EFFECTS OF POWER QUALITY ON METERING

S.W.E.M.A.

Southwest Electrical Metering Association

POWERMETRIX

Steve Hudson, P.E.
VP of Hardware Engineering
Steve.Hudson@powermetrix.com
10737 Lexington Drive
Knoxville, TN 37932
www.powermetrix.com

POWERMETRIX

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?

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

Southwest Electrical
Metering Association

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

POWERMETRIX

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

Power Analyzer

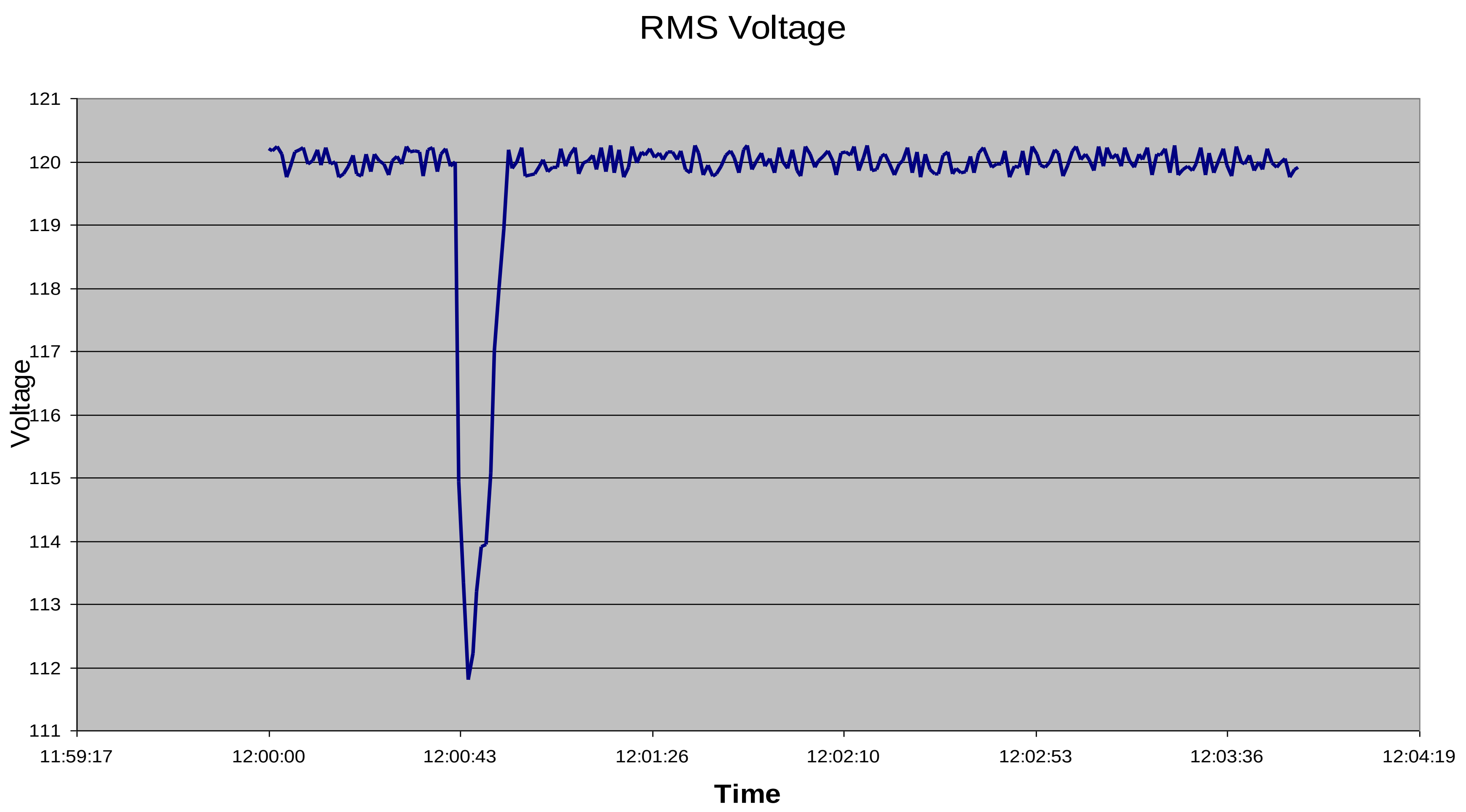
- Measure data over a period of time to establish a trend
- Normally logs data to a PC or may be self-contained
- Used to determine ways to reduce energy usage and find and eliminate power quality issues

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

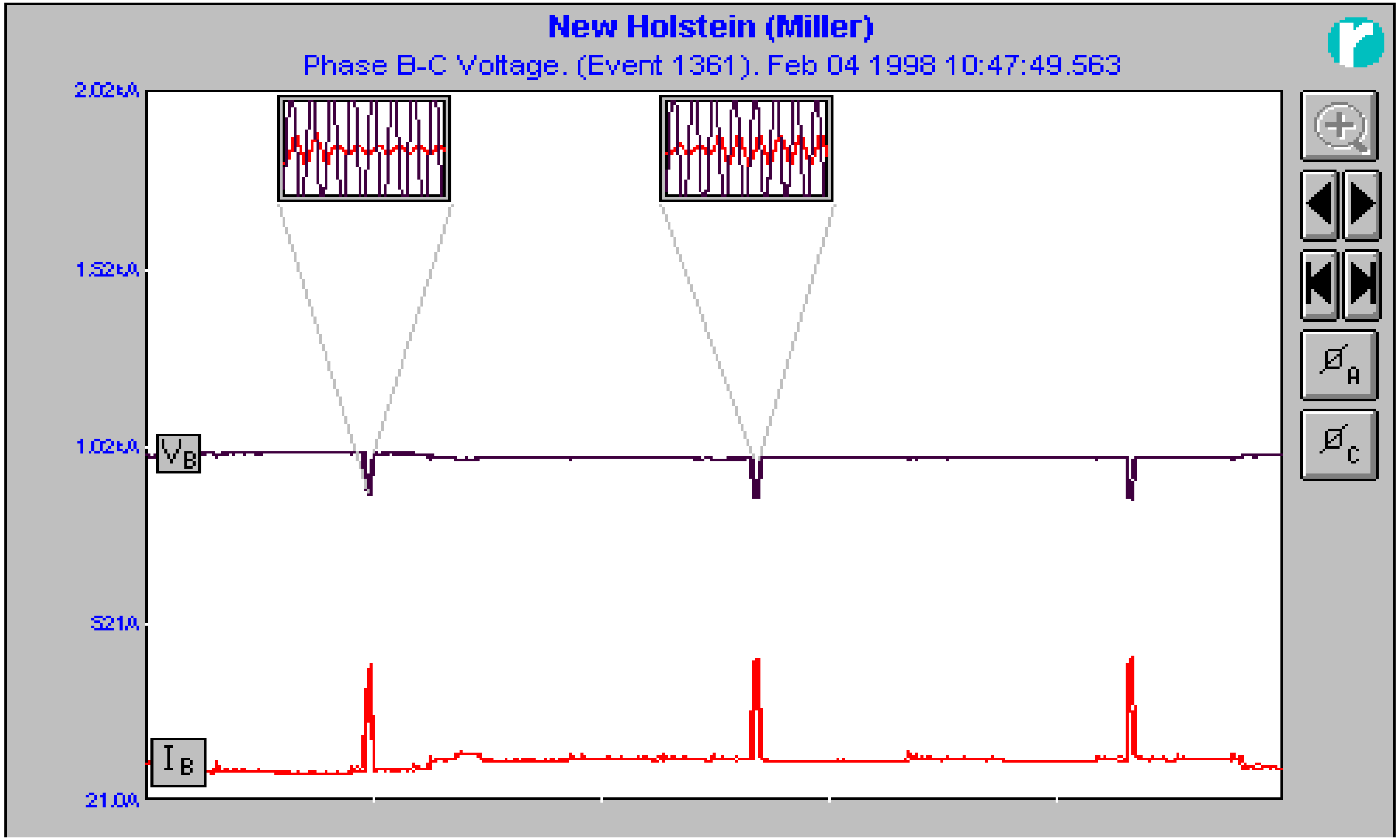
Power Quality Issues

Sag



Southwest Electrical Metering Association

Power Quality Issues

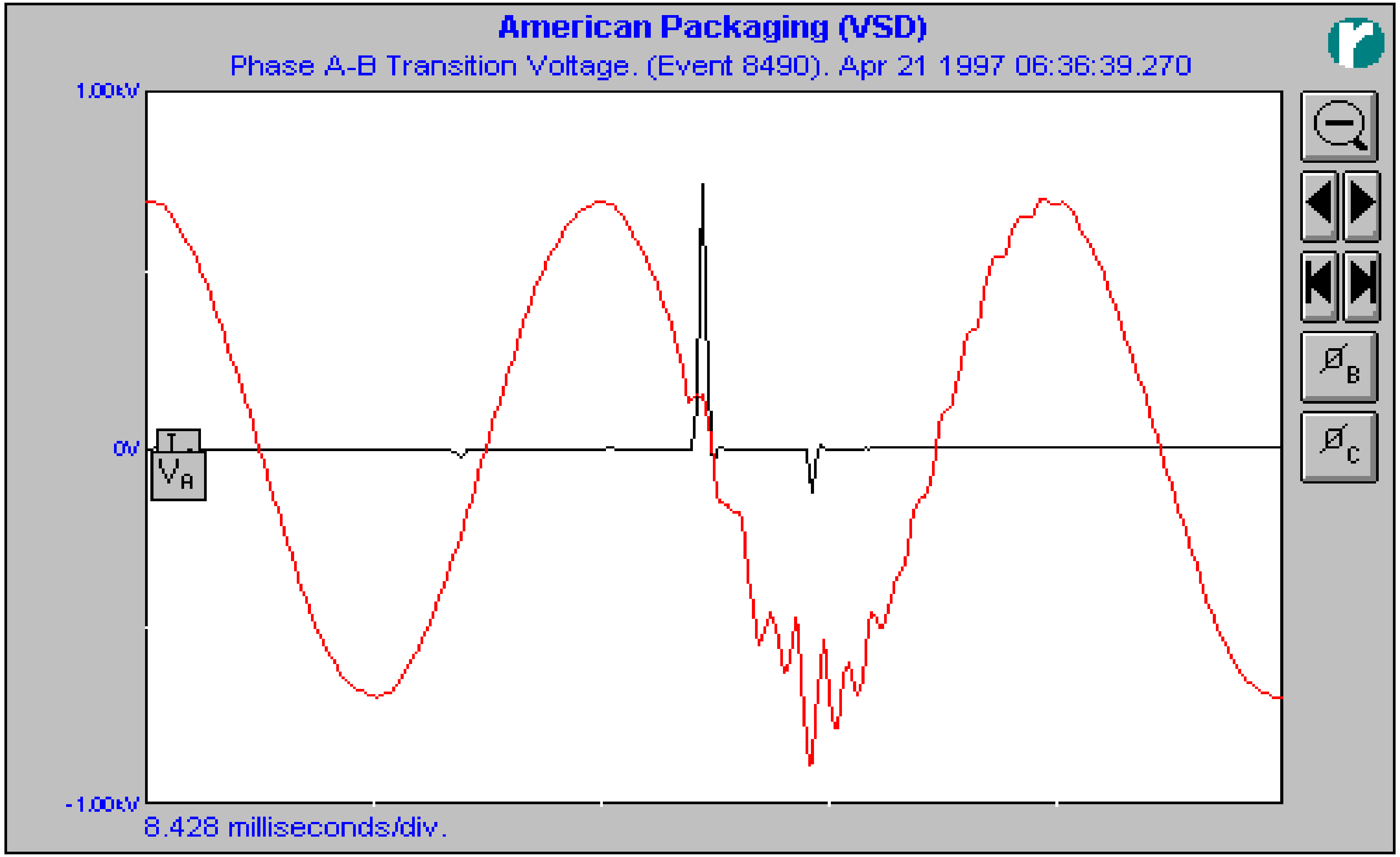


POWERMETRIX

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

Power Quality Issues



Transient Caused by Capacitor Bank Switching

S.W.E.M.A.
Southwest Electrical Metering Association

Power Quality Issues

- Voltage Regulation
  - Long term variations in voltage
  - ANSI C84.1 defines two **<u>service</u>** 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

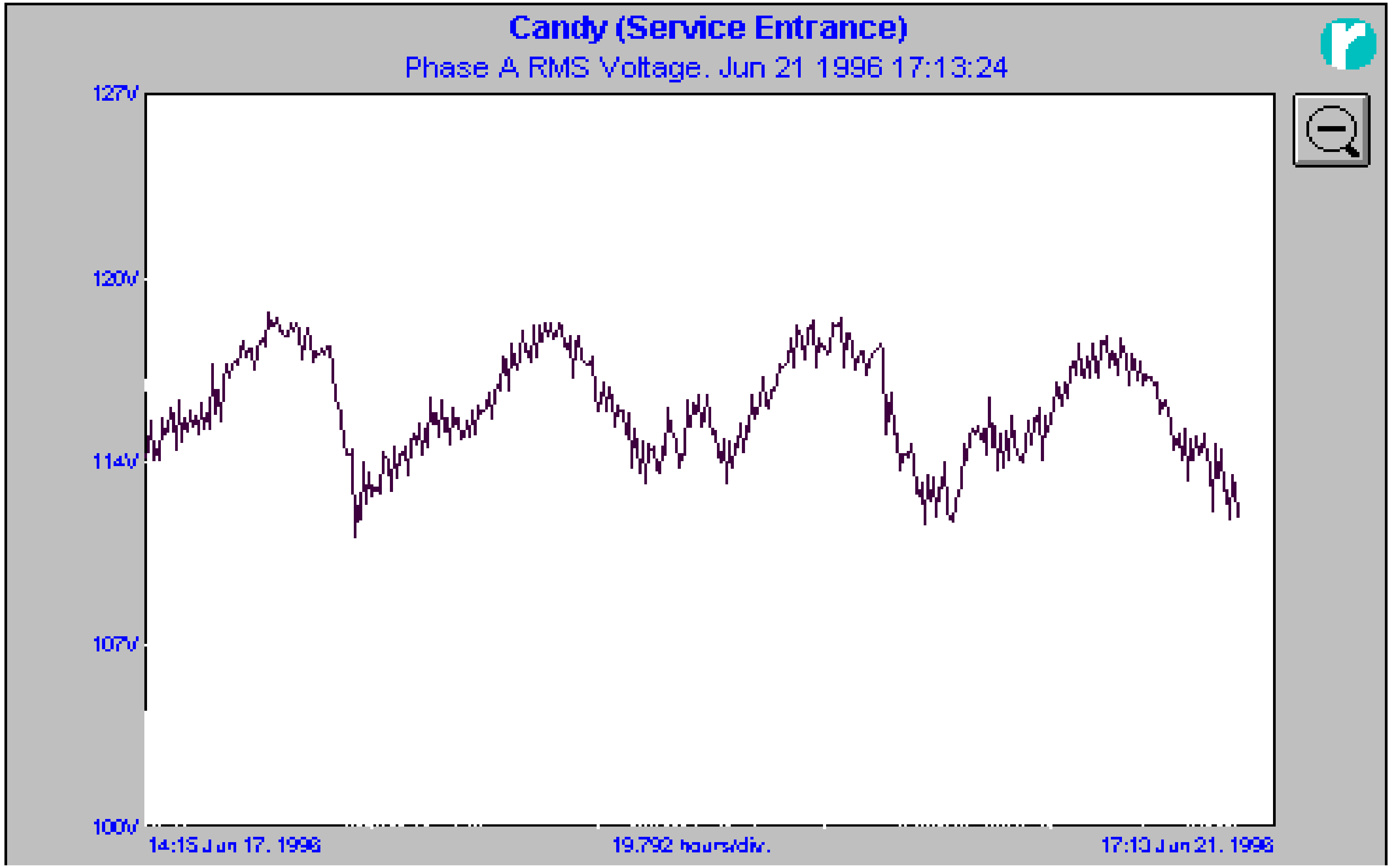
POWERMETRIX

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.

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

Southwest Electrical Metering Association

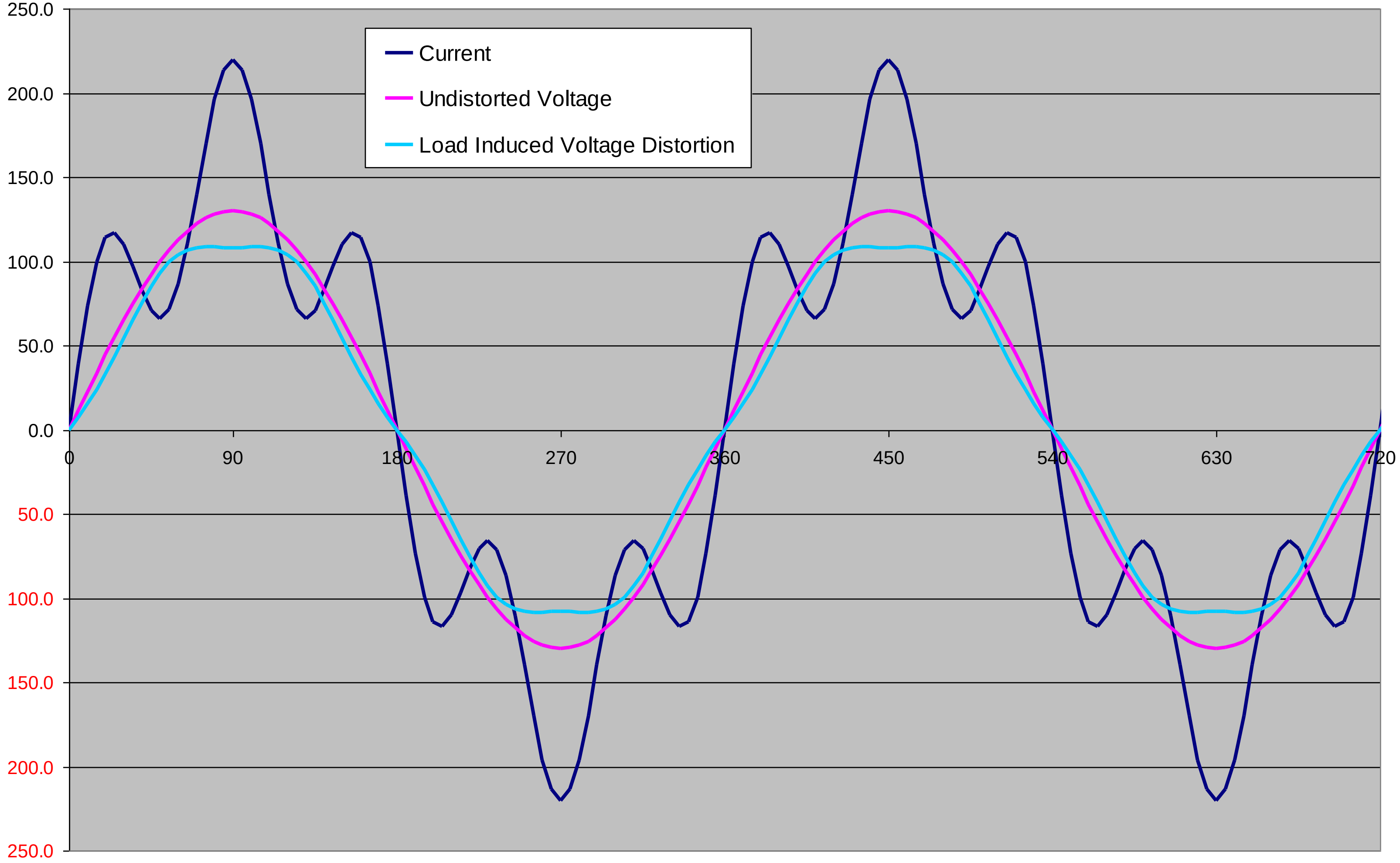
Power Quality Issues

- 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

POWERMETRIX

Southwest Electrical
Metering Association

Power Quality Issues



POWERMETRIX

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

Southwest Electrical
Metering Association

Past Harmonic Sources

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

POWERMETRIX

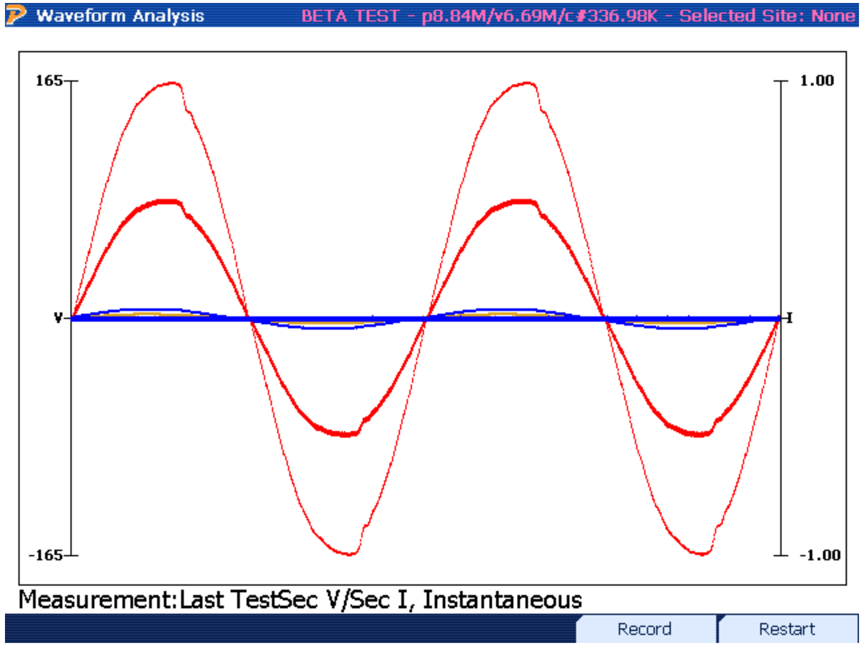
Southwest Electrical
Metering Association

New Harmonic Sources

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

POWERMETRIX

Green 60W Incandescent Bulb



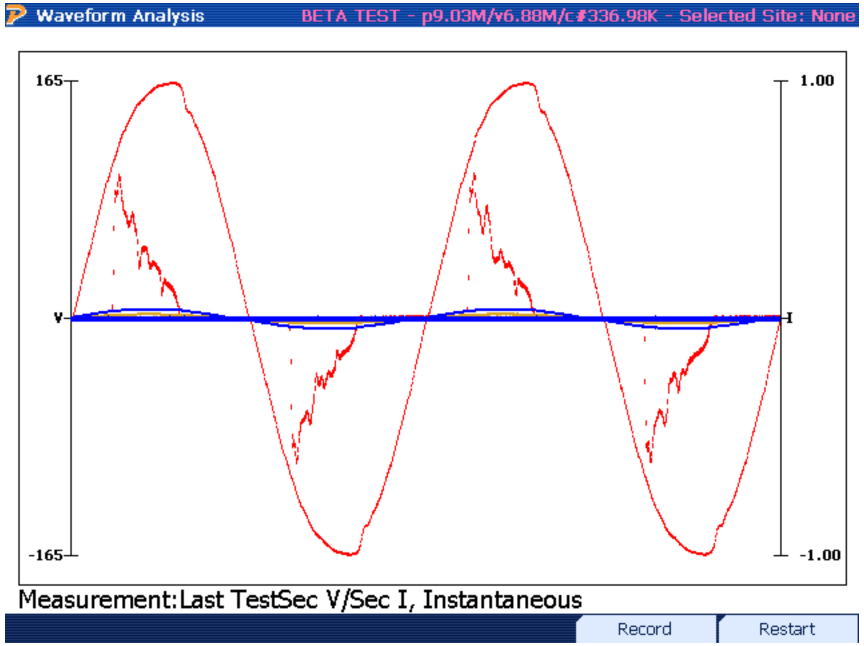
Active Power = 41W

Reactive Power = <1 VAR

Apparent Power = 41VA

Current THD = 1.5%

60W Equivalent CCFL Bulb



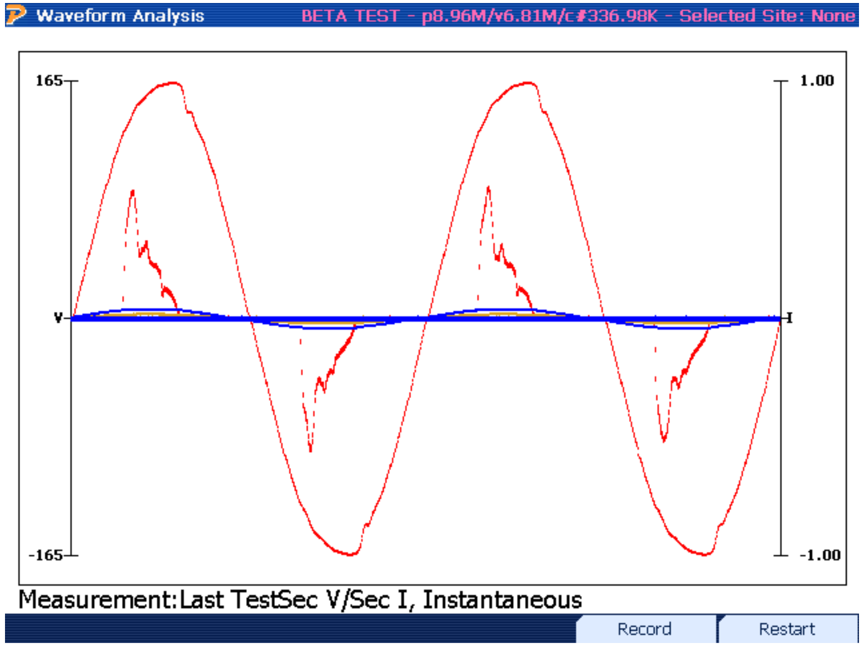
Active Power = 14 W

Reactive Power = 6 VAR

Apparent Power = 16 VA

Current THD = 88%

60W Equivalent LED Bulb



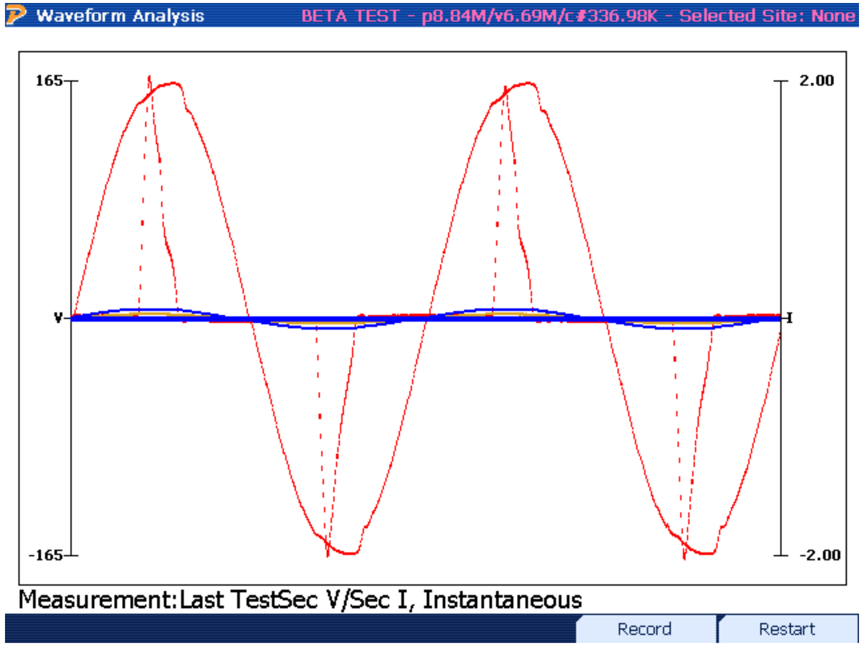
Active Power = 11 W

Reactive Power = 4 VAR

Apparent Power = 12 VA

Current THD = 111%

Laptop Computer Power Supply



Active Power = 35 W

Reactive Power = 6 VAR

Apparent Power = 37 VA

Current THD = 144%

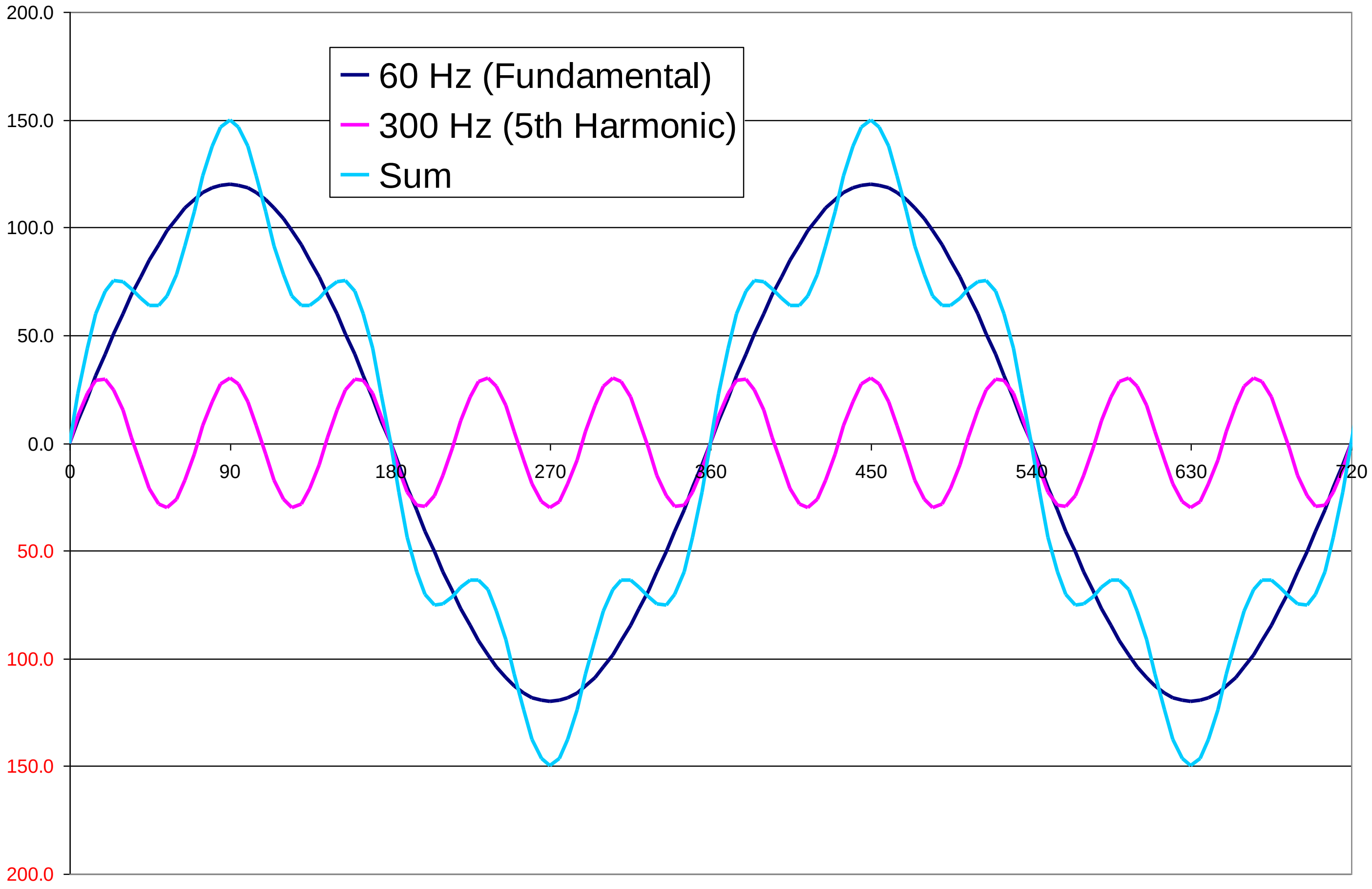
Harmonics Theory

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

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

Southwest Electrical Metering Association

Harmonics Theory

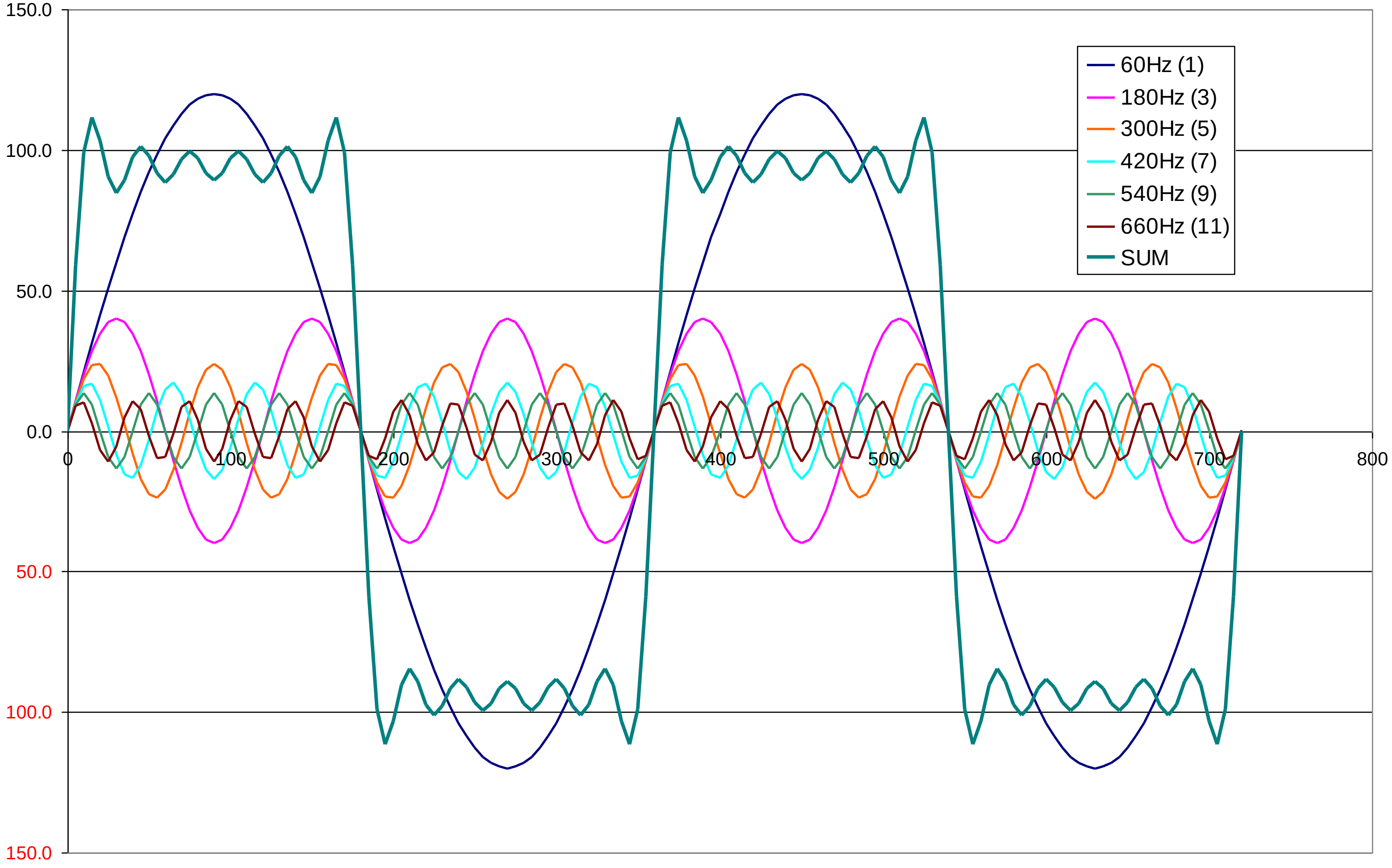


$$V(t) = \sqrt{2}\sum_{n=1}^{\infty}\left(V_n Sin(n\omega_0 t - \alpha_n)\right)$$

POWERMETRIX

Southwest Electrical Metering Association

Harmonics Theory



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

POWERMETRIX

Southwest Electrical Metering Association

Harmonic Theory
An Alternate Approach

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

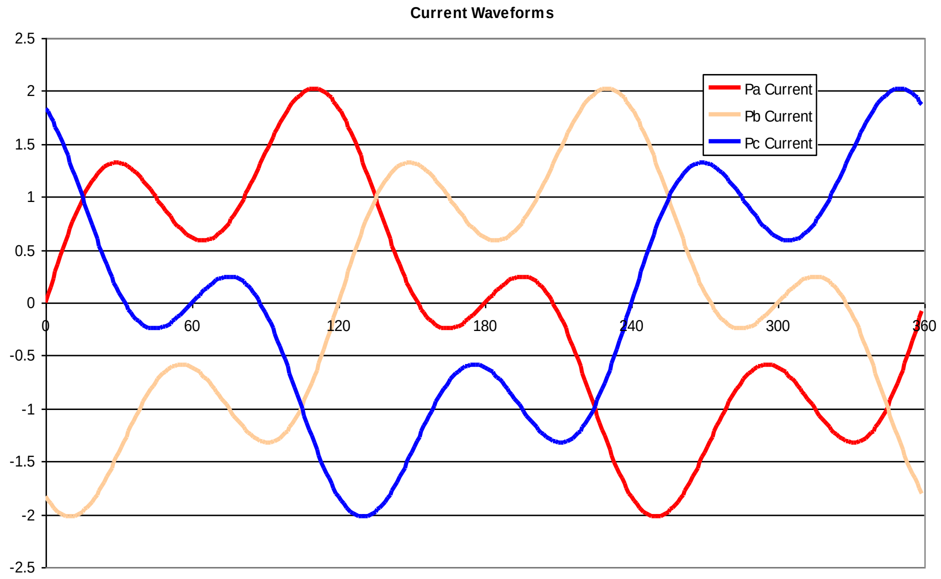
Name	F	2^{nd}	3^{rd}	4^{th}	5^{th}	6^{th}	7^{th}	8^{th}	9^{th}
Freq	60	120	180	240	300	360	420	480	540
Seq	+	-	0	+	-	0	+	-	0

POWERMETRIX

Southwest Electrical Metering Association

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



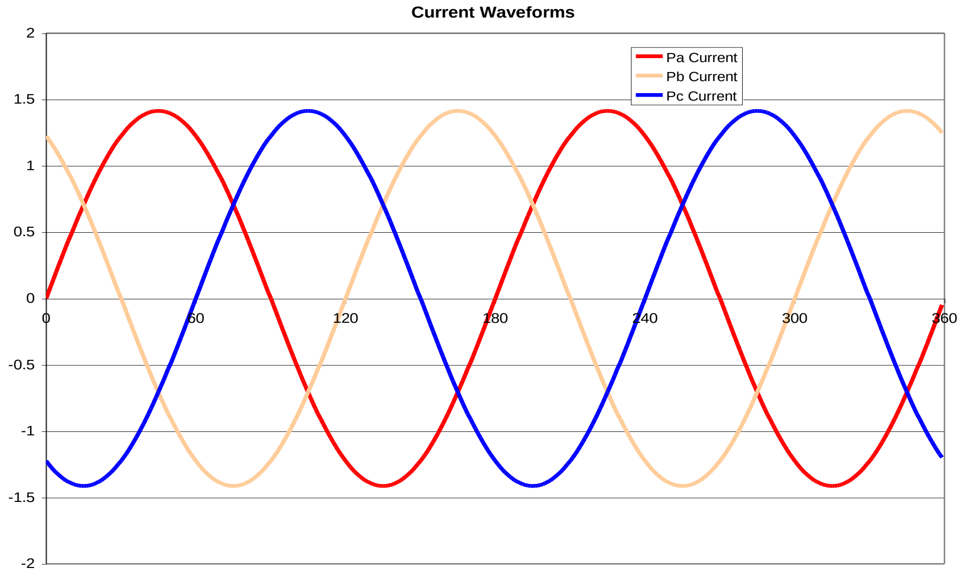
Positive (+)

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

POWERMETRIX

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



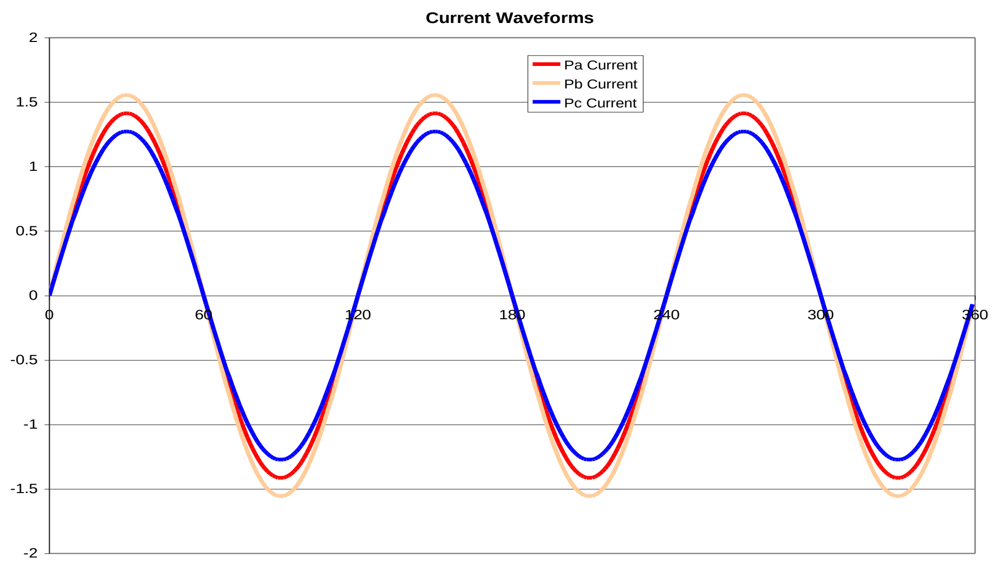
Negative (-)

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

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

Southwest Electrical Metering Association

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

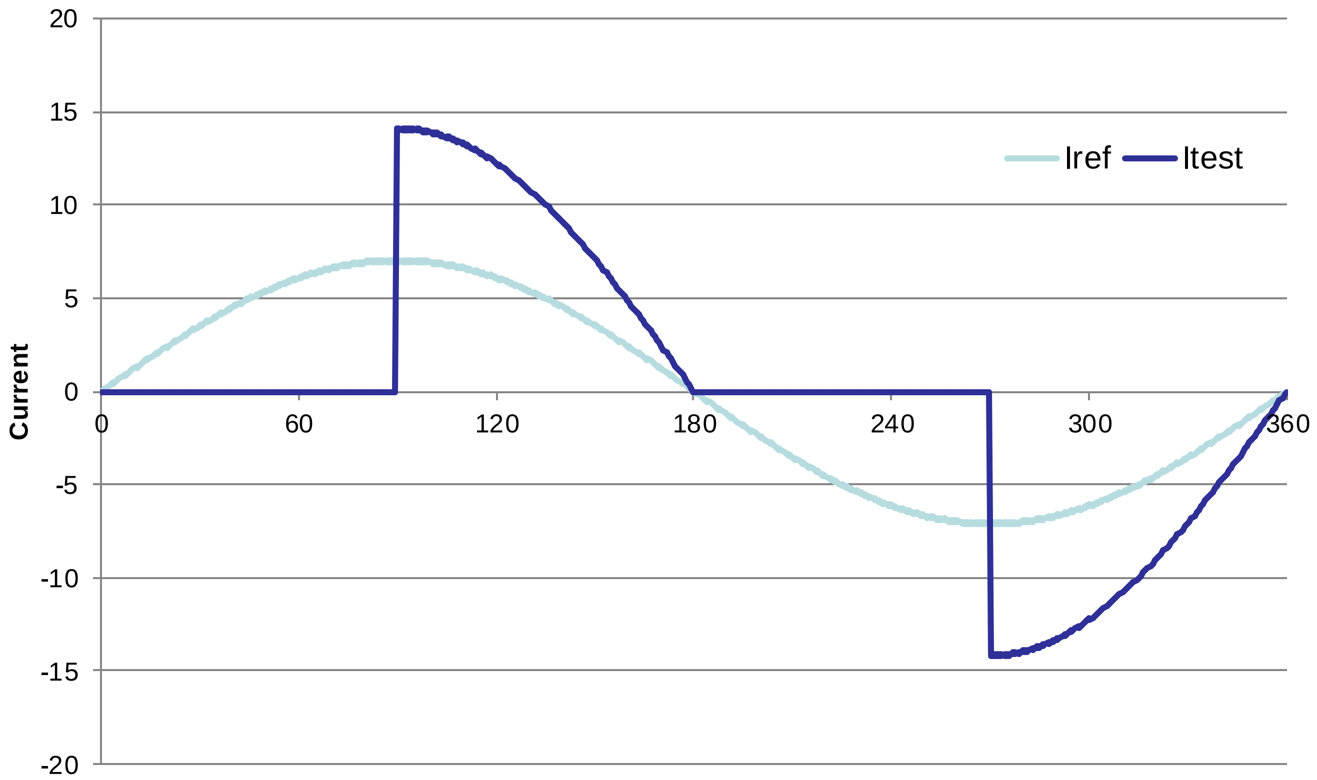
POWERMETRIX

Harmonics & Metering Accuracy

- UPDATE: Latest ANSI C12 standards will 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.

Southwest Electrical Metering Association

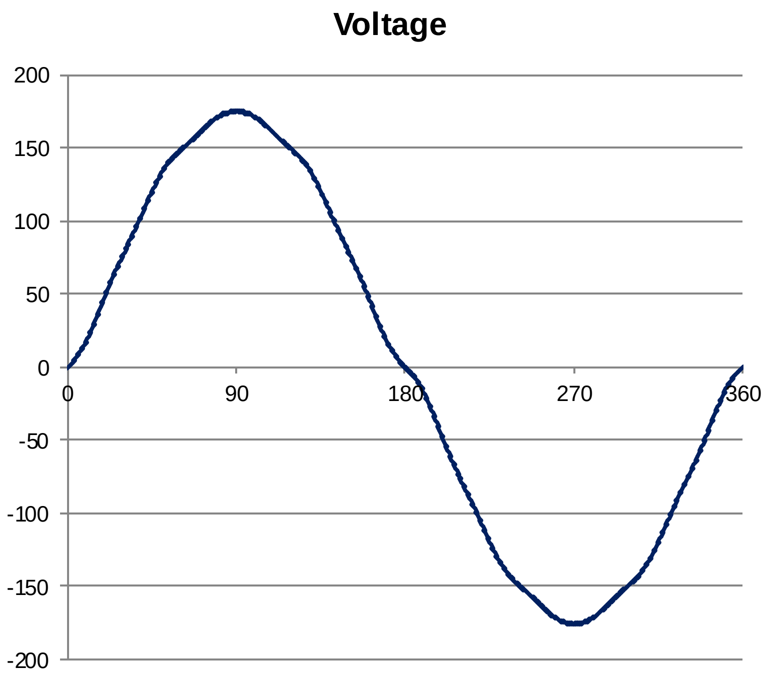
Harmonics & Metering Accuracy

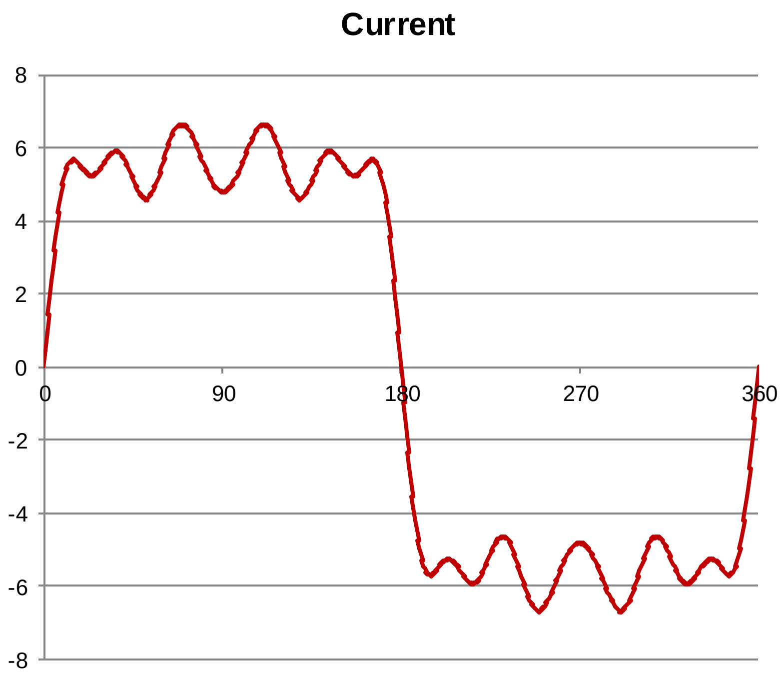


Waveform #1 - 90 Degree Phased Fired Waveform
Typical for a light dimmer set to 50%

POWERMETRIX

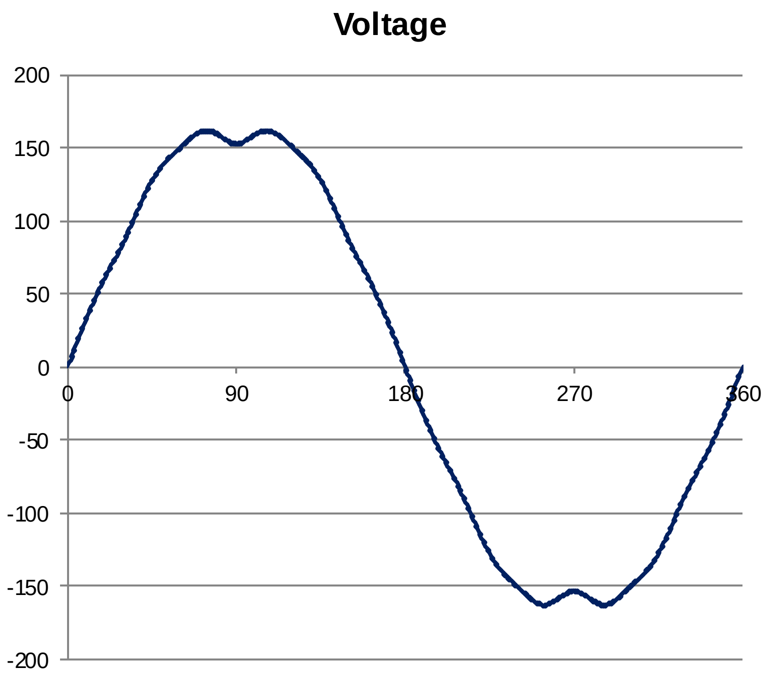
Harmonics & Metering Accuracy

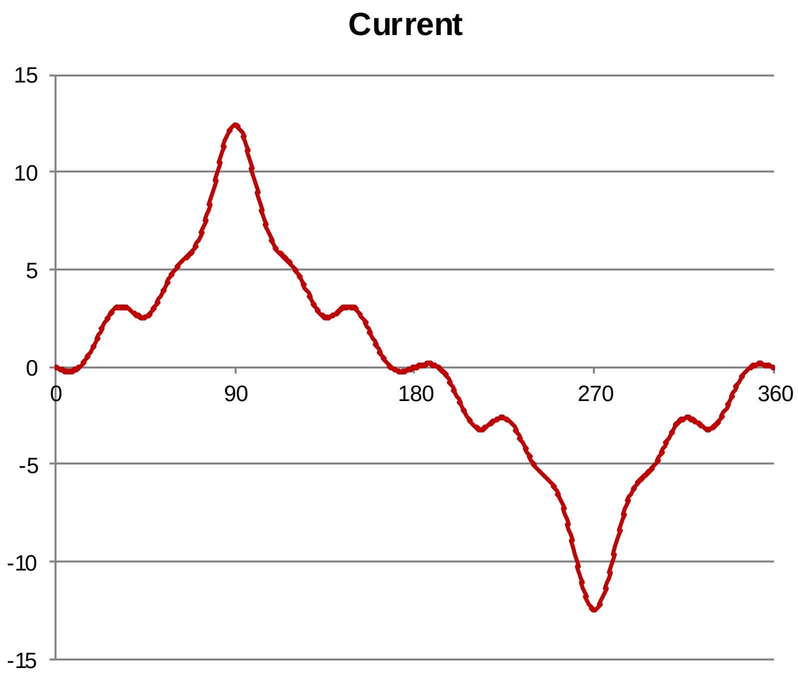




Waveform #2 - Quadriform Waveform
Switched Load Device

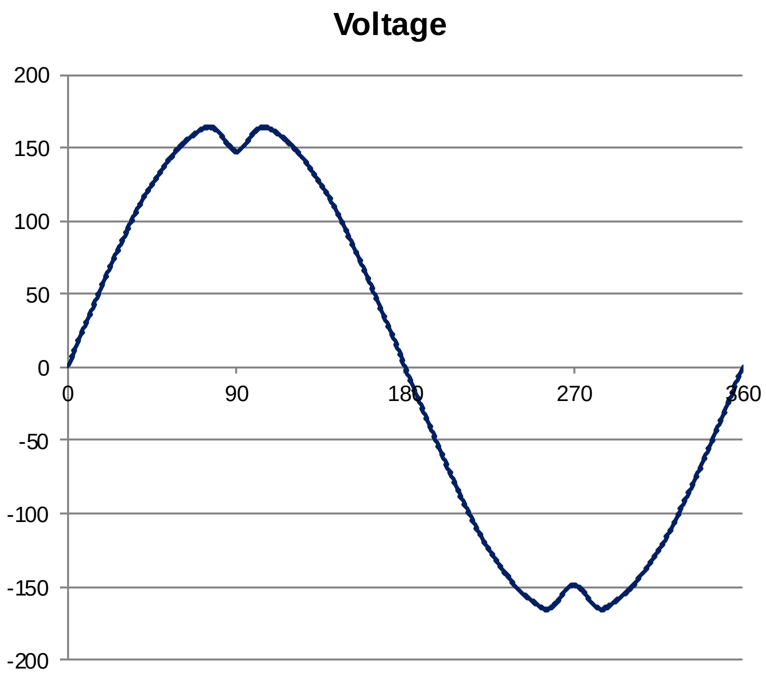
Harmonics & Metering Accuracy

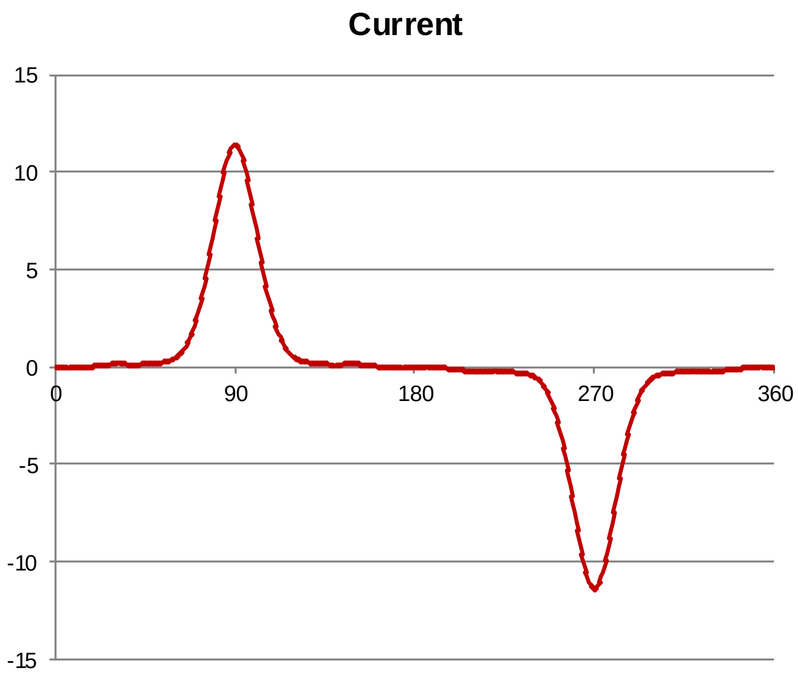




Waveform #3 - Peaked Waveform
Switching Power Supply

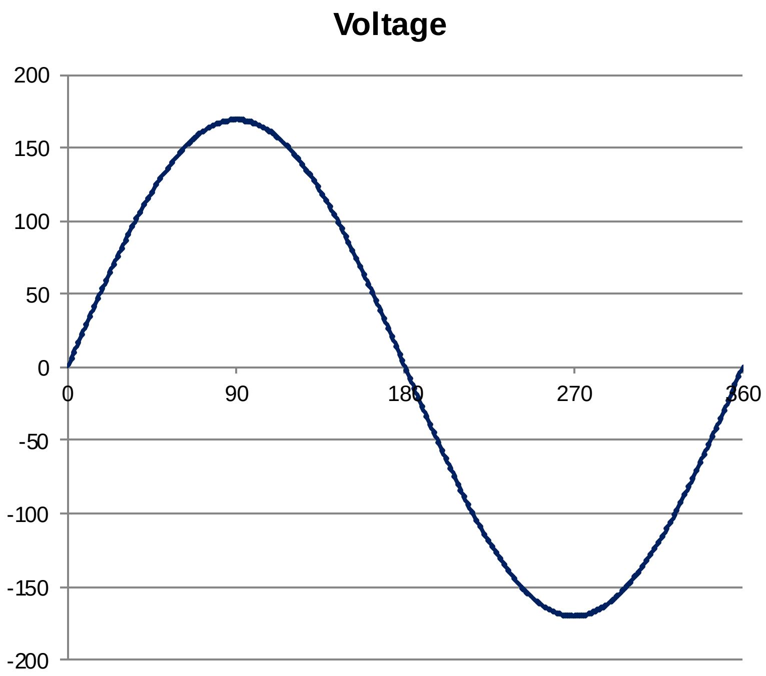
Harmonics & Metering Accuracy

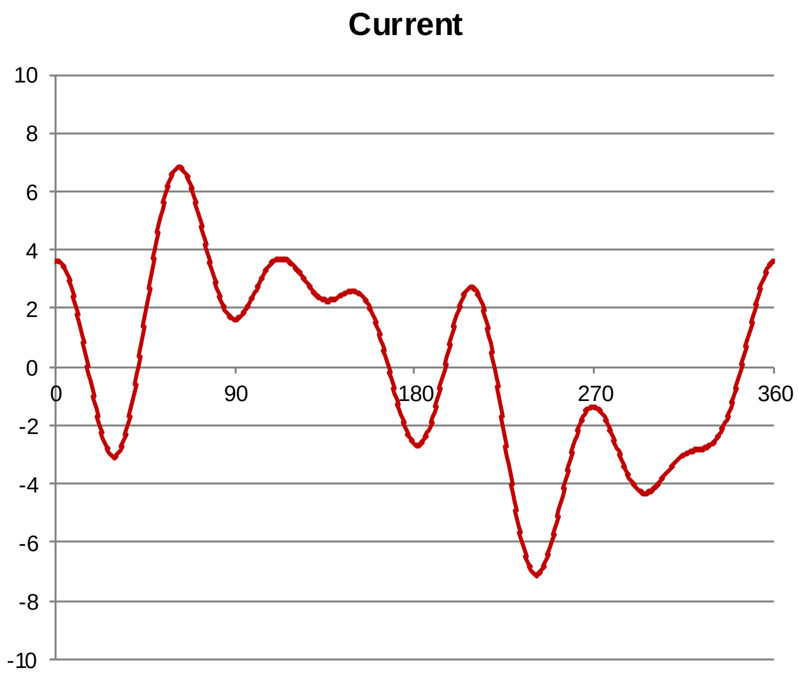




Waveform #4 - Pulse Waveform
Switching Power Supply

Harmonics & Metering Accuracy

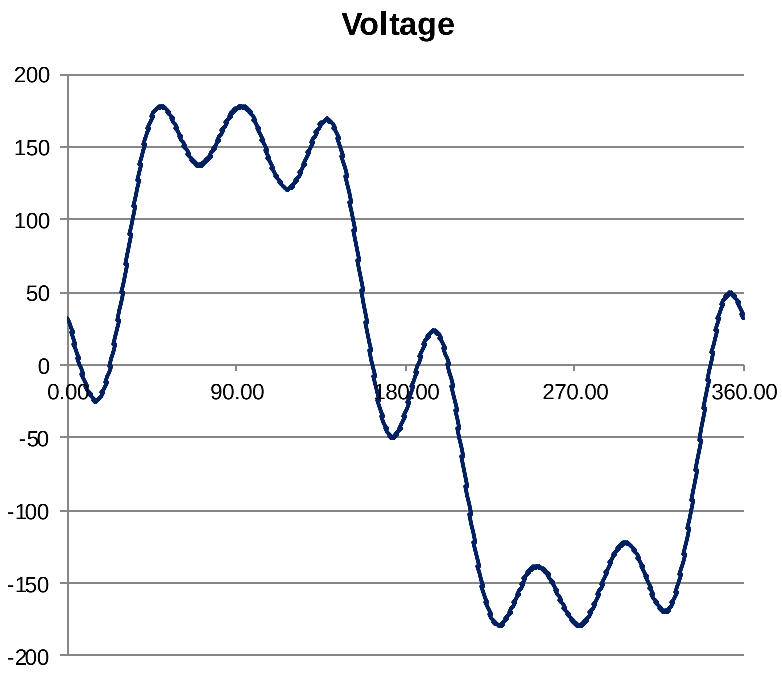


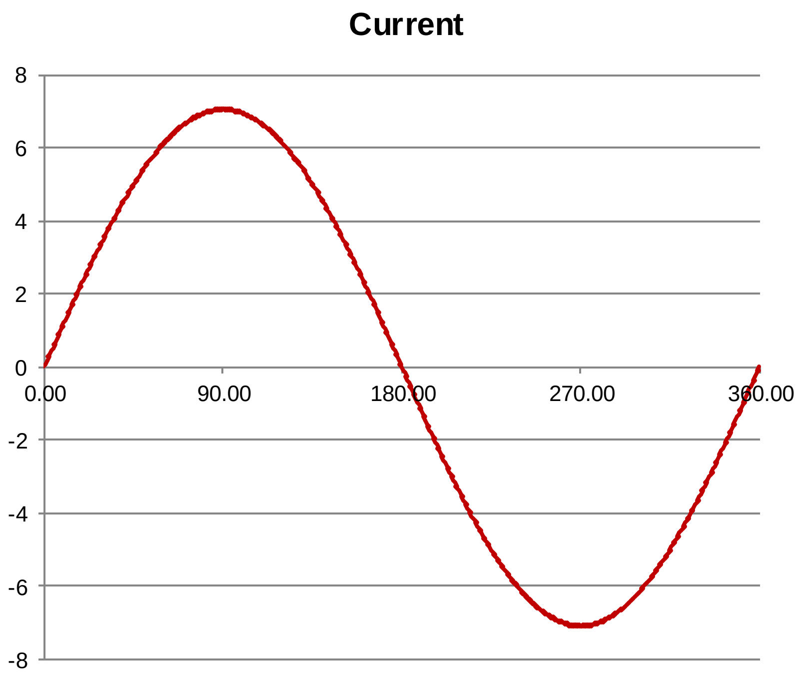


Waveform #5 – Multiple Zero Crossing Current Waveform

Harmonics & Metering Accuracy

Southwest Electrical Metering Association





Waveform #6 – Multiple Zero Crossing Voltage Waveform

POWERMETRIX

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

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 transformer reduces 3rd harmonics in neutral
- There is no "one size fits all" solution

Case Study #1
East Knox Solar Array

1MW Solar Farm in Knoxville, TN
4608 Panels - Built 2010

S.W.E.M.A.
Southwest Electrical Metering Association

East Knox Solar Array

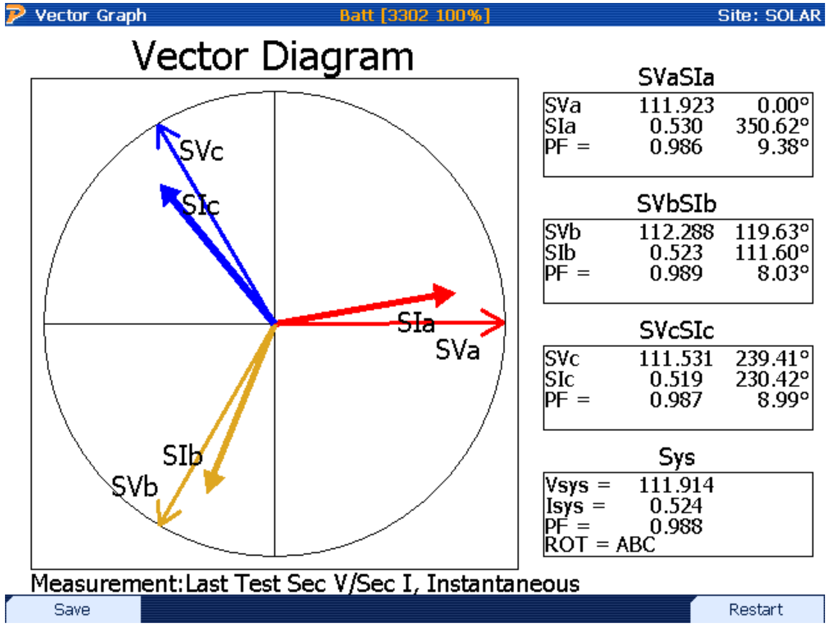
Four DC-AC Inverters
8.4kV Transformer

POWERMETRIX

East Knox Solar Array

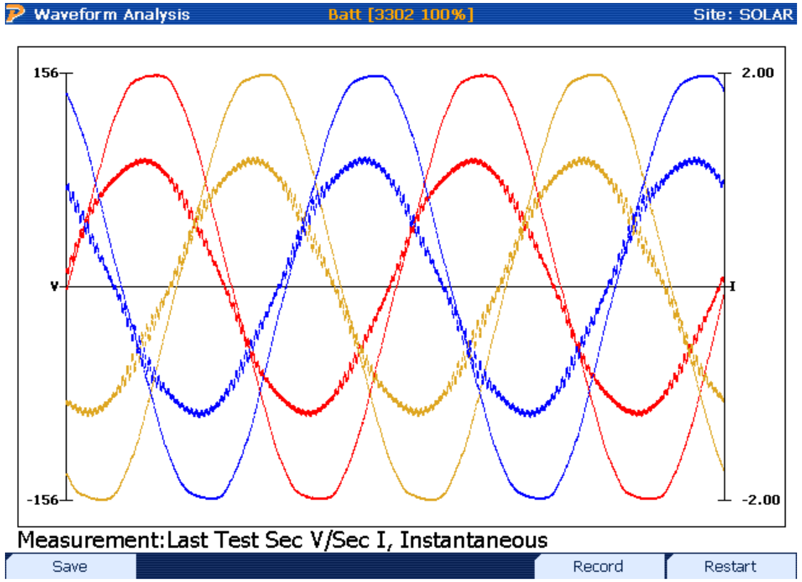
- Local utility monitors energy with one bi-directional form 9S meter
- 200:5 CT’s
- 70:1 PT’s

East Knox Solar Array



- Current vectors are LEADING
- Meter is setup so that positive energy flow is from the solar array to the utility

East Knox Solar Array



- Power outputs are well filtered
- Harmonics are >70th harmonic
- Meter should have no problems

Southwest Electrical Metering Association

East Knox Solar Array

Customer Load Test Results Batt [3302 100%] Site: SOLAR

Customer Load Meter Test

Registration

% Registration	99.994

Test Info

Time(sec)	113.505
Time Left	0.000
Pulses Exp	3.0002
Pulses Act	3.0000
Meter PF	0.9852

Sys Info

Wh	5.4003
VAh	5.4814
VARh	-0.9389
V	111.962
I	0.5182

Test Complete

Restart | Edit Test Notes | View Trend | Done

- Customer Load Meter Test has excellent results
- Note NEGATIVE VARh due to leading current

POWERMETRIX

East Knox Solar Array

- Overhead CT’s are testing using a high voltage current probe to measure primary current
- Pay attention to the polarity of the CT
- Secondary current is available at the meter test switch

Southwest Electrical Metering Association

East Knox Solar Array

CT Testing Results — Batt [3302 90%] — Site: None

Measured Ratio: 200.00	PASS	A
Nameplate Ratio: 200 : 5	Primary Amps: 18.93	
Ratio Error (%): 0.00%	Secondary Amps: 0.473	
Phase Error (degrees): 0.238°	Phase Error (minutes): 14' 16"	

Measured Ratio: 200.99	PASS	B
Nameplate Ratio: 200 : 5	Primary Amps: 16.99	
Ratio Error (%): 0.49%	Secondary Amps: 0.423	
Phase Error (degrees): 0.014°	Phase Error (minutes): 0' 49"	

Measured Ratio: 200.24	PASS	C
Nameplate Ratio: 200 : 5	Primary Amps: 16.43	
Ratio Error (%): 0.12%	Secondary Amps: 0.410	
Phase Error (degrees): 0.280°	Phase Error (minutes): 16' 49"	

Graphs | Exit

POWERMETRIX

Southwest Electrical Metering Association

East Knox Solar Array

Capture Burden Measurement — Batt [3302 90%] — Site: None

Total Burden (Ohms): 0.1955 — A

Length: Feet:	70.00	Volts:	0.03
Diameter: AWG:	12.00	Amps:	0.3685
Wire Burden (Ohms):	0.1112	Measured Burden (Ohms):	0.0843

Total Burden (Ohms): 0.1504 — B

Length: Feet:	70.00	Volts:	0.01
Diameter: AWG:	12.00	Amps:	0.3597
Wire Burden (Ohms):	0.1112	Measured Burden (Ohms):	0.0393

Total Burden (Ohms): 0.1688 — C

Length: Feet:	70.00	Volts:	0.02
Diameter: AWG:	12.00	Amps:	0.3580
Wire Burden (Ohms):	0.1112	Measured Burden (Ohms):	0.0577

Direct Burden Measurement gives the EXACT burden on the secondary

POWERMETRIX

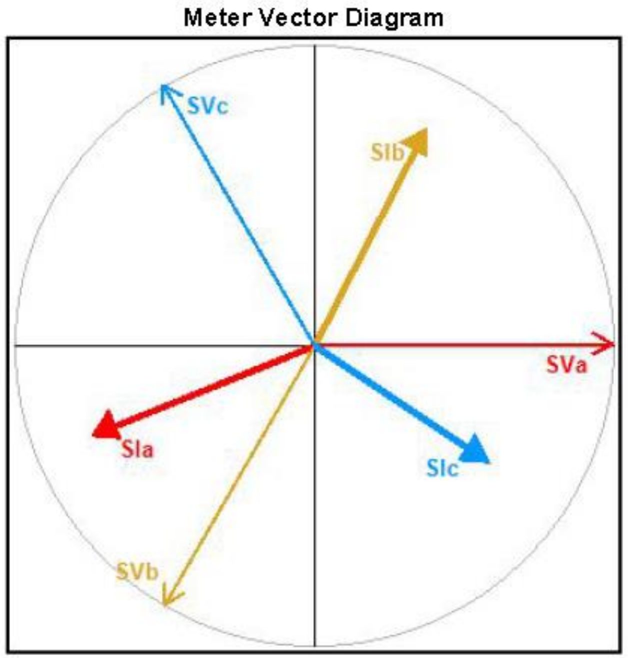
Southwest Electrical Metering Association

Case Study #2
Gila River PV Power Plant

87kW Solar Farm at Hu Hu Kam Hospital
Sacaton, AZ

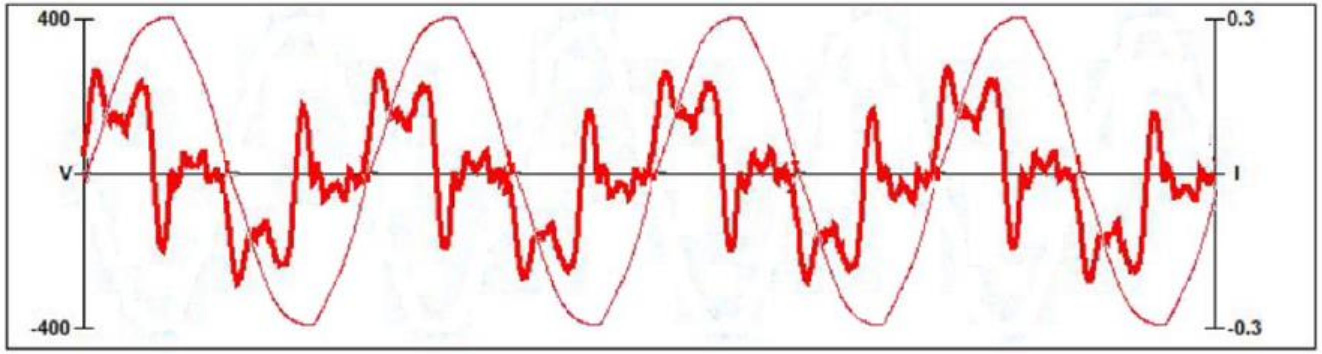
POWERMETRIX

Gila River PV Power Plant



- The vector diagram for a renewable site may have current vectors 180° out when the site is generating power.
- Whr, VARhr, and PF may also be negative when generating power.

Gila River PV Power Plant



Voltage and Current Harmonics

V THD = 2%

I THD = 50 to 60%

Square wave current due to inverter

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

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

Southwest Electrical Metering Association

Questions? Comments?
Want a copy of this presentation?
Go to
powermetrix.com/presentations/

Thank you for your time!

POWERMETRIX