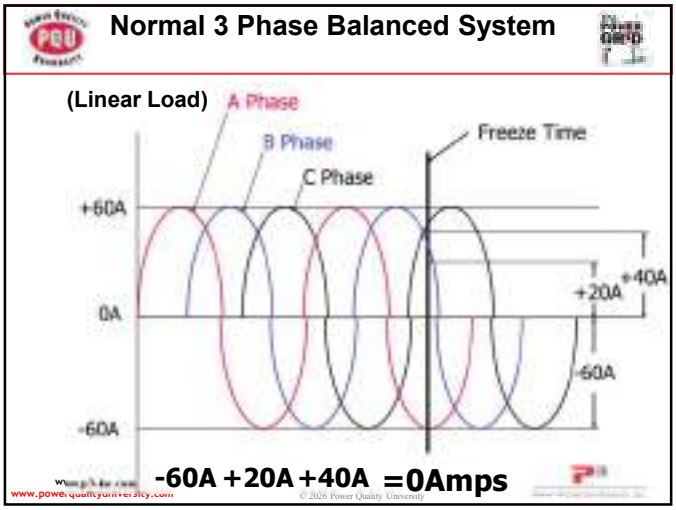

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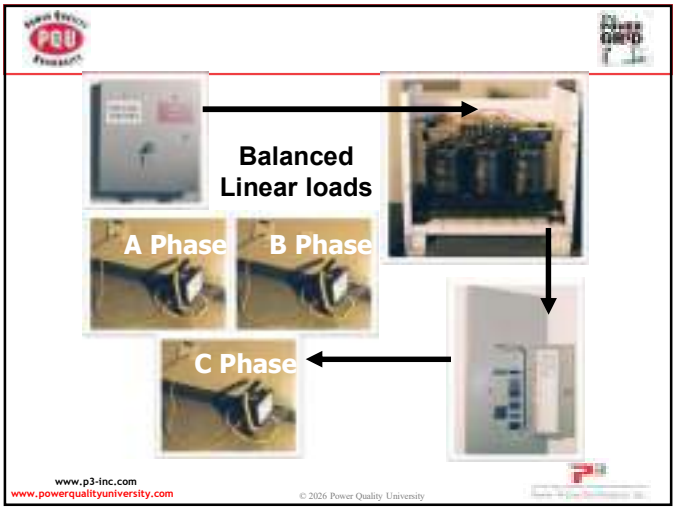

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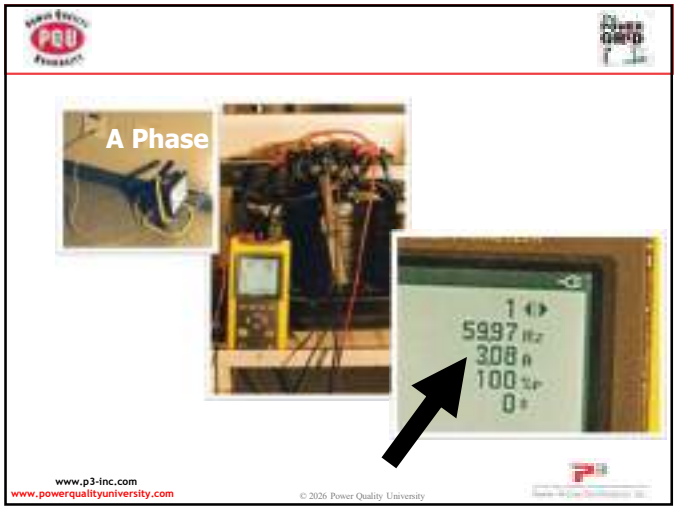

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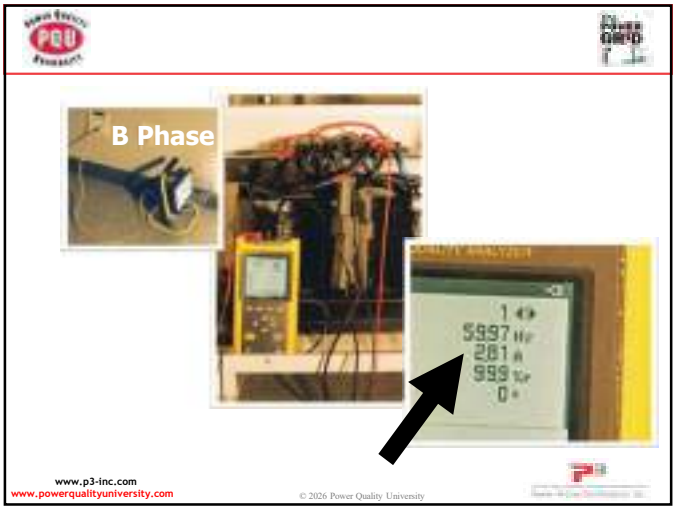

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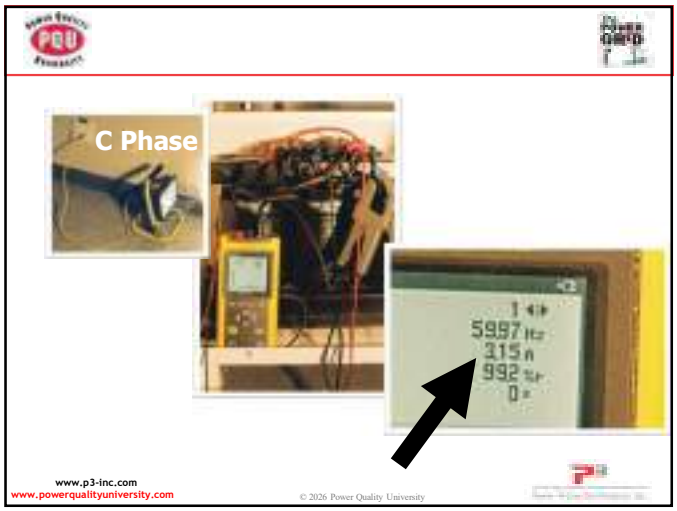

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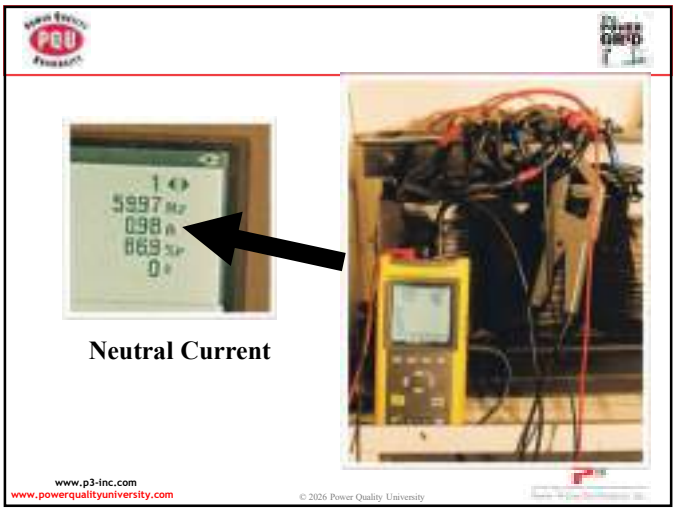

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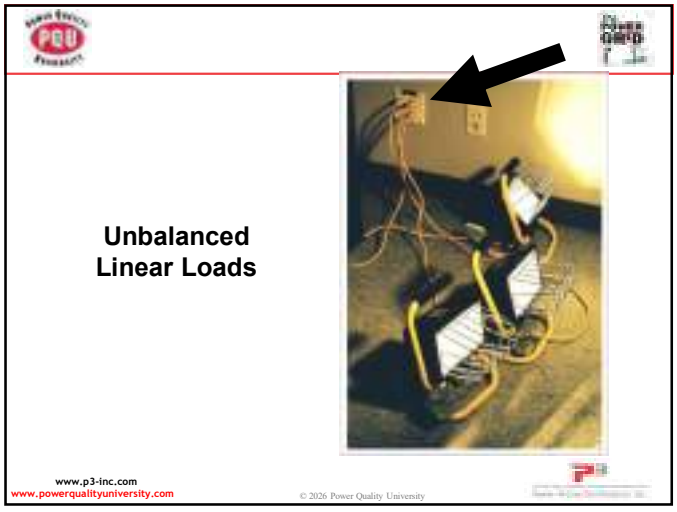

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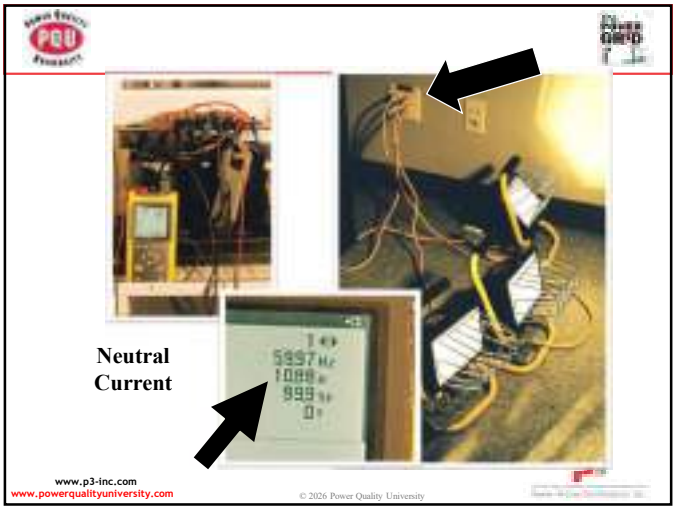

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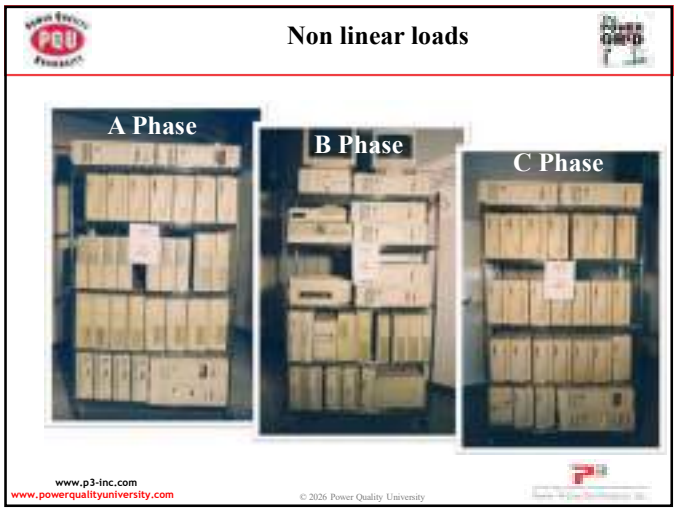
Non linear loads
A Phase
B Phase
C Phase
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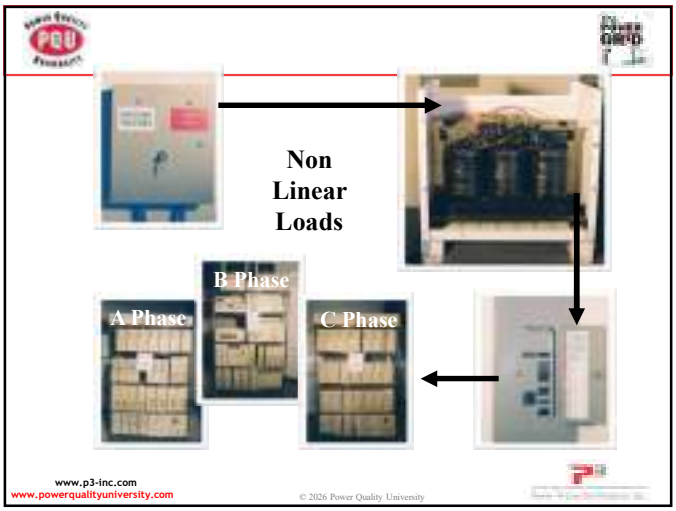
Non
Linear
Loads
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A Phase
780
14.49
13.9
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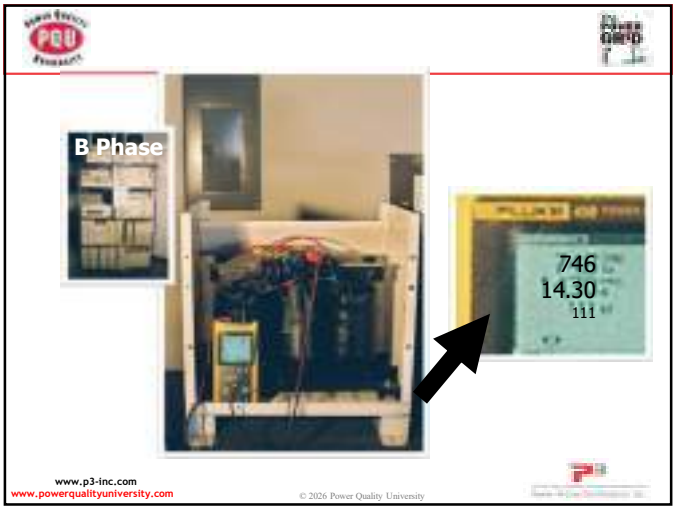
B Phase
746
14.30
111
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36


C Phase
73.4
14.81
108
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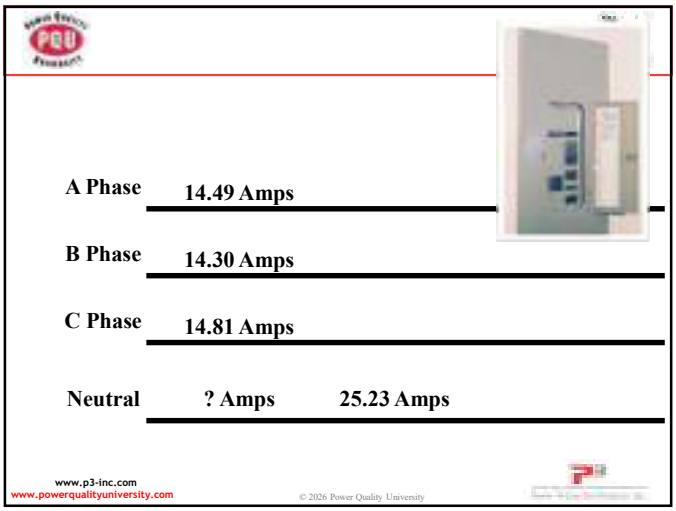
A Phase 14.49 Amps
B Phase 14.30 Amps
C Phase 14.81 Amps
Neutral ? Amps 25.23 Amps
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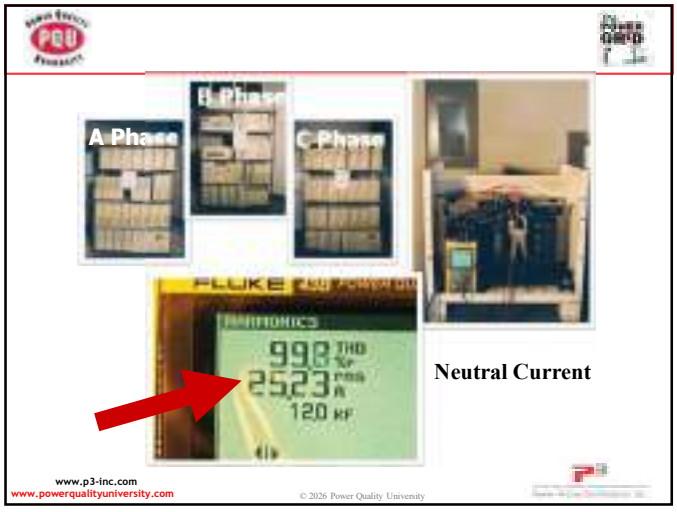
A Phase
C Phase
25.23
120
Neutral Current
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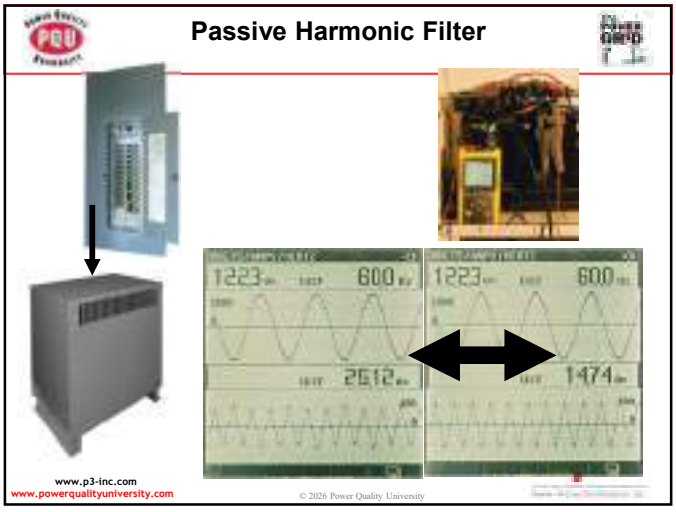
Passive Harmonic Filter
1223
600
2612
1474
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These Harmonic current flows on the neutral may be **1.73** times larger than the supply current.

IEEE 519 is the standard used to determine maximum Harmonic distortion levels. They are different between voltage and current.

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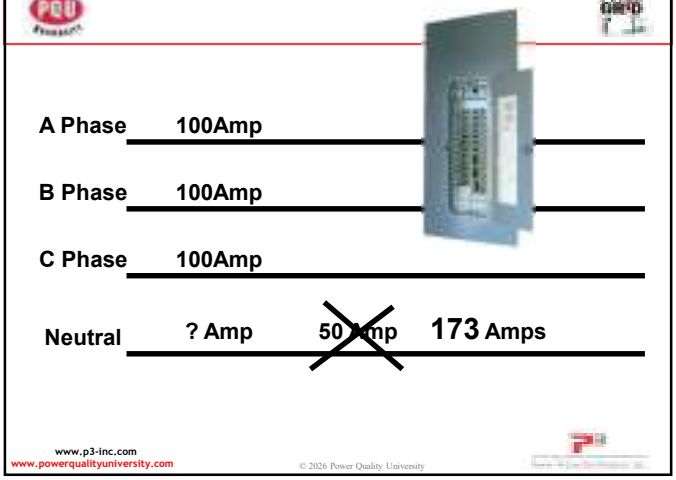

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Harmonics occur when equipment uses current in a Non-Linear fashion.

Equipment that commonly does this:

- Personal Computers
- Various Office Equipment Copiers, Printers etc…
- Electronic and Magnetic Ballast's
- Modern Welders
- Variable Frequency Drives
- Any device that uses Switched-Mode Power Supplies

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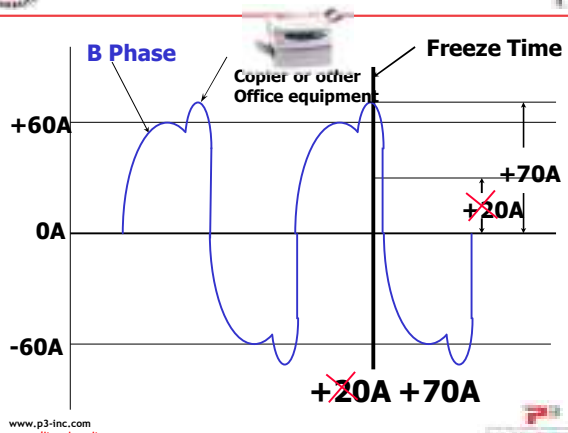
Harmonic 3 Phase Un-Balanced System



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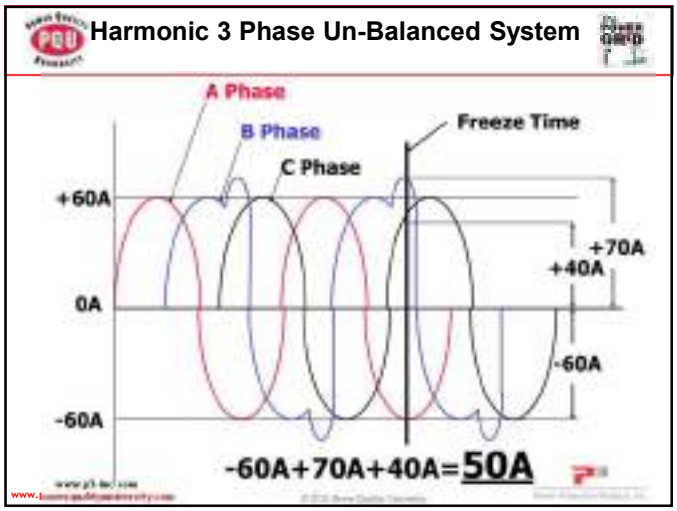

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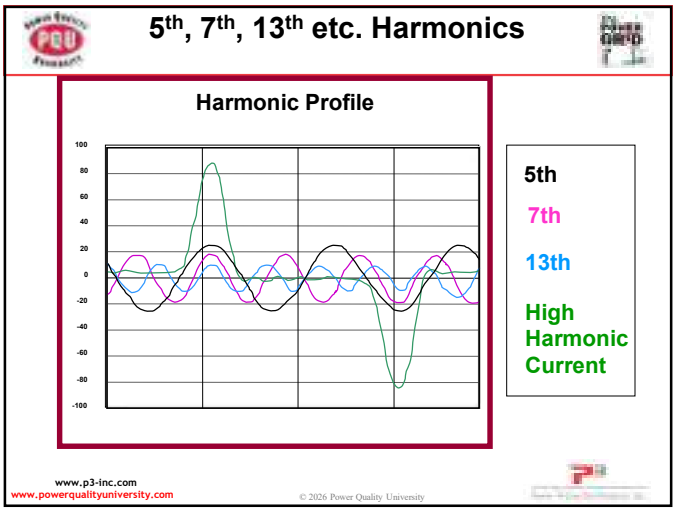

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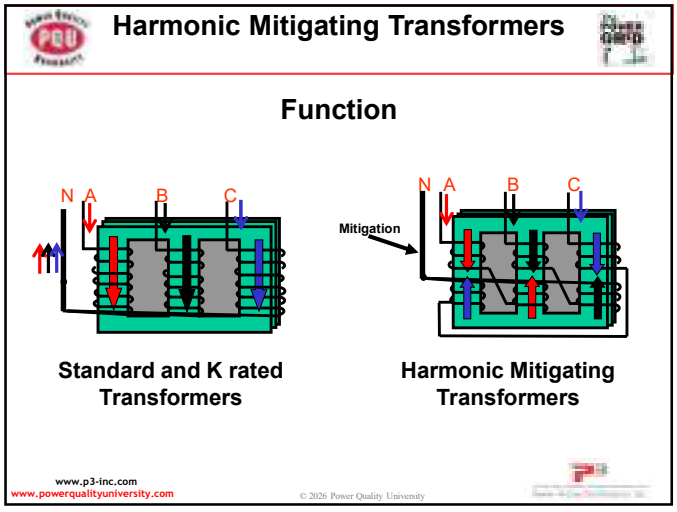

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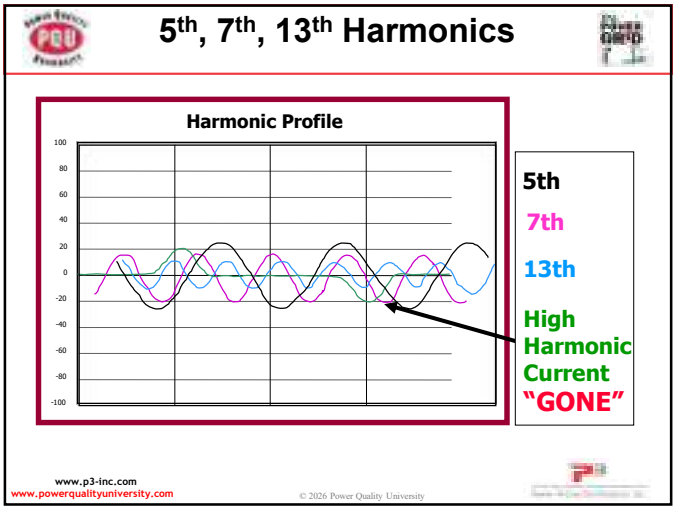

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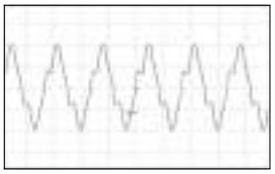
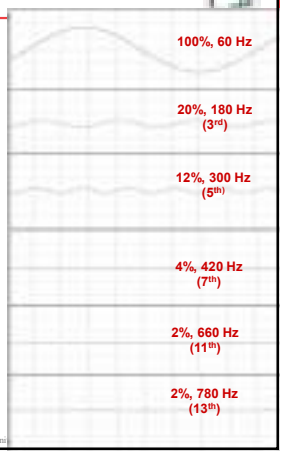
Harmonics

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…
Non-incandescent 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

Harmonic = Pulse +/-1 (and multiples)
i.e. 6 Pulse Drive - 5, 7, 11, 13, 17, 19,…

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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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Current Harmonics

Example:

Typical Office Building
1200A 208Y/120 service
30K AIC

The Maximum IEEE Harmonic distortion is:

30,000 AIC / 960 = 31

31 on the IEEE chart is 8%

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Past IEEE 519-Voltage

Maximum Harmonic Voltage Distortion

Voltage	TVD
69kV and below	5%

TVD=Total Voltage Distortion

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Present 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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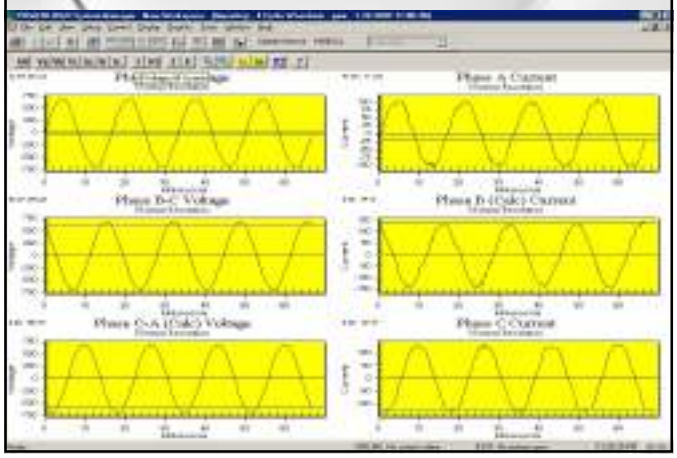
Harmonics: Low Harmonic Waveform



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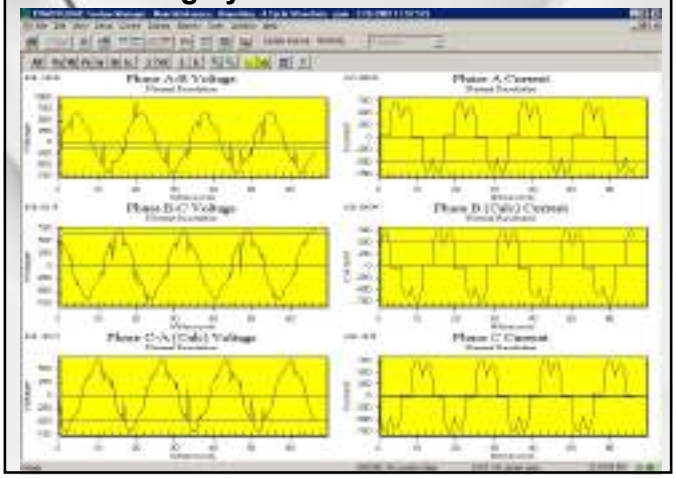
Highly Distorted Waveform



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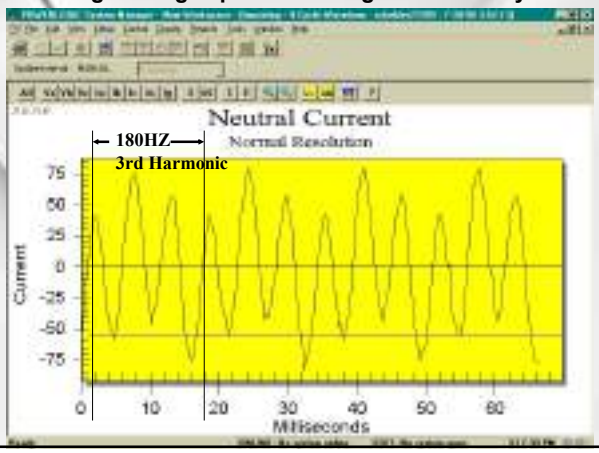
Since current flow induces voltage, you may see very large voltage spikes with large Harmonic systems.



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- Harmonic currents travel throughout your power system.
- Since they are not at 60HZ they can damage capacitors and transformers that are designed to operate only at 60HZ
- Harmonics can cause damage and unexpected shutdown of Computers, Variable Frequency Drives, UPS Systems, lighting systems and other electronic equipment.

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Harmonic Problems- Transformers

When harmonic currents flow through a transformer, the transformer will heat up more than one with 60Hz currents flowing through it. This is caused by "eddy current" loses in the core and coil windings of the transformer.

What are "eddy currents"?

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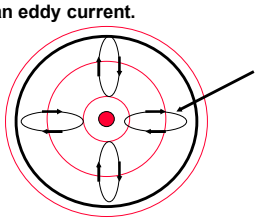
Harmonic Problems - Transformers

When these magnetic lines of force cut through the wire they induce current flow. This current flow (internal to the wire) is called an eddy current.



The higher frequency current (caused by harmonics) running through the transformer core and coils cause eddy currents to flow more readily in each of the core and coil winding conductors.
These eddy currents cause excessive heat to build up in the transformer leading to damage and limiting the life of the transformer.

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Harmonic Problems - Transformers

This figure shows that the de-rating can reach 50% when the transformer supplies more than 70% of its load to single phase power supplies of electronic load equipment.

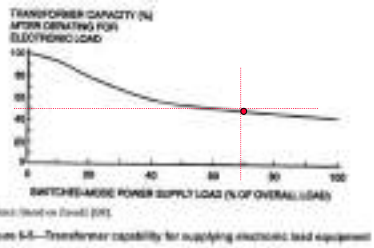

Figure 8-5 shows an example of a de-rating curve (appearing in Zavadil et al. [B8]2) obtained by more accurate computations based on IEEE Std C57.110. Source: Based on Zavadil [B8].

Source-IEEE Std. 1100

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Harmonic Problems

Variable Frequency Drives, Computers, UPS Systems



DC bus Voltage with Clean Voltage

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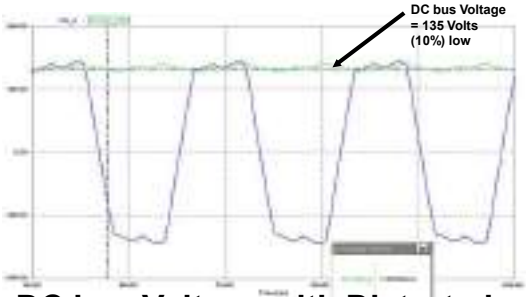
Harmonic Problems

Variable Frequency Drives, Computers, UPS Systems



DC bus Voltage with Distorted Voltage – 10% lower

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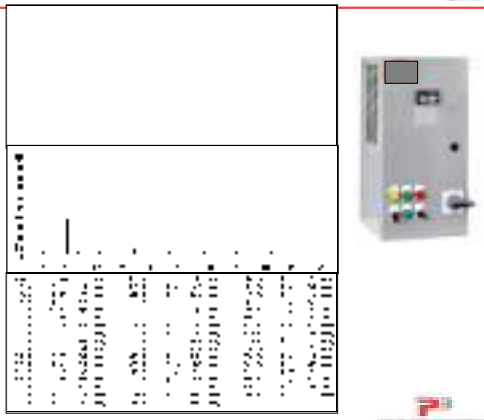
Harmonic Sources - VFD's



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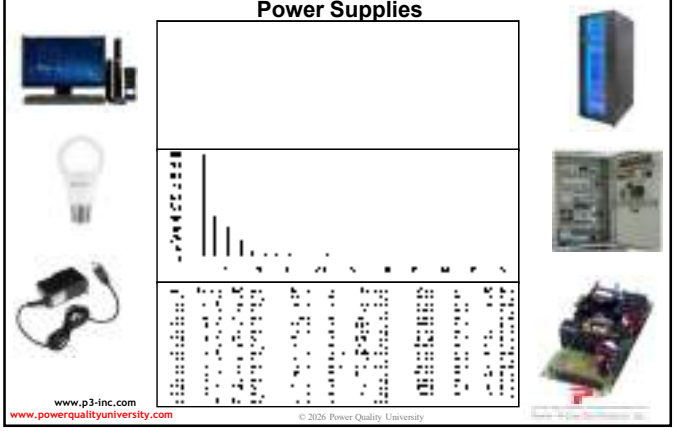
Harmonic Sources - Switch Mode

Power Supplies



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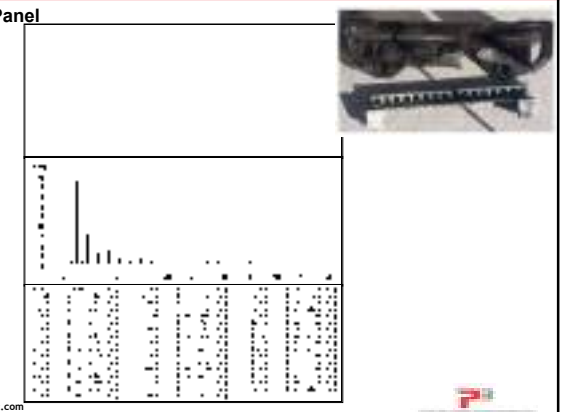
Harmonics – Panel Neutral

Neutral of Panel



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Harmonics & energy losses with motors



	A	B	C	
Fundamental	0°	120°	240°	A-B-C
3rd harmonic	A' 3 x 0° (0°)	B' 3 x 120° (360° – 0°)	C' 3 x 240° (720° – 0°)	no rotation
5th harmonic	A'' 5 x 0° (0°)	B'' 5 x 120° (-120°)	C'' 5 x 240° (-240°)	C-B-A
7th harmonic	A''' 7 x 0° (0°)	B''' 7 x 120° (120°)	C''' 7 x 240° (240°)	A-B-C
9th harmonic	A'''' 9 x 0° (0°)	B'''' 9 x 120° (1080° – 0°)	C'''' 9 x 240° (2160° – 0°)	no rotation

Source: AllAboutCircuits.com

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Harmonics & energy losses with motors

Rotation sequences according to harmonic number

+	1st	7th	13th	19th	← Rotates with fundamental
0	3rd	9th	15th	21st	← Does not rotate
-	5th	11th	17th	23rd	← Rotates against fundamental



Source: AllAboutCircuits.com

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Harmonics & energy losses with motors

"...the life span of the motor will be shortened by half if the overheating is increase by 8°C, 10°C, and 12°C for the insulation classes E, B, and F respectively."

IEEE Document 0-7803-4509-6/98 Effects of Voltage Harmonics on the Electrical and Mechanical Performance of a Three-Phase Induction Motor

Harmonic #	Increase in Operational Temperature
3rd Alone	3.5°C
5th Alone	5°C
7th Alone	3.8°C

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Harmonic Damage



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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Harmonic Problems-Capacitors

Example: **A capacitor bank has reactance, measured in Ohms.**

$X_C = 1 / 2\pi fc$

Lets say we have a Power Correction capacitor that has a reactance of 12 ohms at 60HZ.
Then,
12 ohms = 1 / 2 x 3.14 x 60Hz x .00022F

If this capacitor is in a 480 Volt circuit 40 Amps will flow in the capacitor (480Volts / 12 ohms = 40 Amps).

If we have 3rd (180 Hz) harmonics present.
Then,
Reactance = 1 / 2 x 3.14 x 180Hz x .00022F
Reactance = 4 ohms

We will now see 120 Amps flow in the capacitor.
(480 Volts / 4 ohms = 120 Amps)

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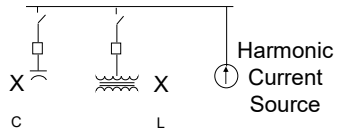
Parallel Resonance

- 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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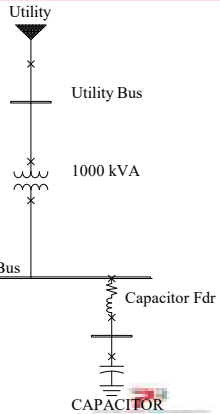
Harmonic Modeling - Example

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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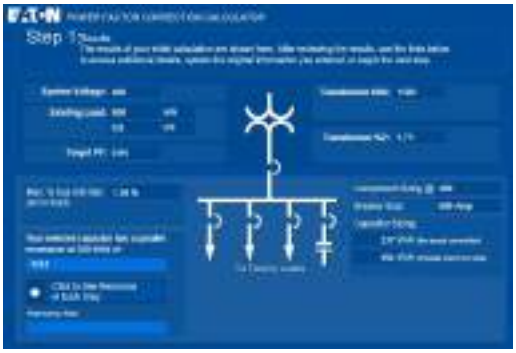
Configuring a Solution



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Detecting a Harmonic System Problem

Use a Harmonic analyzer test meter



Use a Power Monitoring System

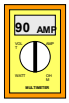


Use a True RMS Volt-Ohm-Ammeter



COMPARED TO:

An Averaging Volt-Ohm-Ammeter



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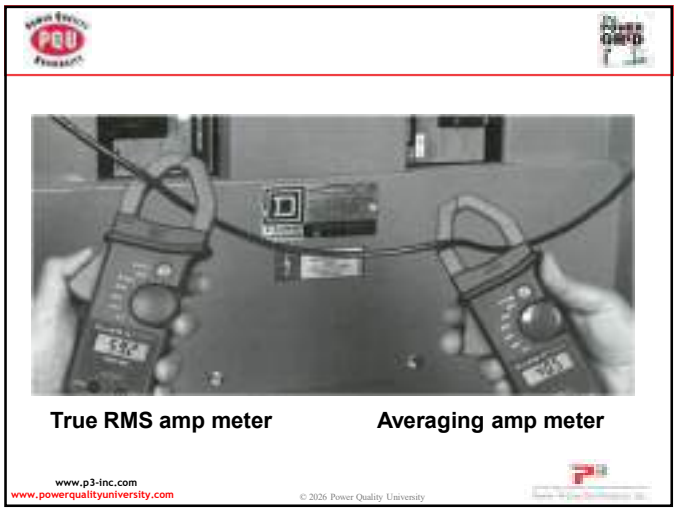
True RMS amp meter
Averaging amp meter
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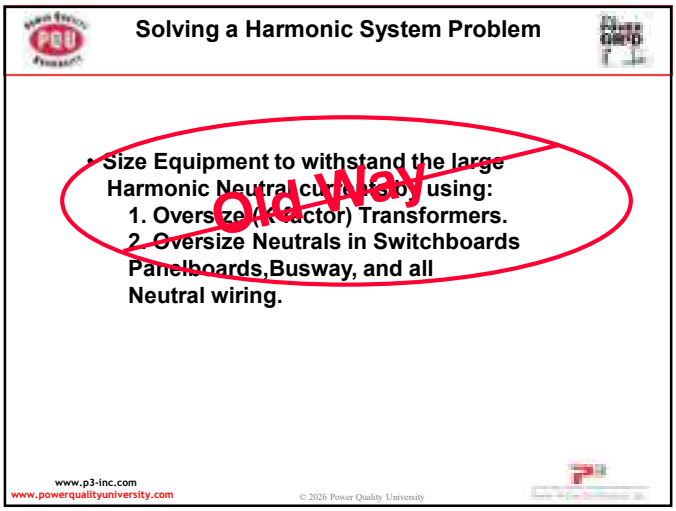
Solving a Harmonic System Problem
Old Way
Size Equipment to withstand the large Harmonic Neutral current by using:
1. Oversize (K-Factor) Transformers.
2. Oversize Neutrals in Switchboards Panelboards,Busway, and all Neutral wiring.
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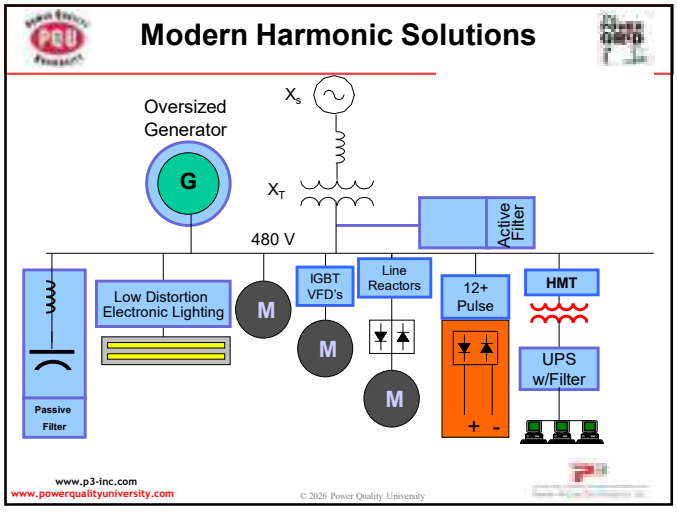
Modern Harmonic Solutions
Oversized Generator
G
X_s
X_T
480 V
Active Filter
Low Distortion Electronic Lighting
M
IGBT VFD's
M
Line Reactors
M
12+ Pulse
HMT
UPS w/Filter
Passive Filter
+ -
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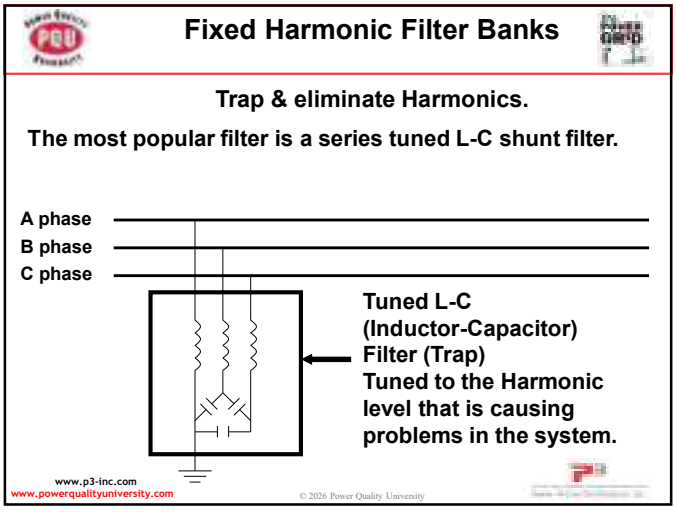
Fixed Harmonic Filter Banks
Trap & eliminate Harmonics.
The most popular filter is a series tuned L-C shunt filter.
A phase
B phase
C phase
Tuned L-C (Inductor-Capacitor) Filter (Trap) Tuned to the Harmonic level that is causing problems in the system.
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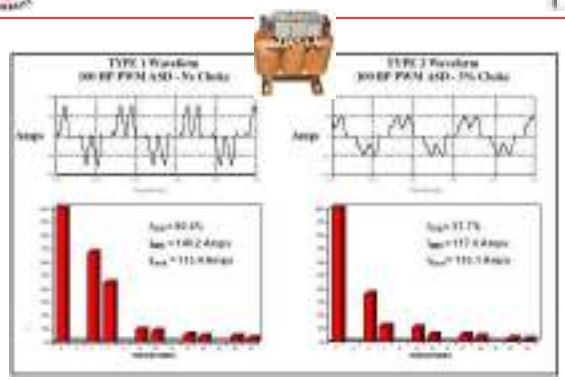
Line Reactors



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Harmonic Solutions

Active Harmonic Filter



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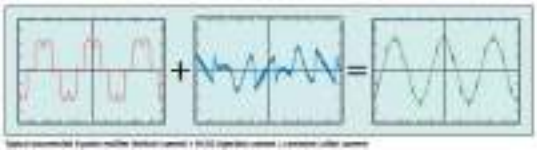
Harmonic Solutions

- Active Harmonic Filter
  - How does it work?
    - Cancels harmonics by injecting the required currents into the electrical system



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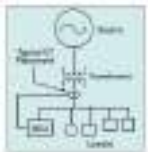
Harmonic Solutions

- Active Harmonic Filter
  - Current Transformers (CTs) are required to sense the currents
  - Filter is applied in parallel with the harmonic loads
  - Minimum 3% Line Reactors or DC Link Chokes are required on all nonlinear loads



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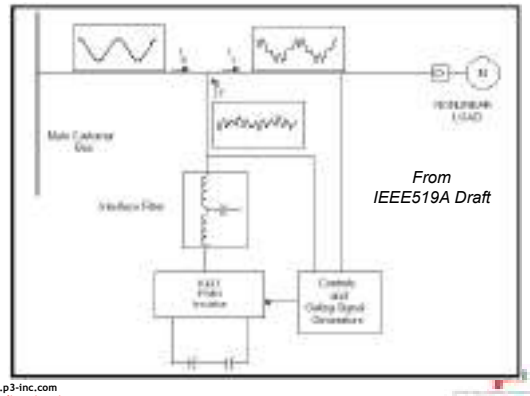
Active Filters



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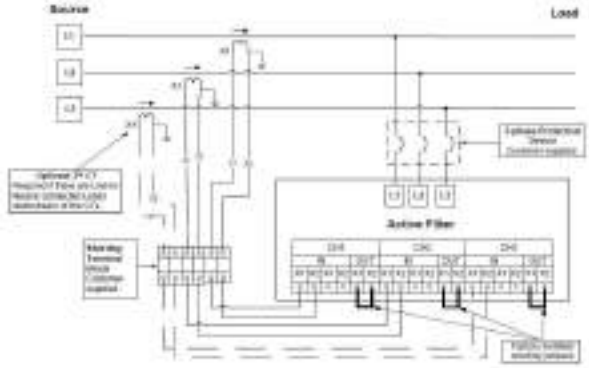
Active Harmonic Connection



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Harmonic Solutions

- Active Harmonic Filter
  - Advantages
    - Active filter automatically adapts to changing load conditions
    - Cannot be overloaded, because active filter is self-limiting
    - Reduced need for engineering studies to create detailed equipment specification
    - Can be used in conjunction with passive power factor correction filters

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Harmonic Solutions

- Active Harmonic Filter
  - Typical Applications
    - Water treatment plants
    - Industrial plants with a significant amount of motor drives
    - Data centers
    - Semiconductor manufacturing plants

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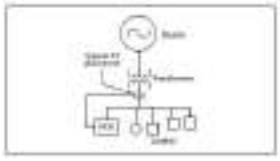
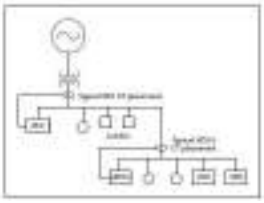
Harmonic Solutions

- Active Harmonic Filter
  - Typical Installations

Standalone Installation



Active Filter used in conjunction with passive PFC filter



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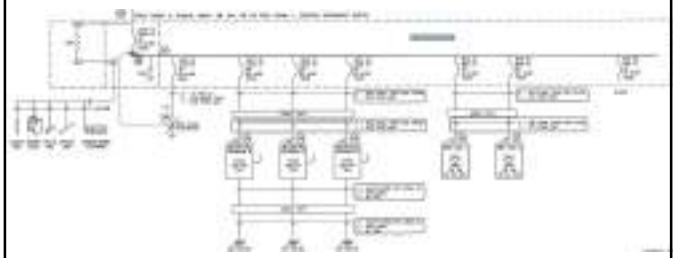

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Case Study



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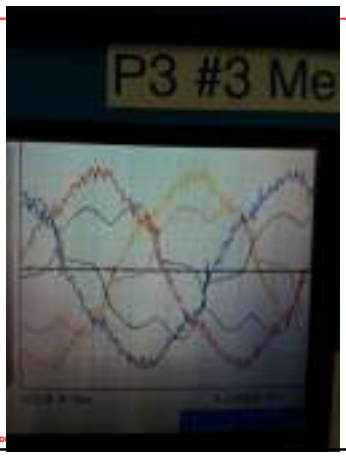
Case Study



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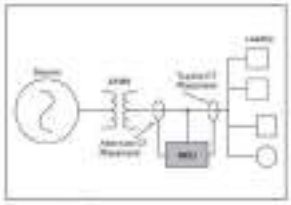
Active Harmonic Correction





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Call to Action – 5 Step Process

1. Build Confidence in your Electrical System

2. Condition the Power for the Equipment and Environment
   - A. Look for Non linear load - known source of problems
   - B. Watch for "Hot Spots" in the electrical system -Transformers
   - C. Identify re-occurring electrical maintenance issues - Circuit board failure
   - D. Pinpoint downtime issues in the electrical system - Tripped breakers, drives etc.

3. Maintain and document all electrical system components (NFPA 70B)

4. Develop a Power Quality improvement plan

5. Engage P3 to help identify and solve Harmonic problems and other Power Quality issues

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At the end of the long 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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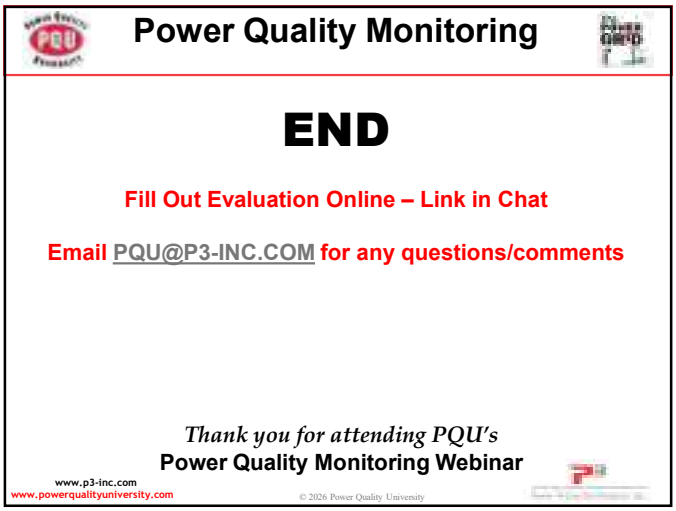
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