# Effects of Power Quality On Metering

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# Focus of this Presentation

- What is power quality?
- What is a power analyzer and how does it help you improve power quality?
- What are some examples of power quality issues?
- How does power quality affect metering?

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# What is Power Quality?

- Customer's view of power quality
  - Flickering lights
  - Equipment reset
  - Tripping of breakers
  - Motors or transformers running hot
  - Lightning or other weather related issues

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# What is Power Quality?

- Utility's view of power quality - Deviation from a pure sinusoidal voltage supply at a frequency of 60 Hz (US).
  - Sags, dips, swells
  - Transient voltages
  - Harmonics
  - Voltage Regulation
  - Frequency Variations

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# What is a Power Analyzer?

- A power analyzer is a device used to measure the components of power:
  - Voltage
  - Current
  - Phase
  - Power Factor
  - Frequency
  - Harmonics

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# Power Analyzer

- Measure data over a period of time to establish a trend
- Normally logs data to a PC or may be self-contained
- Used to determine ways to reduce energy usage and find and eliminate power quality issues

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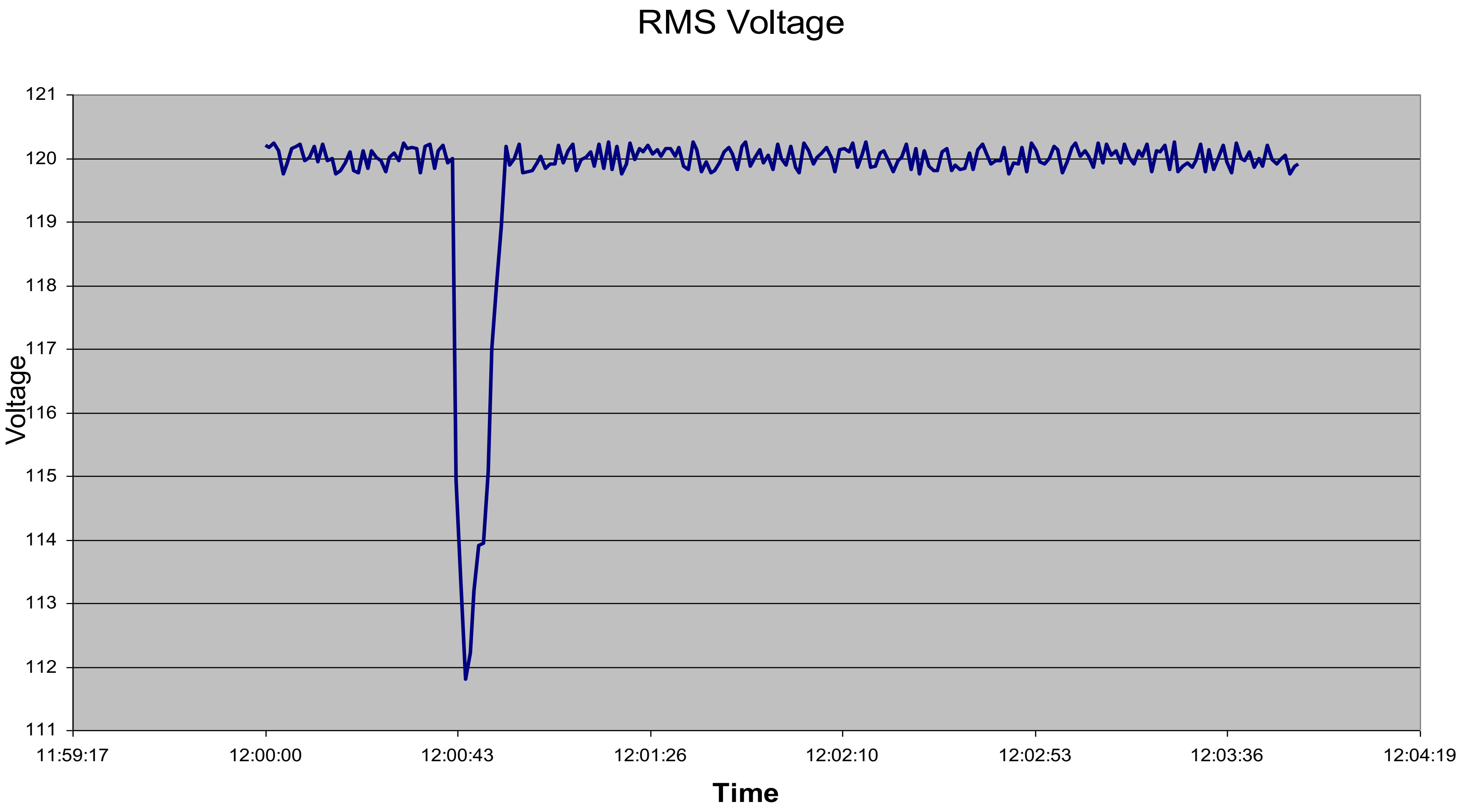
# Power Quality Issues

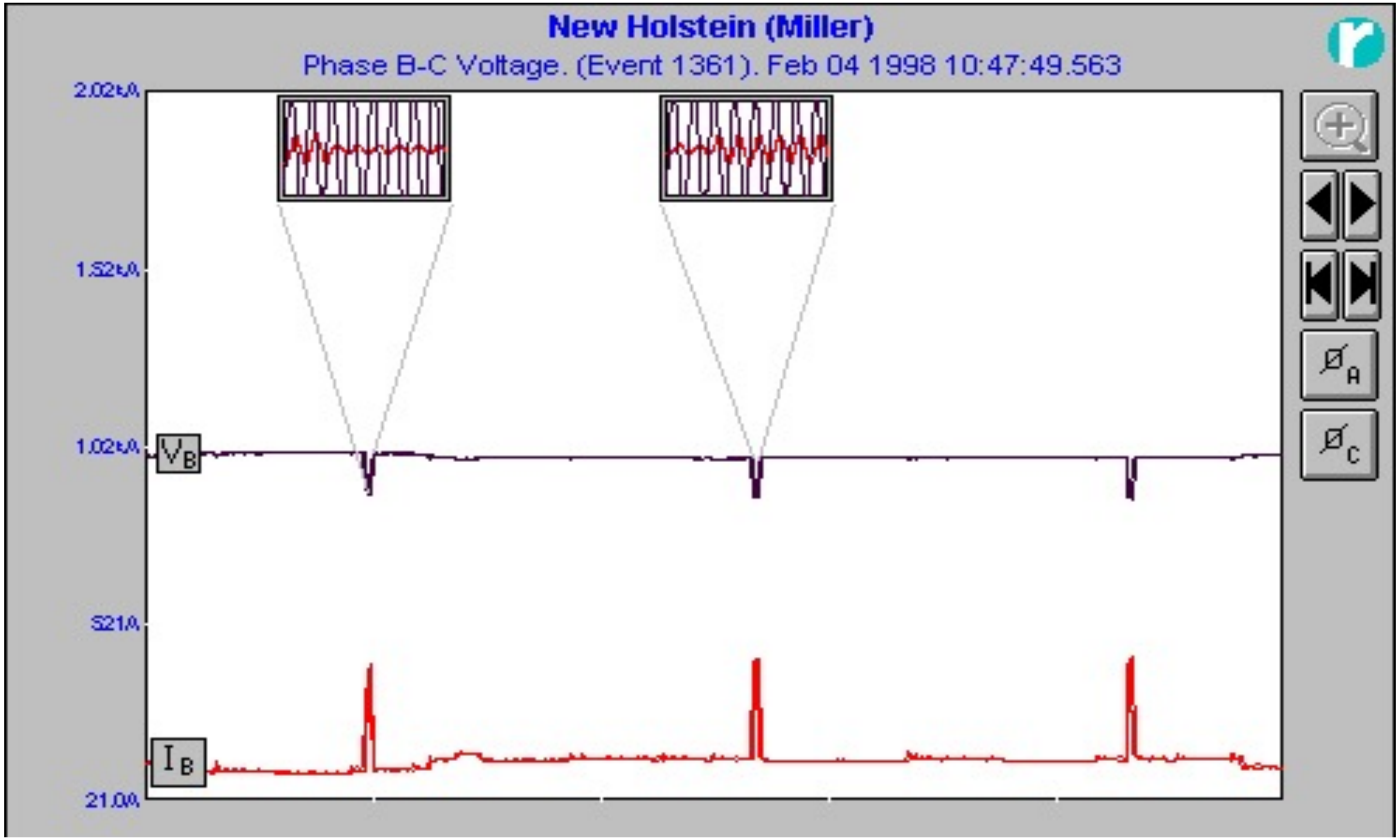
- Sags and swells
  - Deviations from normal RMS voltage which last from 0.5 cycle to several seconds
  - Most common power quality issues
  - Very noticeable to customers
  - Often an infrastructure sizing vs load issue
  - Generally not an issue from a metering accuracy point of view

# Power Quality Issues

## Sag



# Power Quality Issues



# Power Quality Issues

- Transient Voltages
  - Very short deviations from the normal sinusoidal voltage – "spikes"
  - Sources – capacitive switching, lightning
  - Can cause equipment failures both for utility and for customers
  - Other than potential meter damage, doesn't usually cause meter problems

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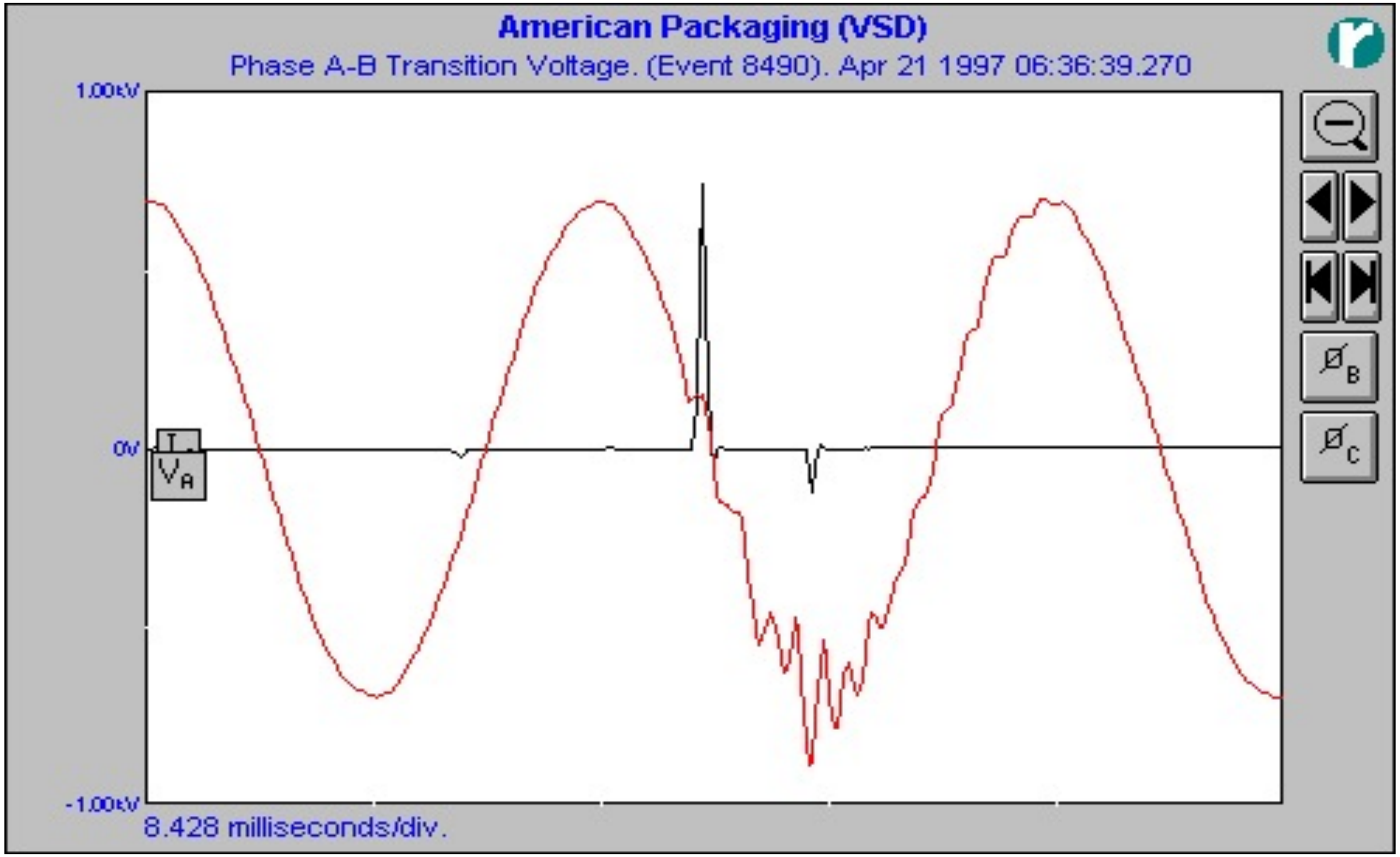
# Power Quality Issues




Transient Caused by Capacitor Bank Switching

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# Power Quality Issues

- Voltage Regulation
  - Long term variations in voltage
  - ANSI C84.1 defines two **service** ranges
    - Range A Normal conditions
      < 600 VAC ±5.0% at service entrance
      > 600 VAC -2.5% +5.0%
    - Range B Short durations or unusual conditions
      -8.3% +5.8%
  - Not a metering accuracy issue

# Power Quality Issues

- Voltage Regulation
  - Long term variations in voltage
  - ANSI C84.1 defines two **utilization** ranges
    - Range A Normal conditions
      < 600 VAC -10% +4.2%
      > 600 VAC -10% +5.0%
    - Range B Short durations or unusual conditions
      -13.3% +5.8%
  - Not a metering accuracy issue

If we provide service that meets the SERVICE range requirement
the customer utilization range requirement should be met.

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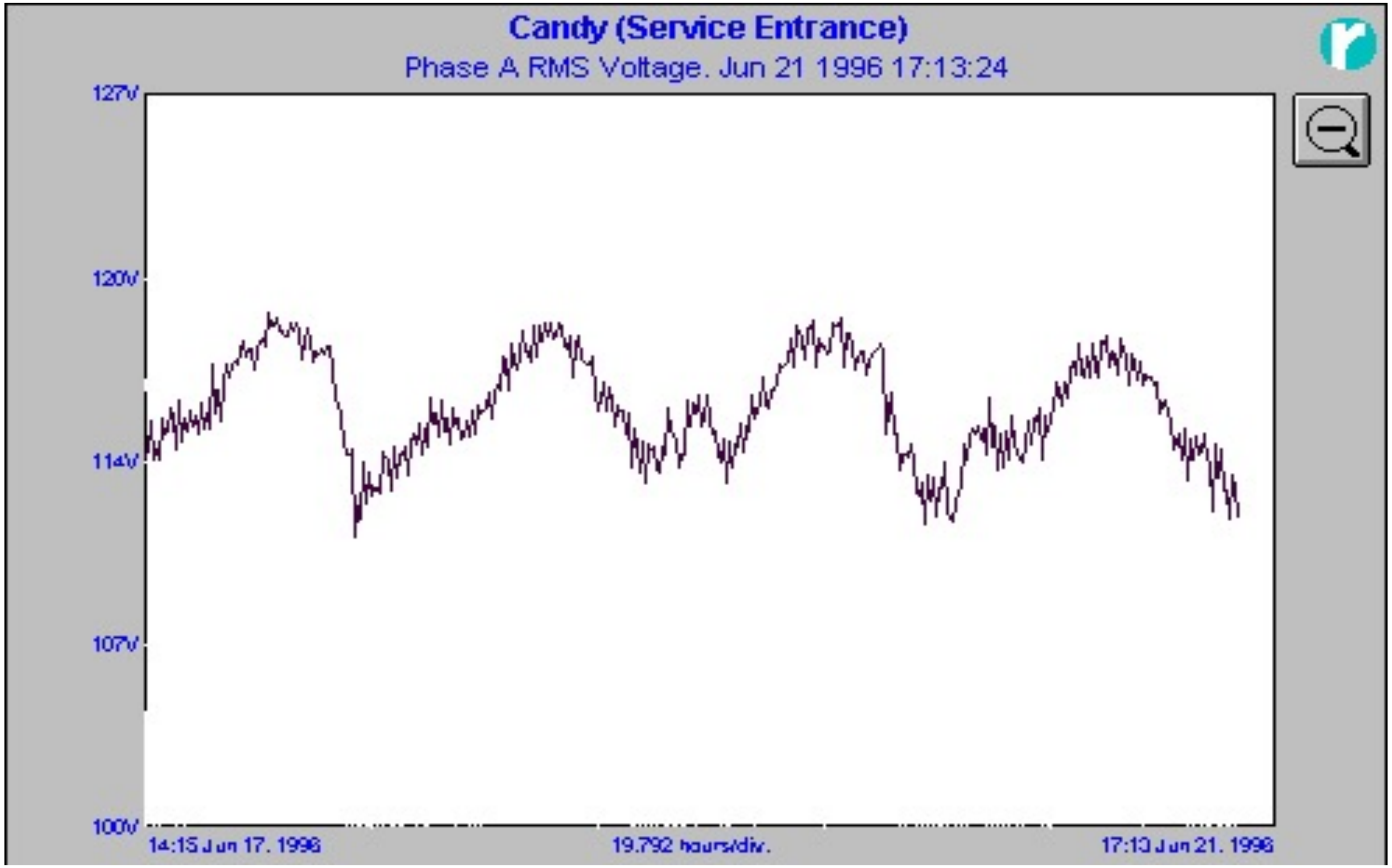
# Power Quality Issues




Voltage regulation issue created by overloaded circuit.

# Power Quality Issues

- Frequency Stability
  - Fluctuations are generally small and slowly varying averaging to zero
  - Western Grid Data
    - Normal: ±0.015 Hz
    - Sudden Changes: ±0.100 Hz (several times a month)
    - Major Breakup: ±0.750 Hz (once every few years)
  - Can potentially cause metering issues, especially for VAR measurement

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# Power Quality Issues

- Harmonics
  - Repetitive contamination of the voltage or current waveform
  - Generated by non-linear loads. Voltage harmonics are a reflection of the non-linear load on a distribution system with finite impedance
  - Produce a variety of infrastructural problems
  - Generate system losses
  - Can result in metering errors and disputes

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# Harmonics Theory

- Basic Harmonic Theory
  - Harmonics describe disturbances which repeat every cycle for a significant number of cycles
- Engineers use Fourier notation to describe harmonic waveforms

$$V(t) = \sqrt{2}\sum_{n=1}^{\infty}\left(V_n Sin(n\omega_0 t - \alpha_n)\right)$$

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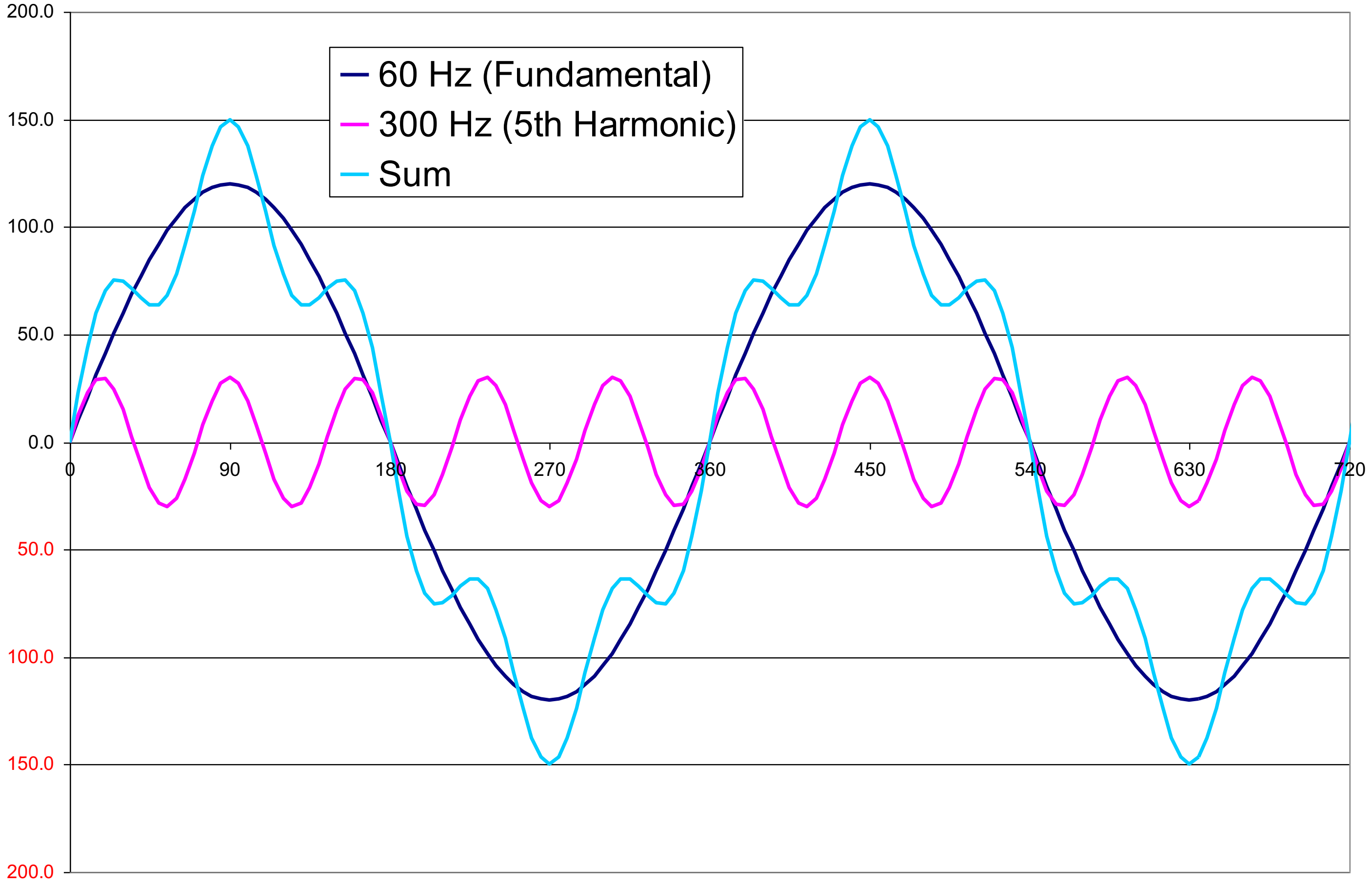
# Harmonics Theory

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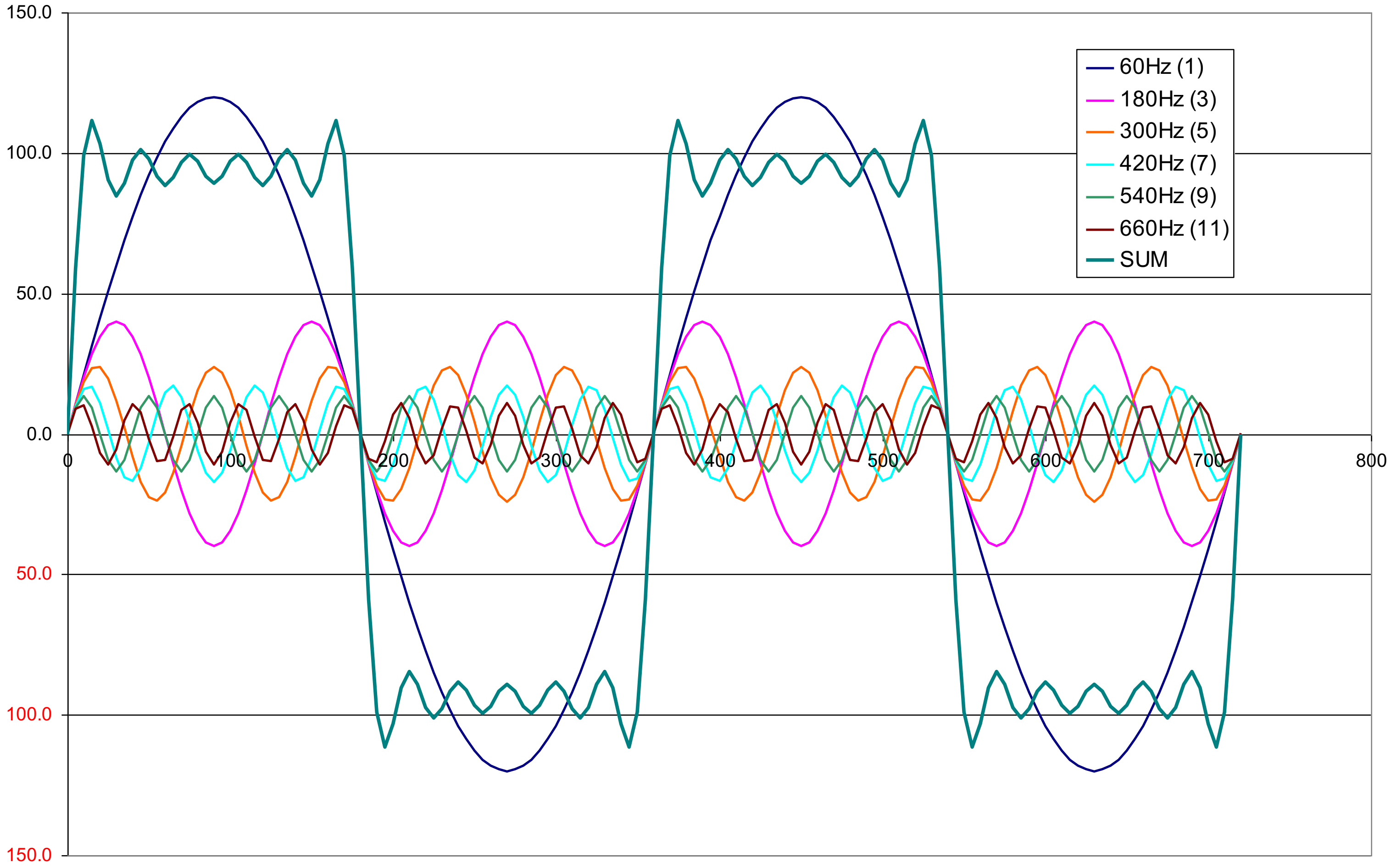
# Harmonics Theory




Even a square wave can be represented as a series of harmonics.

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# Focus on Harmonics

- Where do harmonics come from?
  - Non-linear loads at the customer’s site
  - Coupling from loads at other sites sharing the distribution system
    - One customer’s harmonic current load is converted into voltage harmonics at other customer’s sites by the impedance of the system

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# Past Harmonic Sources

| SOURCE | TYPE | LEVEL |
|---|---|---|
| **Transformer**<br>▪ Saturation<br>▪ Energization | **Current Harmonics<br>3,5,7… & 2,4…** | **1 to 85%** |
| **Arc Furnace Welders** | **Voltage Harmonics<br>5 & 7** | **2.5 to 8%** |
| **Line Commuted Converters** | **Volt. & Cur. Harmonics<br>H = np ± 1** | **10 to 30%** |
| **Static VAR Compensators** | **Current Harmonics<br>H = np ± 1** | **2 to 4%** |
| **Saturable Reactors** | **Current Harmonics<br>3,5,7…** | **1 to 8%** |

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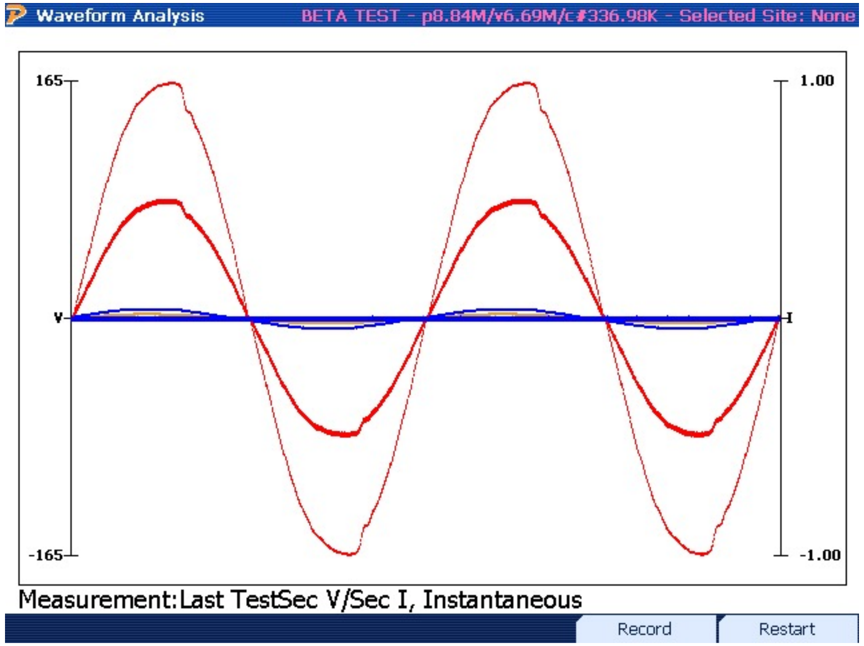
# New Harmonic Sources

| SOURCE | TYPE | LEVEL |
|---|---|---|
| Fluorescent Lighting | Current Harmonics<br>3,5,7… up to > 49 | > 400% |
| Electronic Power Supplies<br>Especially Computers | Current Harmonics<br>3,5,7… up to > 25 | >100% |

# Green 60W Incandescent Bulb



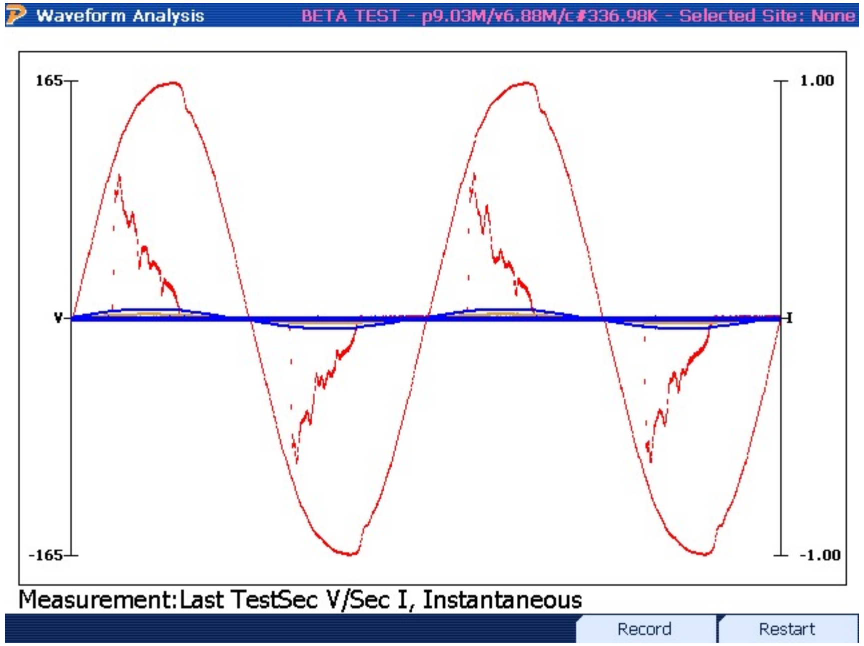

Active Power = 41W

Reactive Power = <1 VAR

Apparent Power = 41VA

Current THD = 1.5%

# 60W Equivalent CCFL Bulb




Active Power = 14 W

Reactive Power = 6 VAR

Apparent Power = 16 VA

Current THD = 88%

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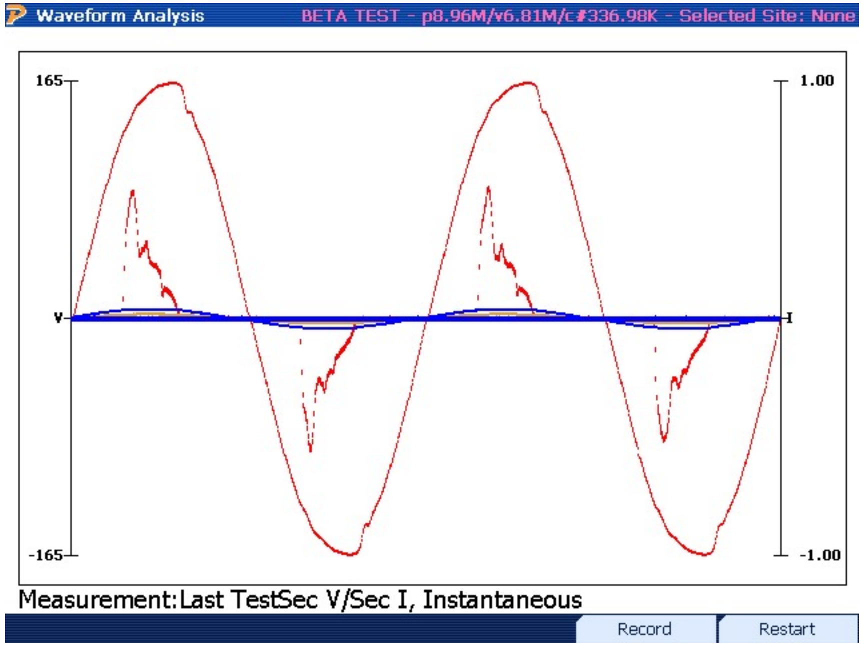
# 60W Equivalent LED Bulb




Active Power = 11 W

Reactive Power = 4 VAR

Apparent Power = 12 VA

Current THD = 111%

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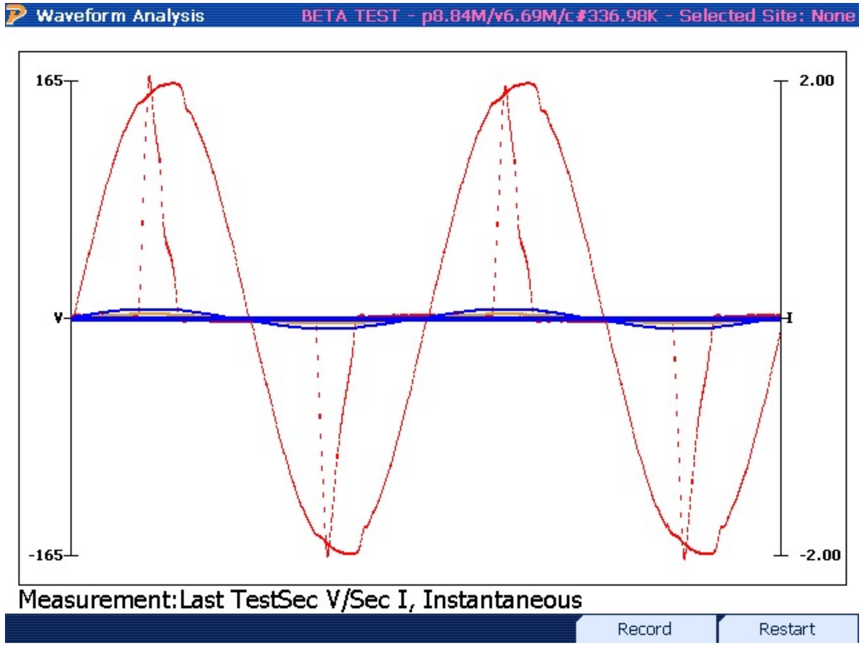
# Laptop Computer Power Supply




Active Power = 35 W

Reactive Power = 6 VAR

Apparent Power = 37 VA

Current THD = 144%

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# Harmonic Theory
## An Alternate Approach

- Harmonics can be grouped into "sequences" which help us understand their effects.

| Name | F | 2nd | 3rd | 4th | 5th | 6th | 7th | 8th | 9th |
|---|---|---|---|---|---|---|---|---|---|
| Freq | 60 | 120 | 180 | 240 | 300 | 360 | 420 | 480 | 540 |
| Seq | + | - | 0 | + | - | 0 | + | - | 0 |

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# Harmonic Theory
## An Alternate Approach

| Name | F | 2nd | 3rd | 4th | 5th | 6th | 7th | 8th | 9th |
|---|---|---|---|---|---|---|---|---|---|
| Freq | 60 | 120 | 180 | 240 | 300 | 360 | 420 | 480 | 540 |
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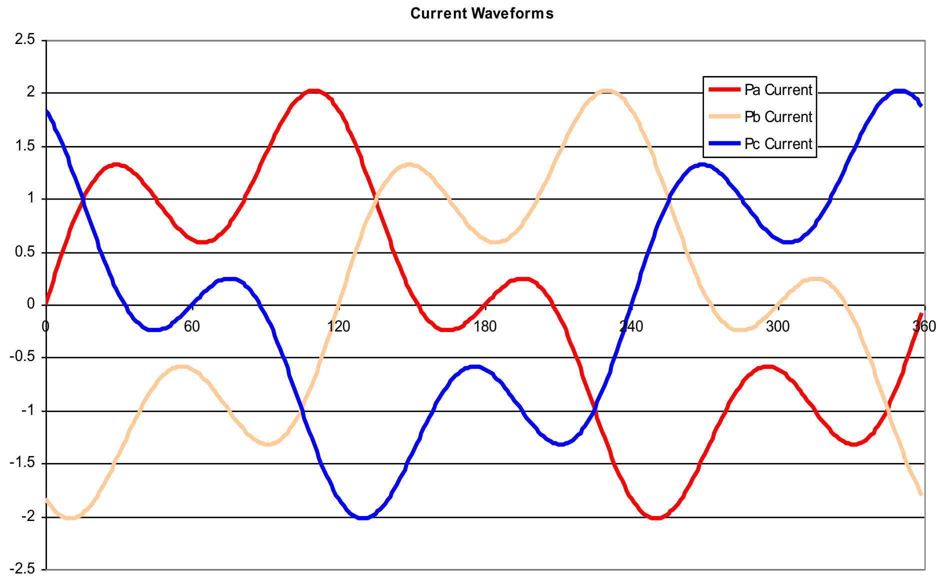


Positive (+)

- If fundamental rotation is ABC then positive (+) sequence harmonics have ABC rotation

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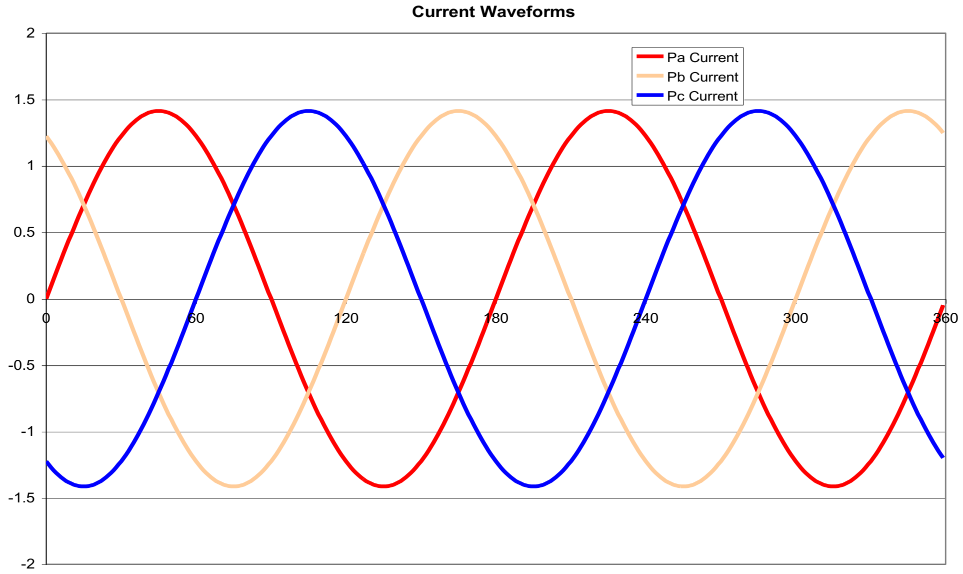
# Harmonic Theory
## An Alternate Approach

| Name | F | 2nd | 3rd | 4th | 5th | 6th | 7th | 8th | 9th |
|---|---|---|---|---|---|---|---|---|---|
| Freq | 60 | 120 | 180 | 240 | 300 | 360 | 420 | 480 | 540 |
| Seq | + | - | 0 | + | - | 0 | + | - | 0 |




Negative (-)

- If fundamental rotation is ABC then negative (-) sequence harmonics have CBA rotation

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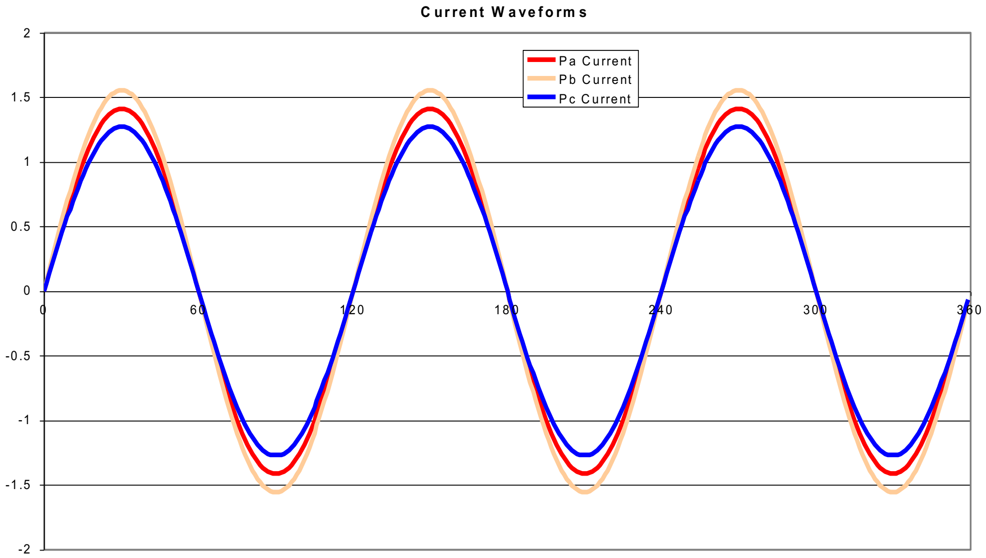
# Harmonic Theory
## An Alternate Approach

| Name | F | 2nd | 3rd | 4th | 5th | 6th | 7th | 8th | 9th |
|---|---|---|---|---|---|---|---|---|---|
| Freq | 60 | 120 | 180 | 240 | 300 | 360 | 420 | 480 | 540 |
| Seq | + | - | 0 | + | - | 0 | + | - | 0 |




ZERO (0)

- If fundamental rotation is ABC then zero (0) sequence harmonics have NO rotation

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# Harmonic Theory
## An Alternate Approach

- Positive (+)
  - Heating of conductors and transformers
- Negative (-)
  - Heating of conductors and transformers
  - Tries to make motors run backwards
- Zero (0)
  - Results in neutral currents which can be larger than phase currents

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# Harmonics & Metering Accuracy

- UPDATE: Latest ANSI C12 standards require meters to be tested under harmonic conditions
  - Six harmonic waveforms that must be tested on all new meters
  - Preliminary testing of proposed waveforms show most meters do well, but a few do very poorly

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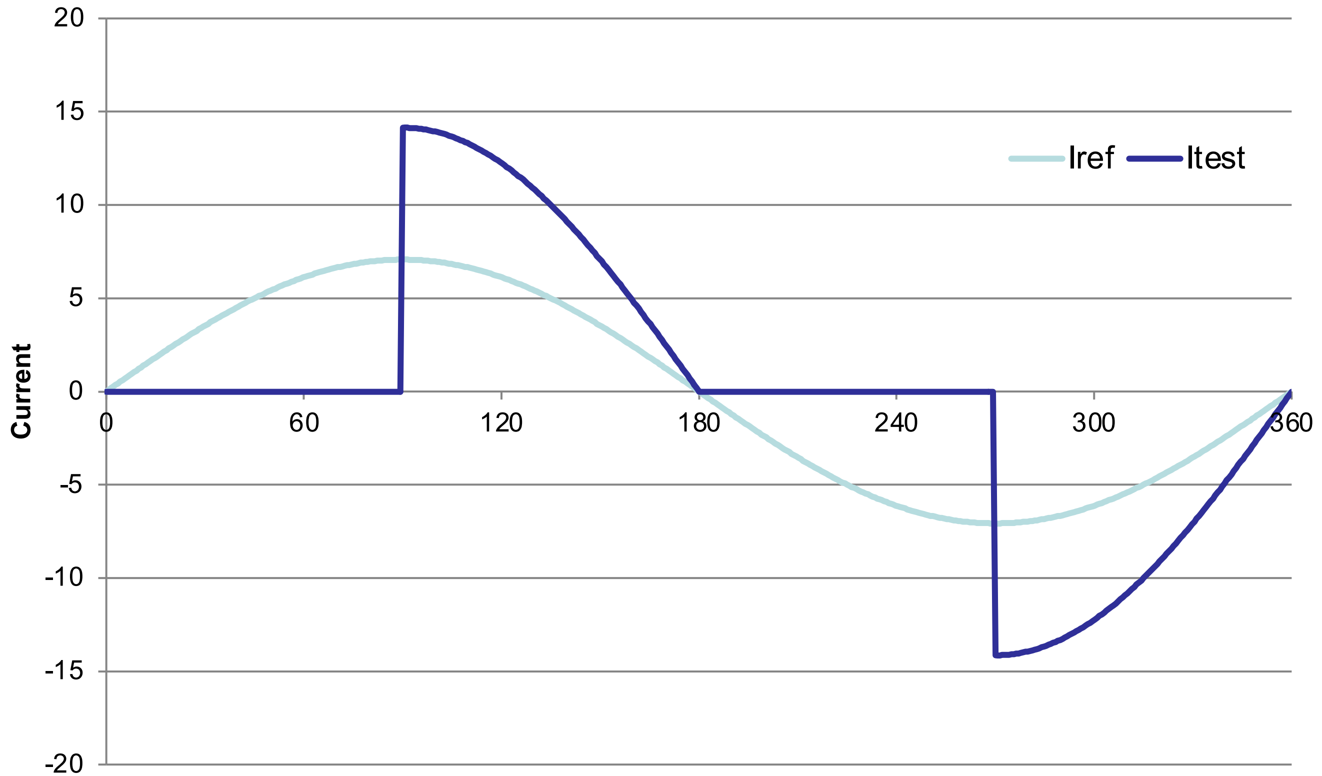
# Harmonics & Metering Accuracy




**Waveform #1 - 90 Degree Phased Fired Waveform**
**Typical for a light dimmer set to 50%**

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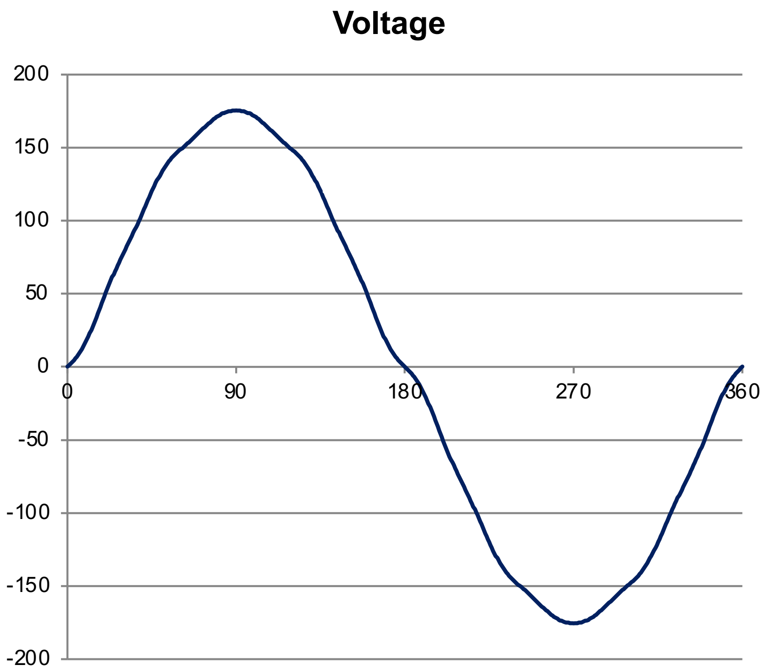
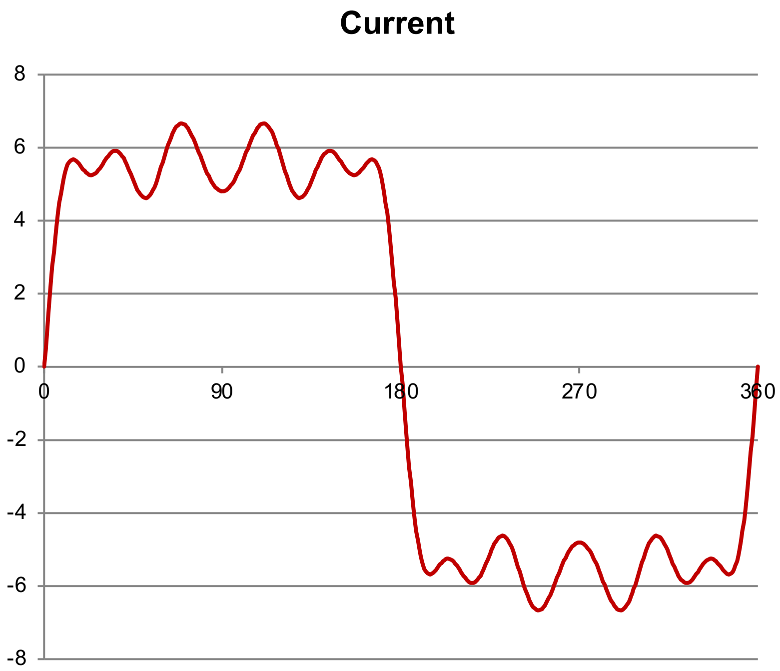
# Harmonics & Metering Accuracy




**Waveform #2 - Quadriform Waveform**
**Switched Load Device**

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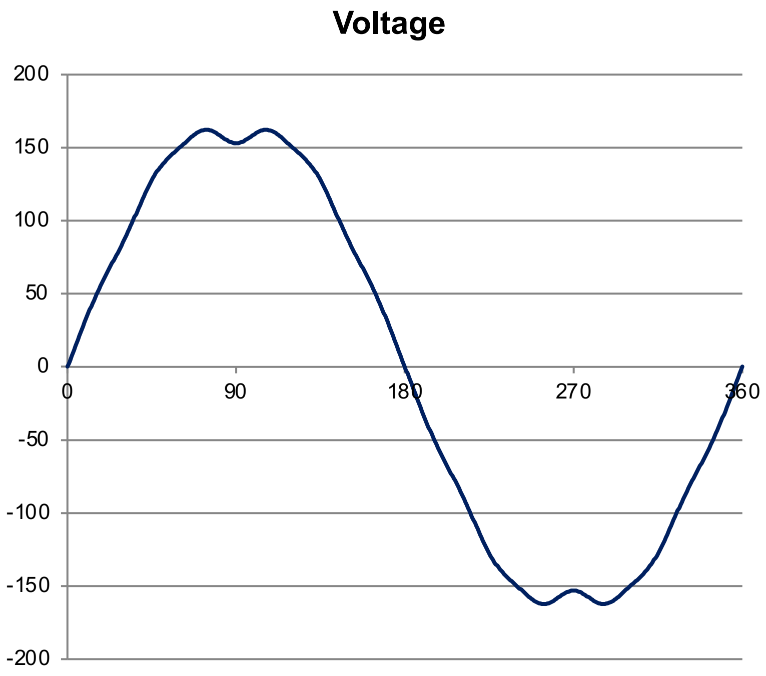
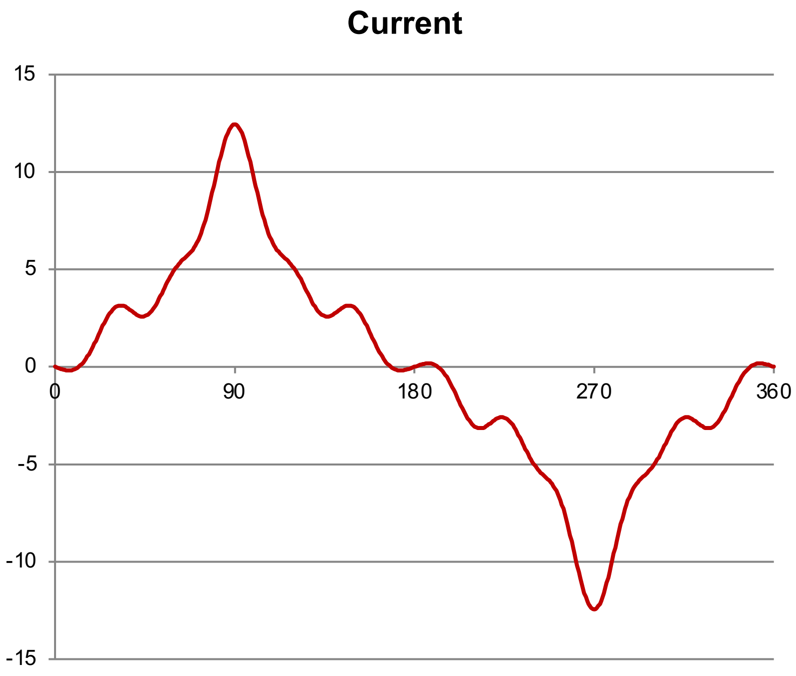
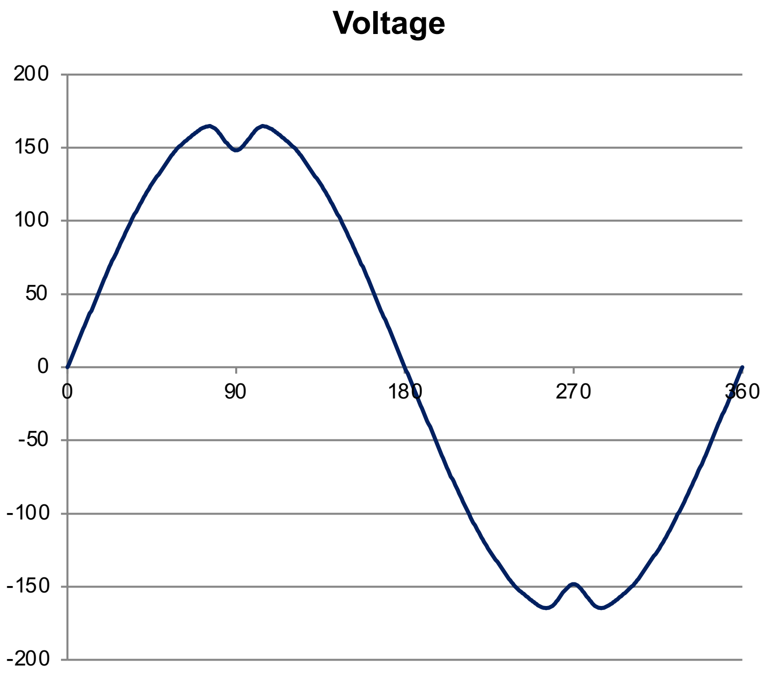
# Harmonics & Metering Accuracy

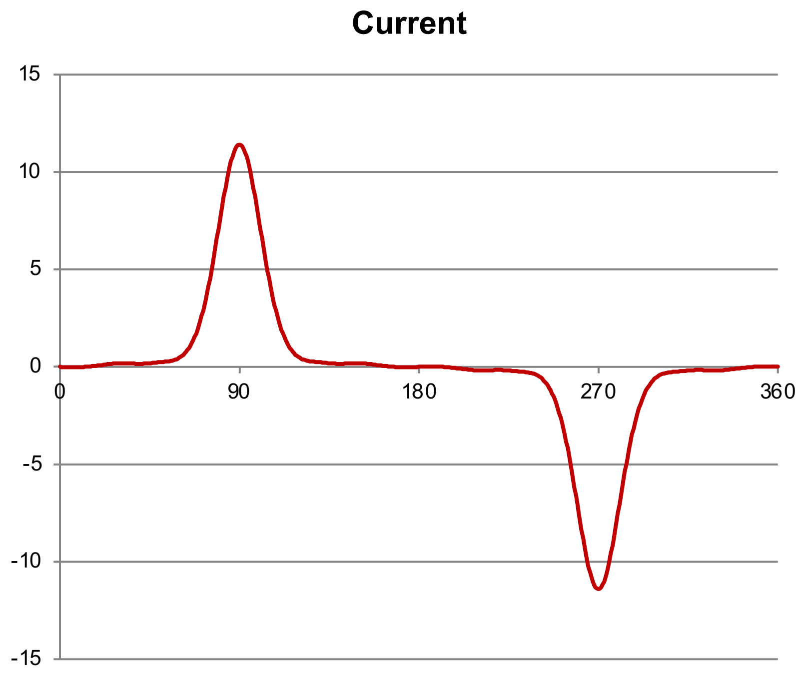



**Waveform #3 - Peaked Waveform**
**Switching Power Supply**

# Harmonics & Metering Accuracy




**Waveform #4 - Pulse Waveform**
**Switching Power Supply**

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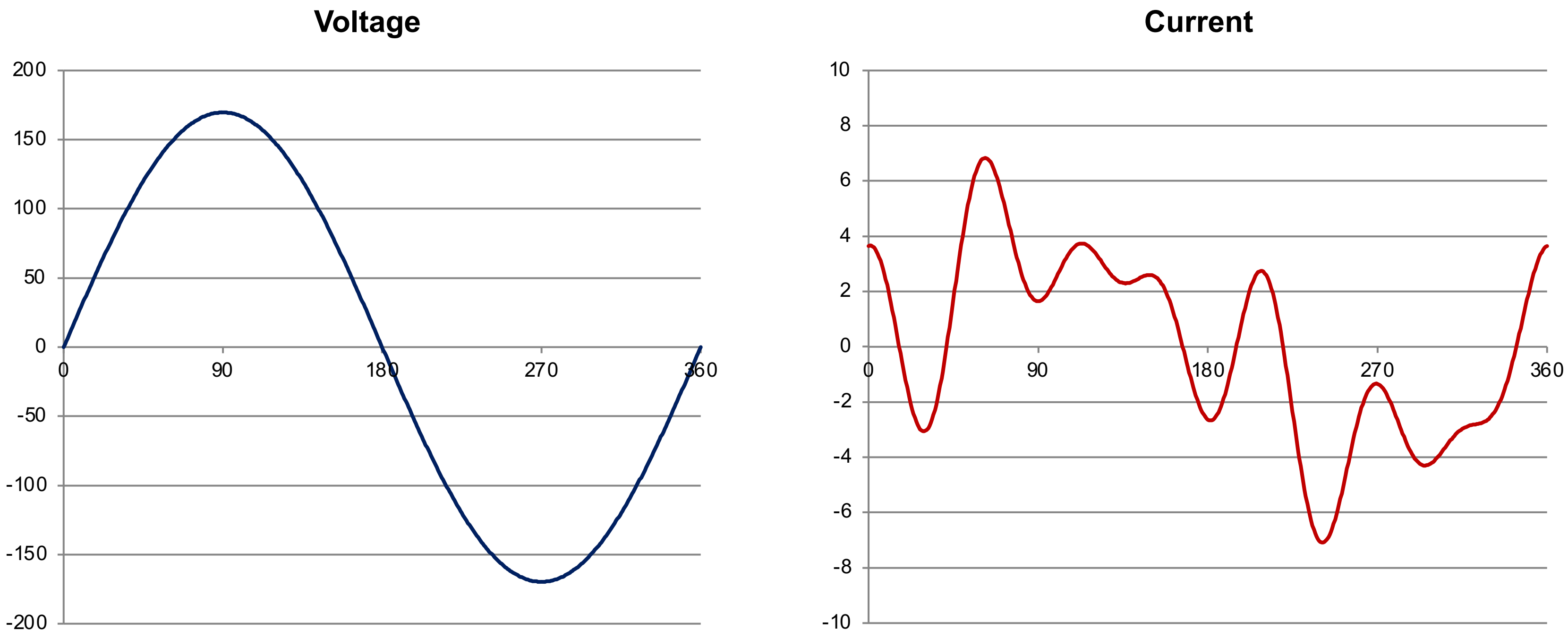
# Harmonics & Metering Accuracy




**Waveform #5 – Multiple Zero Crossing Current Waveform**

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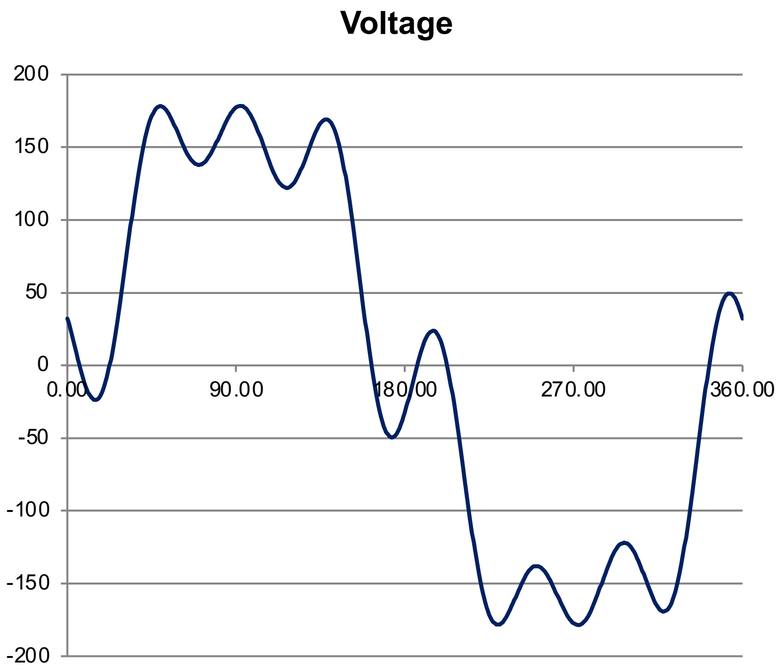
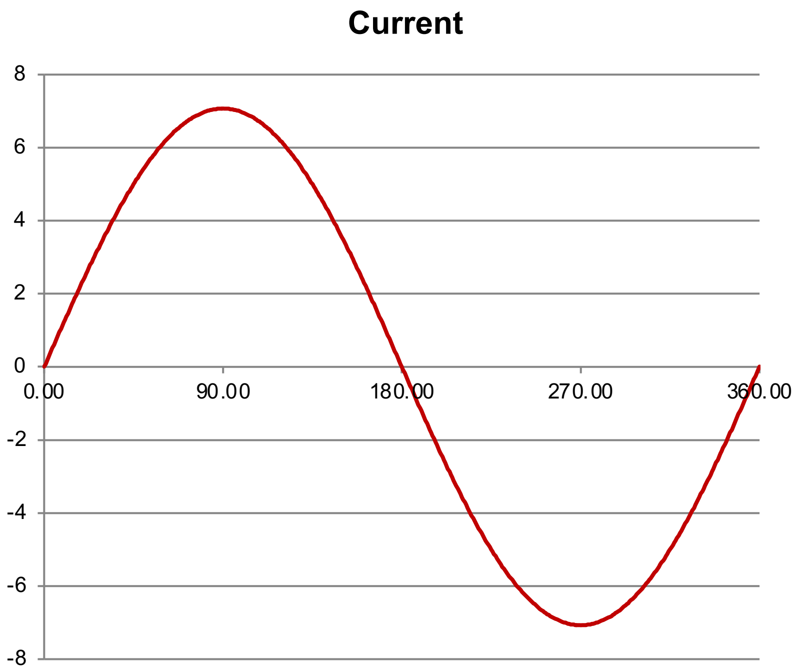
# Harmonics & Metering Accuracy




**Waveform #6 – Multiple Zero Crossing Voltage Waveform**

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# Harmonics & Metering Accuracy

- Primarily affect the calculation of VA, VAR and Power Factor
  - No ANSI standard for these calculations at this time
  - Different manufacturers use different methods and definitions.
  - Most manufacturers allow the user to make several choices for each
  - Differences of over 50 percent in answers can occur in high harmonic situations

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# Power Quality Issues

- Sub Harmonics (Freq < Fundamental)
  - Not addressed in any standard
  - Not measured by FFT based approaches
- Non-Harmonic High Frequency Disturbances
  - Not addressed in any standard
  - Not measured by FFT based approaches
- Sudden Load Changes
  - Not addressed in any standard
  - Not measured by FFT based approaches

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# Harmonic Compensation

- Harmonics can be compensated for at the customer's facility
- Solution must be tailored to the problem
- Examples of solutions:
  - Active Filter – mirror image of harmonic
  - Tuned Filter – effective but expensive
  - Zig zag transfomer reduces 3$^{rd}$ harmonics in neutral
- There is no "one size fits all" solution

# IEEE Power Quality Standards

- SCC-22 Power Quality Standards Coordinating Committee
- 1159: Monitoring Electric Power Quality
  - 1159.1: Guide for Recorder and Data Acquisition Requirements
  - 1159.2: Power Quality Event Characterization
  - 1159.3: Data File Format for Power Quality Data Interchange
- P1564: Voltage Sag Indices
- 1346: Power System Compatibility with Process Equipment
- P1100: Power and Grounding Electronic Equipment
- 1433: Power Quality Definitions
- P1453: Voltage Flicker
- 519: Harmonic Control in Electrical Power Equipment
- P519A: Guide for Applying Harmonic Limits on Power Systems

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# IEC Power Quality Standards

- 61000-1-X Definitions and methodology
- 61000-2-X Environment
- 61000-3-X Limits
- 61000-4-X Test and measurements
- 61000-5-X Installation and mitigation
- 61000-6-X Generic immunity and emissions standards
- Working Groups and Committees
    - SC77A Low Frequency EMC Phenomena
    - TC77/WG1 Terminology
    - SC77A/WG1 Harmonics and other low frequency disturbances
    - SC77A/WG6 Low frequency Immunity Tests
    - SC77A/WG2 Voltage fluctuations and other low frequency disturbances
    - SC77A/WG9 Power Quality measurement methods

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