Power Quality
Notes 3-2 (MT)

Marc Thompson, Ph.D.
Senior Managing Engineer
Exponent
21 Strathmore Road
Natick, MA 01760

Alex Kusko, Sc.D, P.E.
Vice President
Exponent
21 Strathmore Road
Natick, MA 01760

Adjunct Associate Professor of Electrical Engineering
Worcester Polytechnic Institute
Worcester, MA 01609

Power Quality Measurements

- Motivation for measuring power quality
- Commercial equipment
- Case studies

IEEE Std. 1159

- Wealth of information on power quality terminology and measurement techniques

IEEE Std 1159-1995

IEEE Recommended Practice for Monitoring Electric Power Quality

Comment on “Harmonics”

- In common usage, “harmonics” has come to mean multiples of line frequency
- However, a typical line current or voltage could have harmonics at other frequencies as well, e.g. from switching power converters, drive PWM frequencies, etc.
  - Often called “interharmonics”

Motivation for Monitoring Power Quality

- Diagnose incompatibilities between source and load
- Develop power quality baseline needed
- Predict future performance
- Economic - especially if critical loads are present

Possible Effects on Equipment of Power Quality Events

- Transients --- dielectric failure, insulation breakdown, reduced MTBF
- Sags --- shutdown due to undervoltage
  - Can be mitigated by UPS
- Swells --- reduced equipment life

Power Quality Events

Table 1. Summary of Power Quality Variation Categories

Power Quality Variation Category	Method of Characterizing	Typical Causes	Example Power Conditioning Solutions
Impulsive Transients	Peak magnitude, Rise time, Duration	Lightning, Electro-Static Discharge, Load Switching	Surge Arresters, Filters, Isolation Transformers
Oscillatory Transients	Waveforms, Peak Magnitude, Frequency Components	Line/Cable Switching, Capacitor Switching, Load Switching	Surge Arresters, Filters, Isolation Transformers
Sags/Swells	RMS vs. time, Magnitude, Duration	Remote System Faults	Ferroresonant Transformers, Energy Storage Technologies*, UPS
Interruptions	Duration	System Protection (Breakers, Fuses), Maintenance	Energy Storage Technologies*, UPS, Backup Generators
Undervoltages/ Overvoltages	RMS vs. Time, Statistics	Motor Starting, Load Variations	Voltage Regulators, Ferroresonant Transformers
Harmonic Distortion	Harmonic Spectrum, Total Harm. Distortion, Statistics	Nonlinear Loads, System Resonance	Filters (active or passive), Transformers (cancellation or zero sequence components)
Voltage Flicker	Variation Magnitude, Frequency of Occurence, Modulation Frequency	Intermittent Loads, Motor Starting, Arc Furnaces	Static Var Systems

* Note: Energy Storage Technologies refers to a variety of alternative energy storage technologies that can be used for standby supply as part of pow er conditioning (e.g. superconducting magnetic energy storage, capacitors, flyw heels, batteries)

Reference: C. J. Melhorn et. al., "Interpretation and Analysis of Power Quality Measurements," *IEEE 1995 Annual Textile, Fiber and Film Industry Technical Conference*, May 3-4, 1995, pp. 1-9

Power Quality Measurement Instruments

- From voltmeters to spectrum and power quality analyzers and dataloggers ... there is a wide range of equipment used for measuring power quality

AC Voltage Measurement

- Voltmeter
  - Line-neutral and line-line measurements
  - Gives no information as to harmonic content, waveshape, etc.

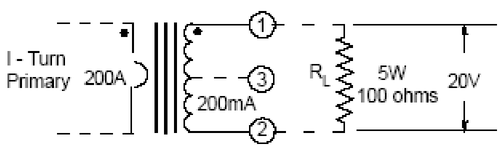
Methods of Determining RMS Value

- Peak method: take peak value and divide by 1.4
  - Works for sinusoids but has errors for non-sinusoidal
- Average method: takes average of rectified waveform and multiplies by a constant
- True RMS
  - Thermal detectors or digital methods

AC Current Measurement

- Resistive shunt
  - Simplest, oldest technology
  - Requires voltage metering and non-inductive resistor
- Current transformer (CT)
  - Low frequency bandwidth limit
- Hall probe
  - Works down to DC, but can drift

200A Current Transformer (CT)



Applications
- Sensing Overload Current
- Ground fault detection
- Metering
- Analog to Digital Circuits

Electrical Specifications @ 20°C ambient

Electrical Specifications	
Primary Current	200A nom., 500A max.
Turns Ratio	1000:1 nominal
Volt per Amp Ratio at 200A for 100 ohm load	0.100 V/A
Volt per Amp Ratio at 20A for 100 ohm load	0.0991 V/A
DC Resistance at 20°C	11 ohms
Dielectric Withstanding Voltage (Hi-pot)	4KVrms
Mechanical Specifications	
Case	Polycarbonate
Encapsulant	Epoxy
Flammibility	Conforms to UL94-VO
Terminals	Pins Ø 1.0mm
Marking	TALEMA Date Code (W/Y) AC1200, Dot at start pin
Approximate Weight	150 grams
Tolerance	±0.2mm

Reference: http://rocky.digikey.com/WebLib/Amveco-Talema/Web%20Data/AC1200.pdf

Clamp on AC Current Probe

i1000s AC Current Probe

Large AC Current Probe

The Fluke i1000s is a clamp-on ac current probe designed to expand oscilloscope applications in industrial and power environments. The Current Probe (shown in figure) provides the following features: Ideal for measuring distorted current waveforms and harmonics.

- Allows accurate measurement of currents from 100 mA to 1000 A rms, 5 Hz to 100 kHz without breaking into the circuit
- A passive filter eliminates noise and ring on rapidly rising di/dt waveform, ensuring accurate screen displays
- Connects directly to an oscilloscope through a reinforced coaxial cable and an insulated BNC connector
- Can be used with Multimeters with optiona PM9081/001 BNC/Banana adapter
- One year warranty

Reference: www.fluke.com

Clamp on Hall Effect Current Probe

i1010 AC/DC Current Clamp

AC/DC Current clamps for DMM's

Fluke Current clamps are the ideal tools to extend the current ranges of Fluke tools.

- Battery-powered Hall-effect probe measures 1 A to 1000 A
- Two ranges: 100 A & 1000A, 1 mV/ Amp output
- Take accurate current readings without breaking the circuit
- Maximum conductor Ø 32 mm
- CAT III 600V safety rating
- Also available with softcase for DMM and clamp (i1010 kit)
- One year warranty

Reference: www.fluke.com

Power Quality Handheld Analyzer

Power Quality Tools >

Fluke 43B Power Quality Analyzer

Get control of power problems

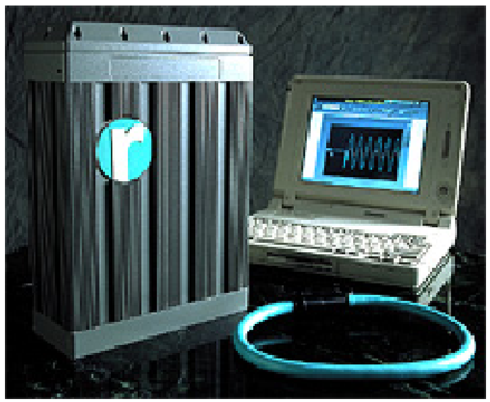
The Fluke 43B Power Quality Analyzer combines the most useful capabilities of a power quality analyzer, scope and multimeter in a single easy-to-use instrument. The user interface is selectable in English, German, French, Italian and Spanish.

Reference: www.fluke.com

Power Quality Recorder

Power Quality Tools >

Reliable Power Meters Power Recorder



Every measurement, every event, on every cycle, all the time – without thresholds

From set-up to finished reports, the RPM Power Recorder is the complete solution to your portable power monitoring needs. The Power Recorder analyzer is all you need to monitor, study and document:

- Loading and load interaction
- Power consumption and demand
- Sags, swells, flicker or transient events
- Ground currents
- Phase relationships, including phase imbalance
- Frequency stability
- Harmonics and noise

Reference: www.fluke.com

Power Quality Monitor Equipment Specs.

SPECIFICATIONS

INPUTS

Voltage
- Four voltage inputs, phase A, B, C, neutral to ground voltage

Current
- Four current inputs, phase A, B, C, and neutral current

Circuit Type
- Single phase, split phase, independent channels, 3-phase wye, 3-phase delta

Input Impedance
- 5 Megohm

Digital
- 8 selectable inputs and 8 outputs through external I/O (optional)

MEASUREMENT RANGE AND CAPABILITY

Voltage
- 5-750 VAC and 0-800 VDC, 6 Kv impulse

Current
- 0-10,000 amps through external current clamps (0-3 VAC input)

Frequency
- DC, 45 to 65 Hz, and 400 Hz

Sample Rate
- 256 samples per cycle, (15.3 KHz @ 60 Hz, 12.8 KHz @ 50 Hz), 32 samples per cycle (400 Hz)

Peak Detector
- 4 MHz (duration greater than 250 nsec and with a frequency content greater than 5 KHz)

Energy/Demand
- Watthours, varhours (supplied, and delivered), thermal demand

Transient
- 250 nanosecond w/ 4 MHz peak detect

Harmonics
- To 63rd voltage, current and power, THD, meets IEC61000-4-7

Flicker
- Pst, Plt, instantaneous, meets IEC 61000-4-15, IEC 868

MEASUREMENT ACCURACY

Resolution
- 14 bit

Voltage, Current
- $\pm$ 0.05% of full scale

Power
- 0.1% of full scale (VA, VAR, Watt, PF)

Energy
- 0.1 % of full scale

RECORDING RATE AND DATA STORAGE

Continuous, or by Exception

Recording Rate
- Adjustable from one cycle up to one week, multiple rates per measurement type

Data Storage
- 10 GB Hard Drive, 64 MB RAM

COMMUNICATIONS

Ethernet
- TCP/IP, 10Base2

Modem
- 56 kBps, V.90 (optional internal or external)

Serial
- RS232

Parallel
- Centronics for local printer

REAL TIME CLOCK

Internal
- 1 sec/day at 77°F (25°C), 4 seconds per day over temperature, keeps time on loss of power

POWER SUPPLY

Input
- 80 to 230 VAC, 50-60 Hz: 125 to 250 VDC (self or externally powered)

Battery (optional)
- 5 minute ride through

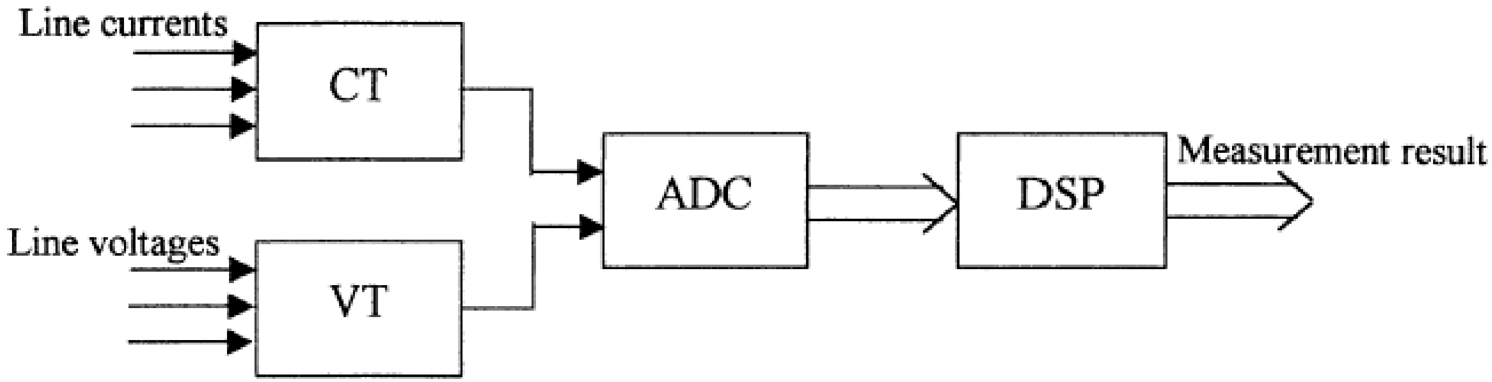
PHYSICAL AND ENVIRONMENTAL

Enclosure
- Weatherproof

Operating Temperature
- 32° to 122°F (0° to 50°C) option for -22° to 122°F (-30° to 50°C)

Reference: www.ametekpower.com

DSP-Based Power Quality Monitor



Reference: A. Ferrero et. al., “A Calibration Procedure for a Digital Instrument for Electric Power Quality Measurement,” I*EEE Transactions on Instrumentation and Measurement*, vol. 51, no. 4, August 2002, pp. 716-722

Case Study 1: Wind Power Power Quality Measurements

- Power quality on a 10 kV grid with 2 wind power turbines
- Two 225 kW pitch controlled wind turbines
- Pole-changing generators, 6/8 poles rated at 225 kW at higher speed, 50 kW at lower speed

Reference: T. Thiringer, “Power Quality Measurements Performed on a Low-Voltage Grid Equipped with Two Wind Turbines,” *IEEE Transactions on Energy Conversion*, vol. 11. No. 3, September 1996, pp. 601-606

Measurement Setup

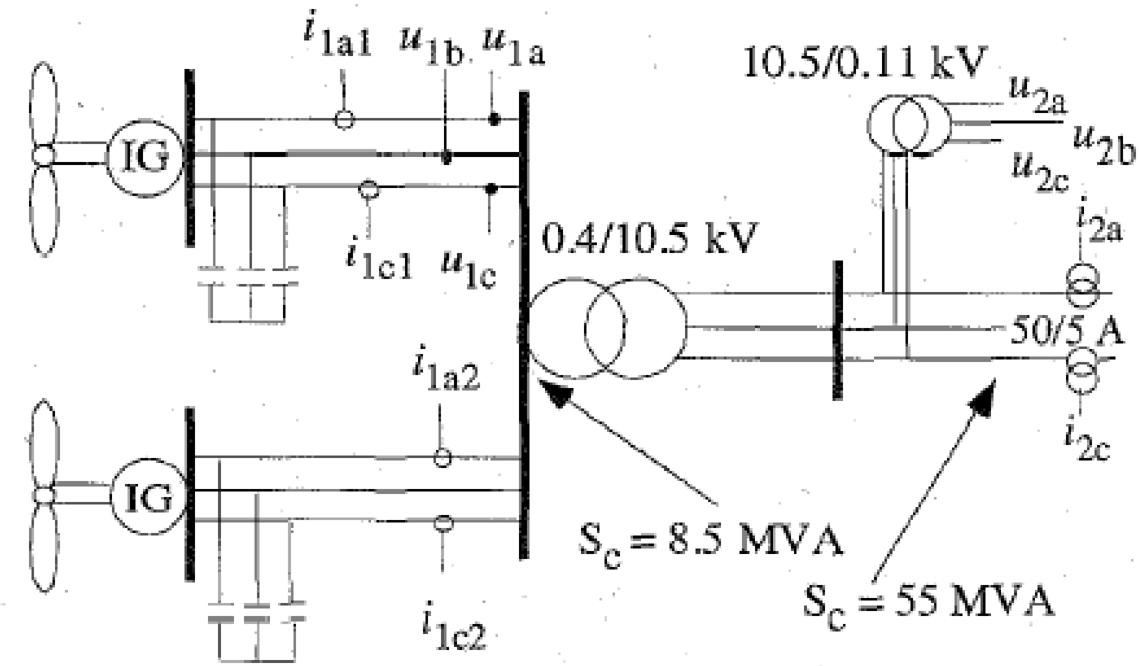


Fig. 1. The wind park and the location of the measurement modules.

Reference: T. Thiringer, "Power Quality Measurements Performed on a Low-Voltage Grid Equipped with Two Wind Turbines," *IEEE Transactions on Energy Conversion*, vol. 11. No. 3, September 1996, pp. 601-606

Power Measurement: Both Turbines Operating

- Power measured at a wind speed of 13 m/s

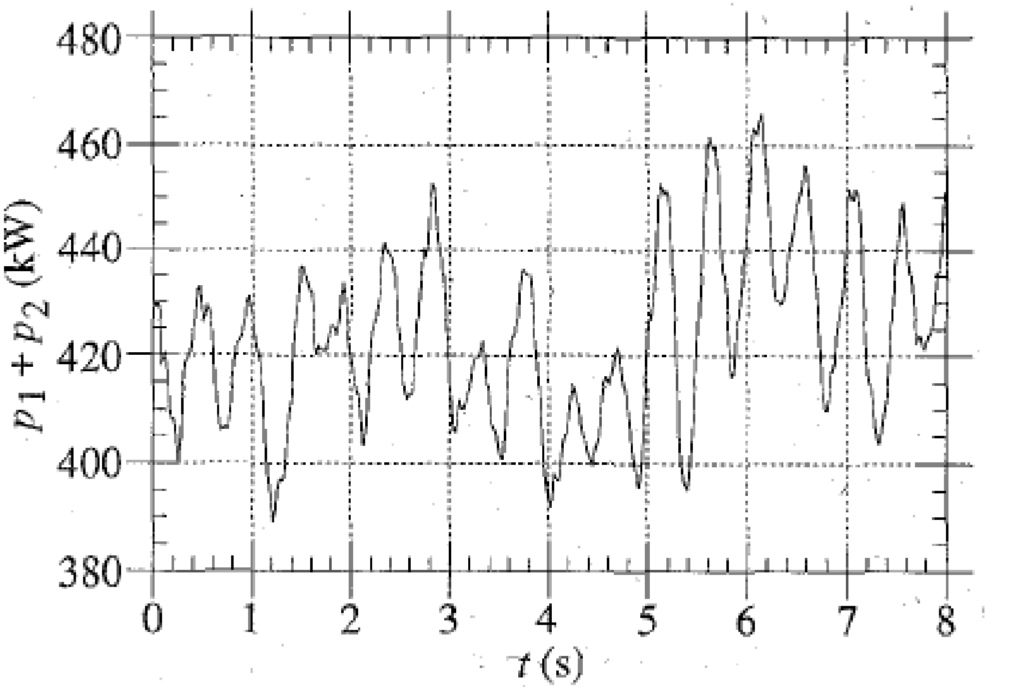


Fig. 4. Measured power from both the wind turbines at 13 m/s.

Reference: T. Thiringer, “Power Quality Measurements Performed on a Low-Voltage Grid Equipped with Two Wind Turbines,” *IEEE Transactions on Energy Conversion*, vol. 11. No. 3, September 1996, pp. 601-606

Voltage Variation on Grid

- Measured and calculated at a wind speed of 13 m/s

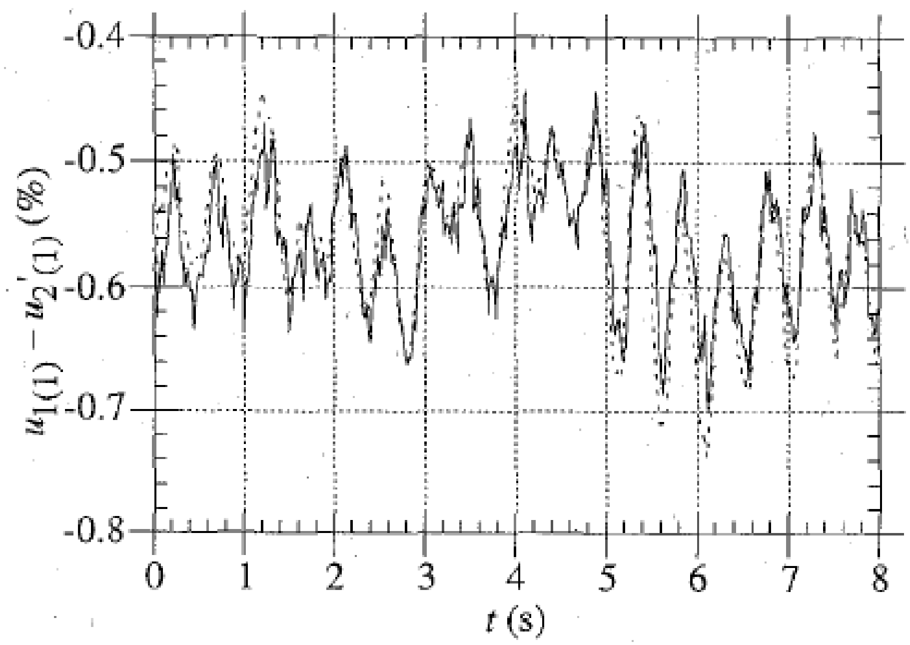


Fig. 5. Measured (solid curve) and calculated (dashed curve) voltage variations caused by the wind turbines.

Reference: T. Thiringer, “Power Quality Measurements Performed on a Low-Voltage Grid Equipped with Two Wind Turbines,” *IEEE Transactions on Energy Conversion*, vol. 11. No. 3, September 1996, pp. 601-606

Wind Power PQ Measurements

- "p" relates to various resonances of wind turbine

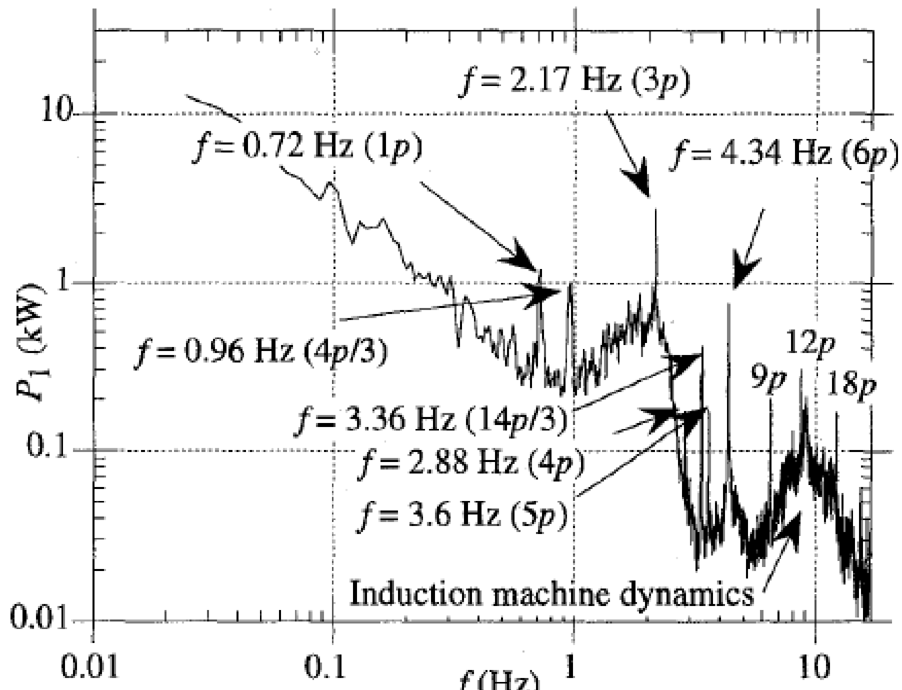


Fig. 7. Spectrum of the power from one wind turbine operating at the higher rotor speed.

Reference: T. Thiringer, "Power Quality Measurements Performed on a Low-Voltage Grid Equipped with Two Wind Turbines," *IEEE Transactions on Energy Conversion*, vol. 11. No. 3, September 1996, pp. 601-606

Wind Power PQ Measurements

- Solid line is IEC 555-3 voltage fluctuations limit

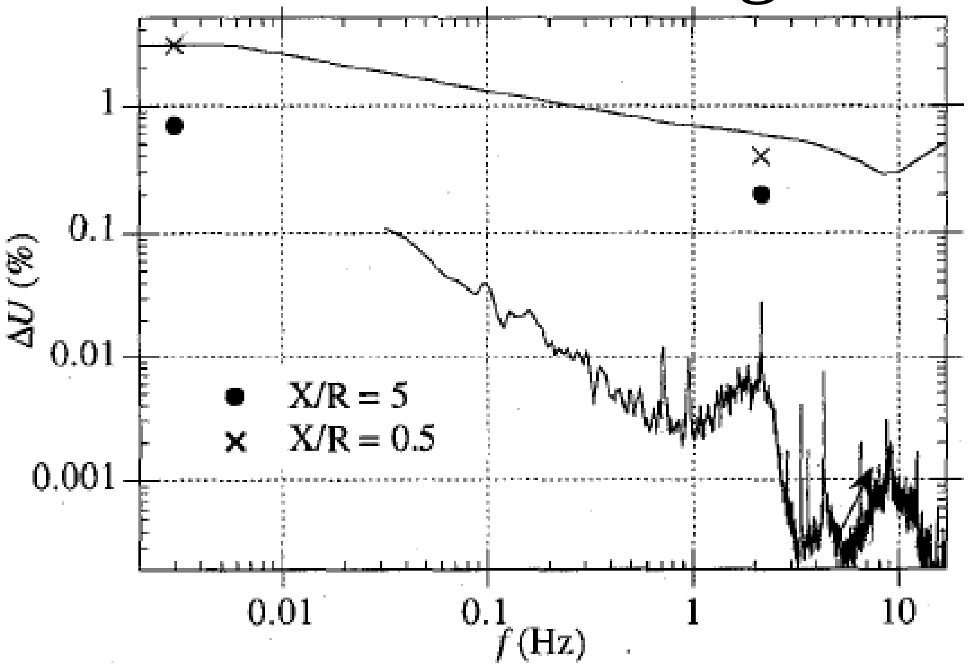


Fig 8. Average voltage spectrum and IEC voltage fluctuation limit, together with some extreme points, the 3*p*-frequency and the steady-state voltage variation caused by the wind turbines

Reference: T. Thiringer, "Power Quality Measurements Performed on a Low-Voltage Grid Equipped with Two Wind Turbines," *IEEE Transactions on Energy Conversion*, vol. 11. No. 3, September 1996, pp. 601-606

Phase Current and Voltage

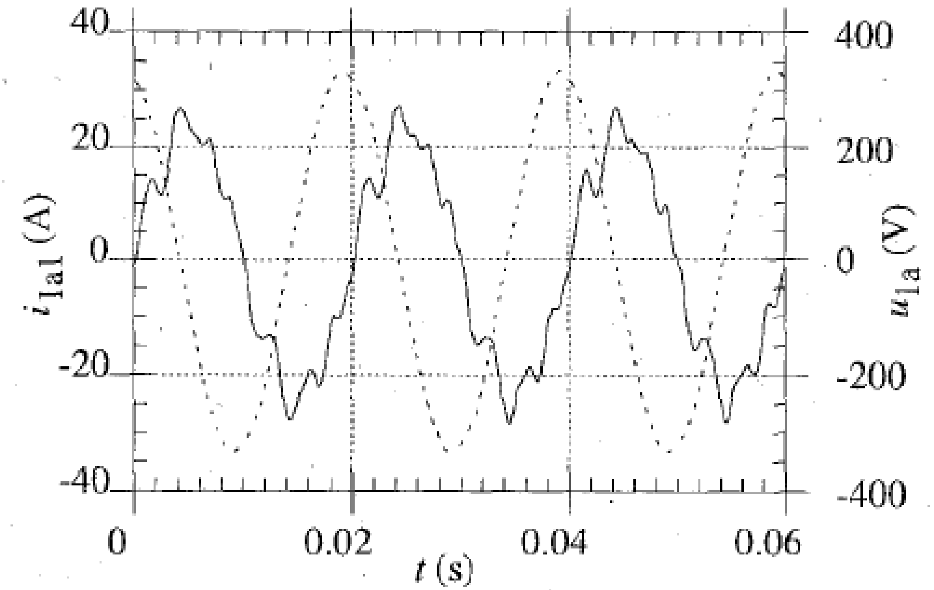


Fig. 9. Measured current (solid) and voltage (dashed) at 5 m/s.

Table 1. Relative harmonic content of the voltages.

order n	5	7	8	9	11	13	15
frequency (Hz)	250	350	400	450	550	650	750
$U_{1(n)}$ (%)	1.1	0.72	0.11	0.072	0.097	0.056	0.018
$U_{2(n)}$ (%)	1.0	0.54	0.09	0.048	0.047	0.016	0.008

Reference: T. Thiringer, "Power Quality Measurements Performed on a Low-Voltage Grid Equipped with Two Wind Turbines," *IEEE Transactions on Energy Conversion*, vol. 11. No. 3, September 1996, pp. 601-606

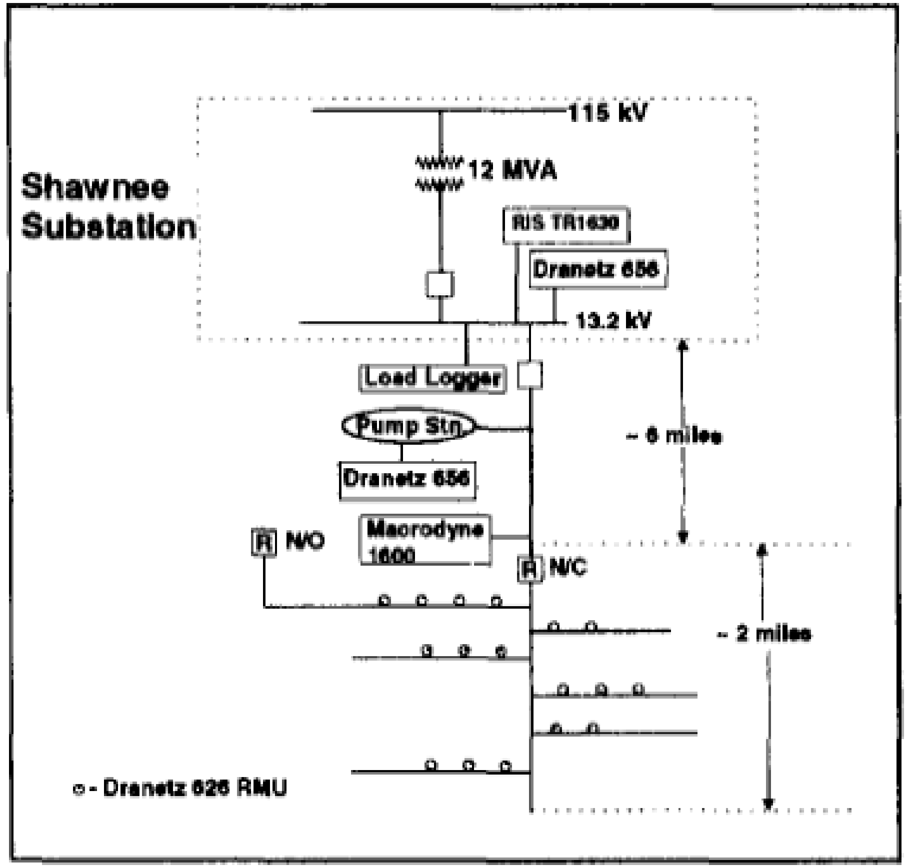
Case Study 2: Niagara Mohawk Study

- 2-year study (1989-1991) on power quality in 17 residences
- Equipment:
  - Dranetz 658 disturbance analyzers
  - Dranetz 626 remote monitoring
  - Telog 800 linecorders

Reference: C. Warren and C. Burns, “Home Power Quality - The Niagara Mohawk Study,” *Proceedings of the 1994 IEEE Power Engineering Transmission and Distribution Conference*, April 10-15, 1994, pp. 634-638

Niagara Mohawk Study

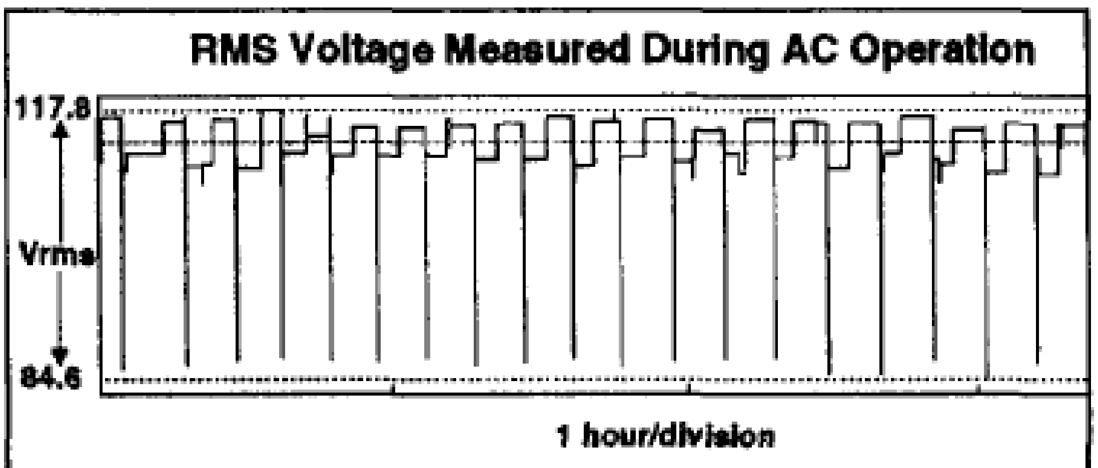
- 17 residences were monitored



Reference: C. Warren and C. Burns, “Home Power Quality - The Niagara Mohawk Study,” *Proceedings of the 1994 IEEE Power Engineering Transmission and Distribution Conference*, April 10-15, 1994, pp. 634-638

Voltage Drops due to Air Conditioner Cycling

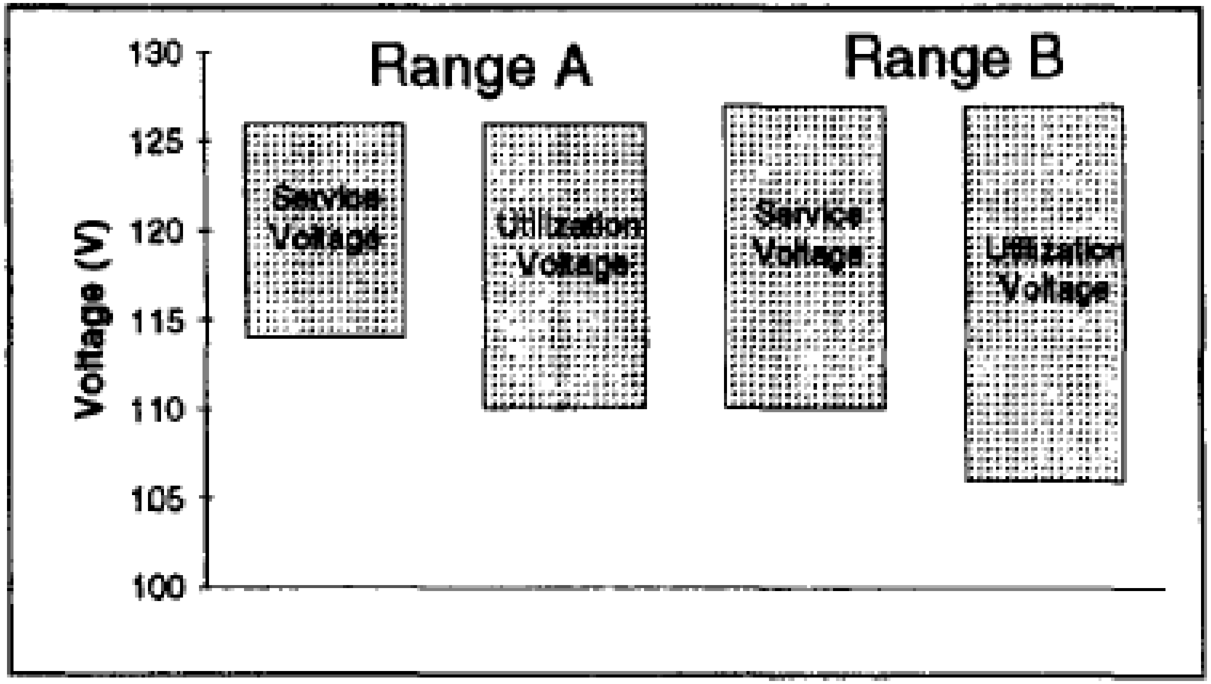
- 3V drop at service entrance to house
- 33V drop at the air conditioner due to house wiring



Reference: C. Warren and C. Burns, "Home Power Quality - The Niagara Mohawk Study," *Proceedings of the 1994 IEEE Power Engineering Transmission and Distribution Conference*, April 10-15, 1994, pp. 634-638

ANSI C84.1 Voltage Limits

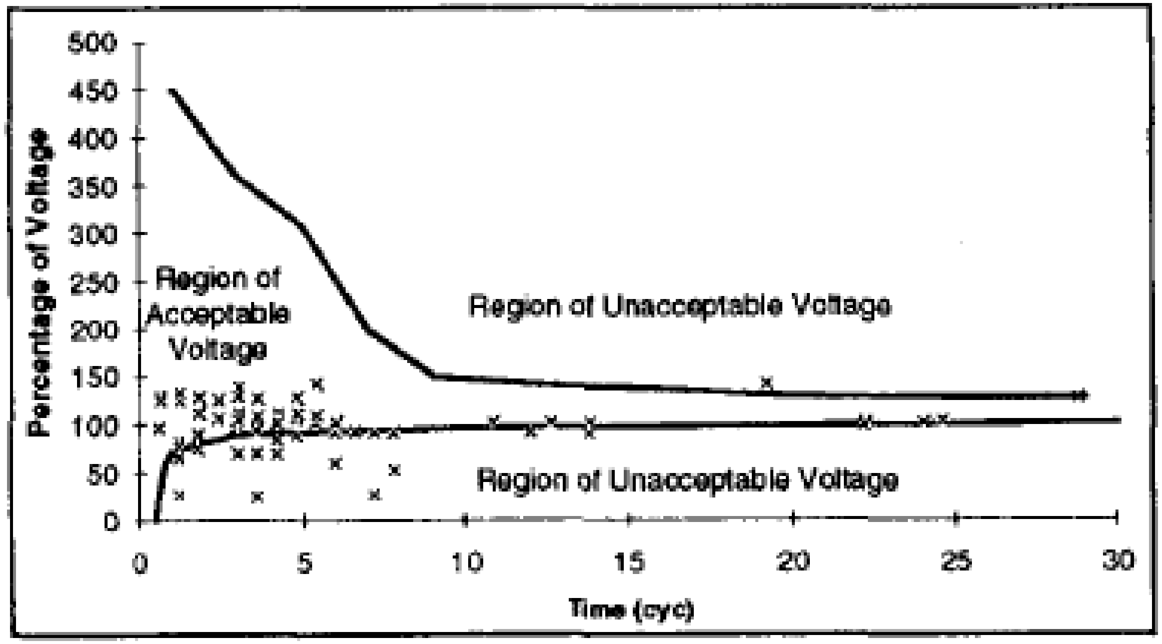
- No time limits associated with these standards



Reference: C. Warren and C. Burns, "Home Power Quality - The Niagara Mohawk Study," *Proceedings of the 1994 IEEE Power Engineering Transmission and Distribution Conference*, April 10-15, 1994, pp. 634-638

CBEMA Curve --- One Year Period

- Measured at one home



Reference: C. Warren and C. Burns, “Home Power Quality - The Niagara Mohawk Study,” *Proceedings of the 1994 IEEE Power Engineering Transmission and Distribution Conference*, April 10-15, 1994, pp. 634-638

Reported Cause of Events

- Factors affecting events
  - House wiring
  - Stiffness of the utility supply

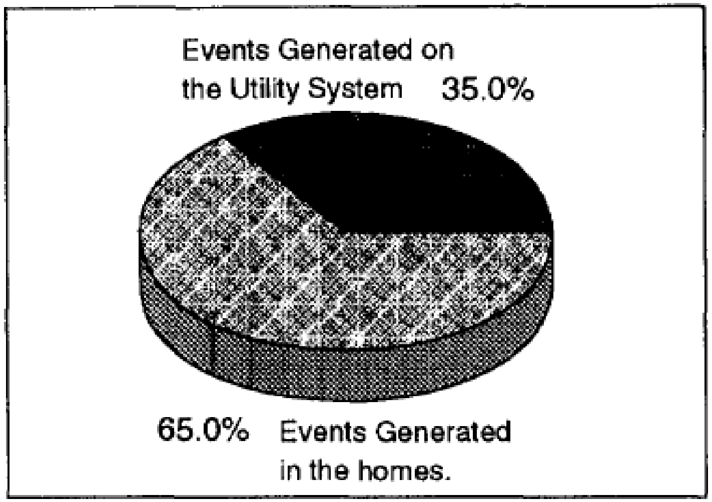


Fig. 5. Utility vs. Home Generation of Power Quality Events.

Reference: C. Warren and C. Burns, "Home Power Quality - The Niagara Mohawk Study," *Proceedings of the 1994 IEEE Power Engineering Transmission and Distribution Conference*, April 10-15, 1994, pp. 634-638

Harmonics

Table 1. Maximum Voltage Distortion per IEEE 519			
Maximum Distortion (%) (>1 hr)	System Voltage		
	<69 kV	69-138 kV	>138 kV
Individual Harmonic Total Harmonic	6 10	3 5	2 3

Table 2. Harmonic Measurements

Device	%THD Avg	%THD Max	% Significant Individual Harmonic
Fan (V)	5-6%	8.8%	2nd - 4.2%
Fan (I)	150%	222%	6th - 64.5%
TV (V)	4-6%	6.6%	2nd - 4%
TV (I)	25%	142%	2nd - 69%
Stereo (V)	3-4%	4.1%	3rd - 3.3%
Stereo (I)	40%	102%	3rd - 68%
Microwave (V)	2-4%	3.9%	
Microwave (I)	30-40%	62.9%	2nd - 59%
Vacuum (V)	6-7%	7.6%	
Vacuum (V)		45.1%	

Reference: C. Warren and C. Burns, "Home Power Quality - The Niagara Mohawk Study," *Proceedings of the 1994 IEEE Power Engineering Transmission and Distribution Conference*, April 10-15, 1994, pp. 634-638

Stereo Operation

- Slight dip in voltage at the crest of 2nd cycle

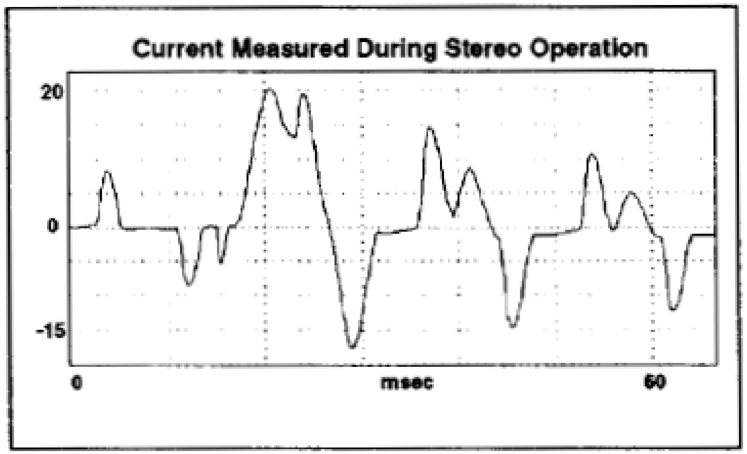


Fig. 6. Current Measured During Stereo Operation.

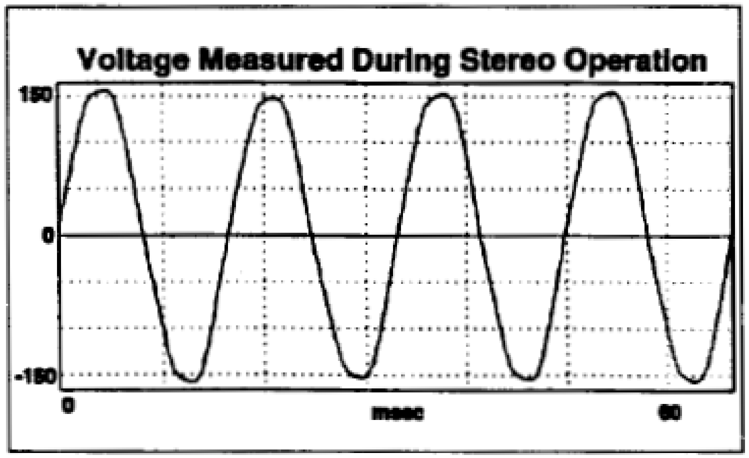


Fig. 7. Voltage Measured During Stereo Operation.

Reference: C. Warren and C. Burns, "Home Power Quality - The Niagara Mohawk Study," *Proceedings of the 1994 IEEE Power Engineering Transmission and Distribution Conference*, April 10-15, 1994, pp. 634-638

Case Study 3: Effects of High Efficiency Lighting

- New York Power Authority study (c. 1995) to determine effect of retrofitting electronic lamp ballasts to replace magnetic ballasts
- Used power quality monitoring equipment from BMI
- CTs used for current measurements on 3 phase power
- Baseline data collected before retrofitting

Reference: C. J. Melhorn et. al., "Effect of High Efficiency Lighting on Power Quality in Public Buildings," *Conference Record of the 1995 Industry Applications Conference*, October 8-12 1995, pp. 2069-2075

THD Study on Phase A Before Retrofit

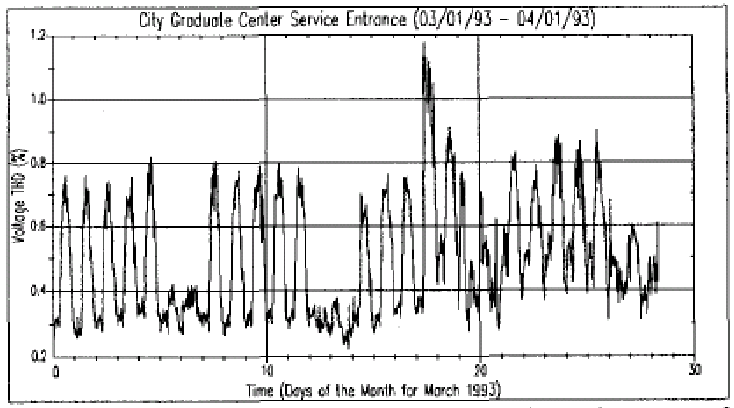


Figure 1: Total Harmonic Voltage Distortion Trend for One Month Before Retrofits.

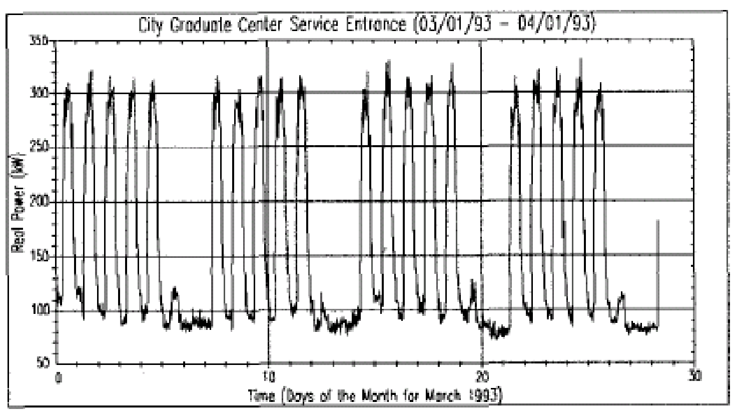


Figure 2: Real Power Trend for One Month Before Retrofits.

Reference: C. J. Melhorn et. al., “Effect of High Efficiency Lighting on Power Quality in Public Buildings,” *Conference Record of the 1995 Industry Applications Conference*, October 8-12 1995, pp. 2069-2075

THD Study on Phase A After Retrofit

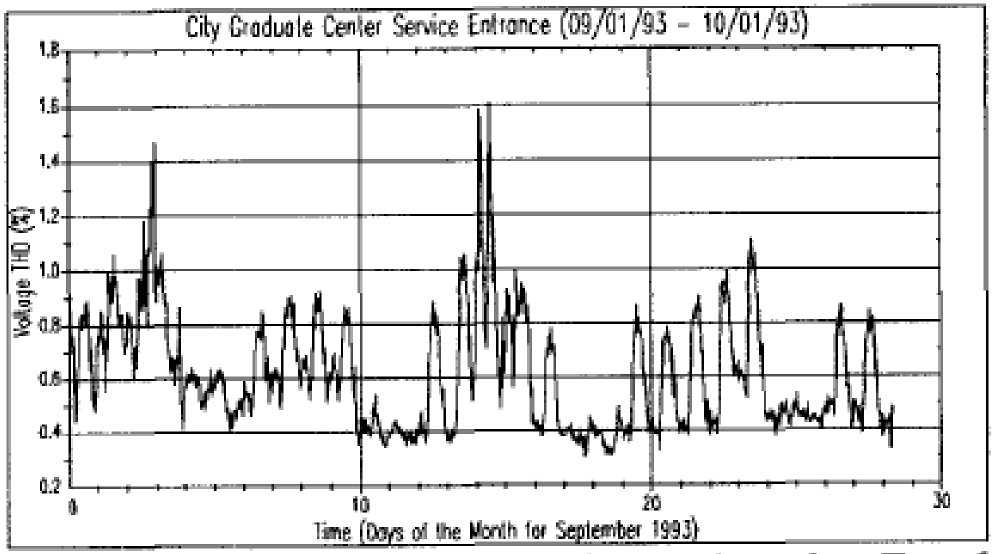


Figure 3: Total Harmonic Voltage Distortion Trend for One Month After Retrofits.

Reference: C. J. Melhorn et. al., "Effect of High Efficiency Lighting on Power Quality in Public Buildings," *Conference Record of the 1995 Industry Applications Conference*, October 8-12 1995, pp. 2069-2075

THD Study on Phase A After Retrofit

- Voltage THD increases after retrofit
  - Prior to retrofit: average THD = 0.49%
  - After retrofit: average THD = 0.62%
  - Within IEEE 519-92 limits in both cases. IEEE recommends voltage distortion at point of common coupling (PCC) to be < 5%

Reference: C. J. Melhorn et. al., "Effect of High Efficiency Lighting on Power Quality in Public Buildings," *Conference Record of the 1995 Industry Applications Conference*, October 8-12 1995, pp. 2069-2075

3rd Harmonic Before and After Retrofit

- 3rd harmonic distortion increases after retrofit

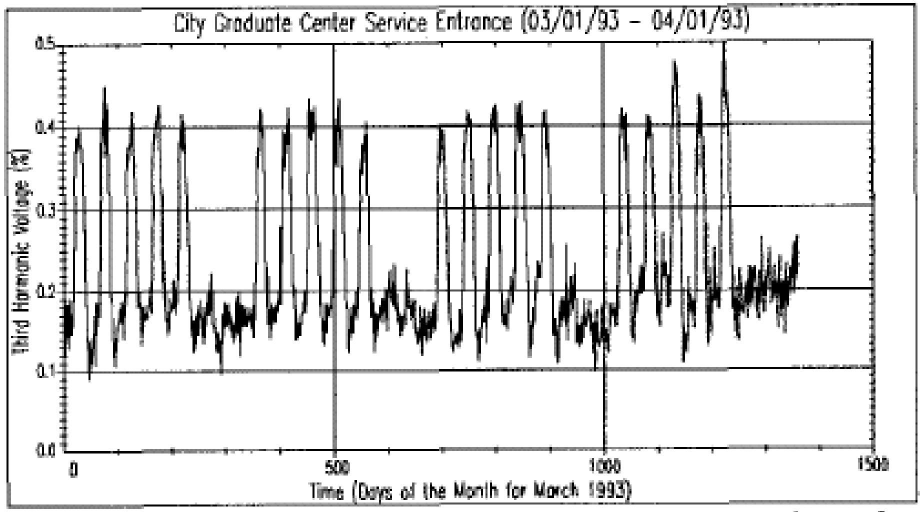


Figure 4: Third Harmonic Voltage Distortion for One Month Prior to Retrofits.

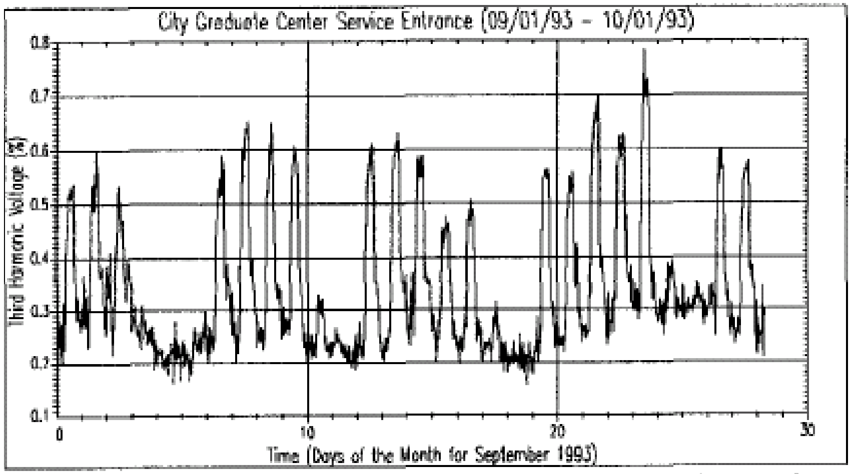


Figure 5: Third Harmonic Voltage Trend for One Month After Retrofits.

Reference: C. J. Melhorn et. al., "Effect of High Efficiency Lighting on Power Quality in Public Buildings," *Conference Record of the 1995 Industry Applications Conference*, October 8-12 1995, pp. 2069-2075

5th Harmonic Before and After Retrofit

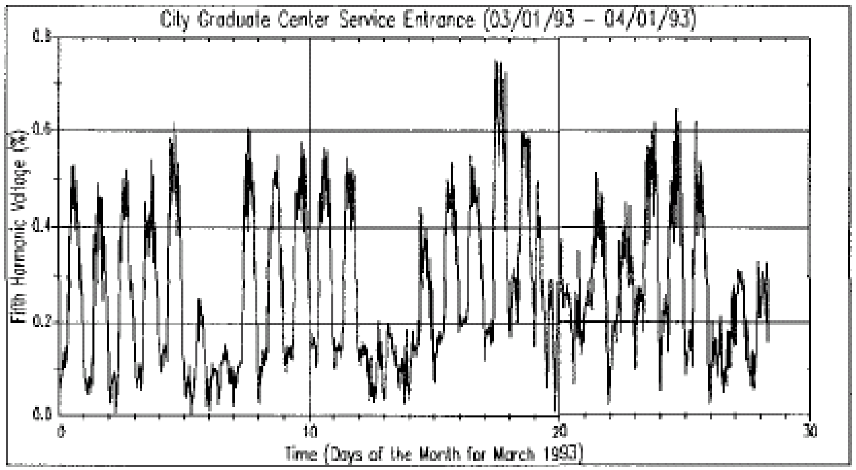


Figure 6: Fifth Harmonic Voltage Trend for One Month Before Retrofits.

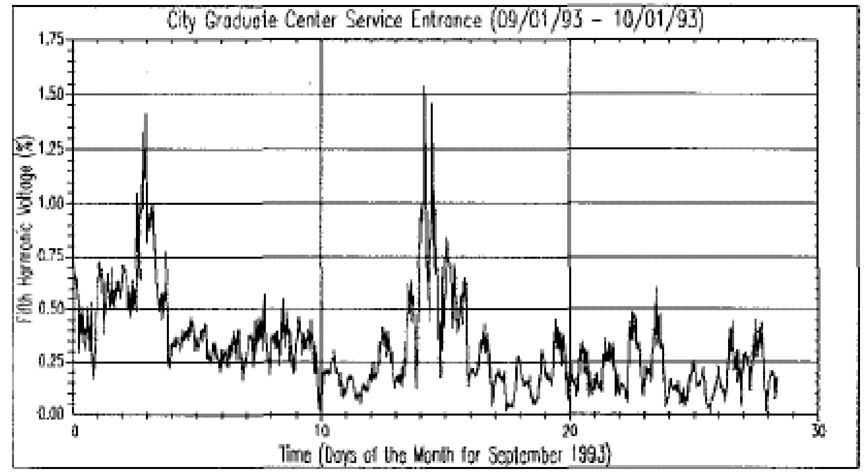


Figure 7: Fifth Harmonic Voltage Trend for One Month After Retrofits.

Reference: C. J. Melhorn et. al., "Effect of High Efficiency Lighting on Power Quality in Public Buildings," *Conference Record of the 1995 Industry Applications Conference*, October 8-12 1995, pp. 2069-2075

Magnetic Ballast Input Current

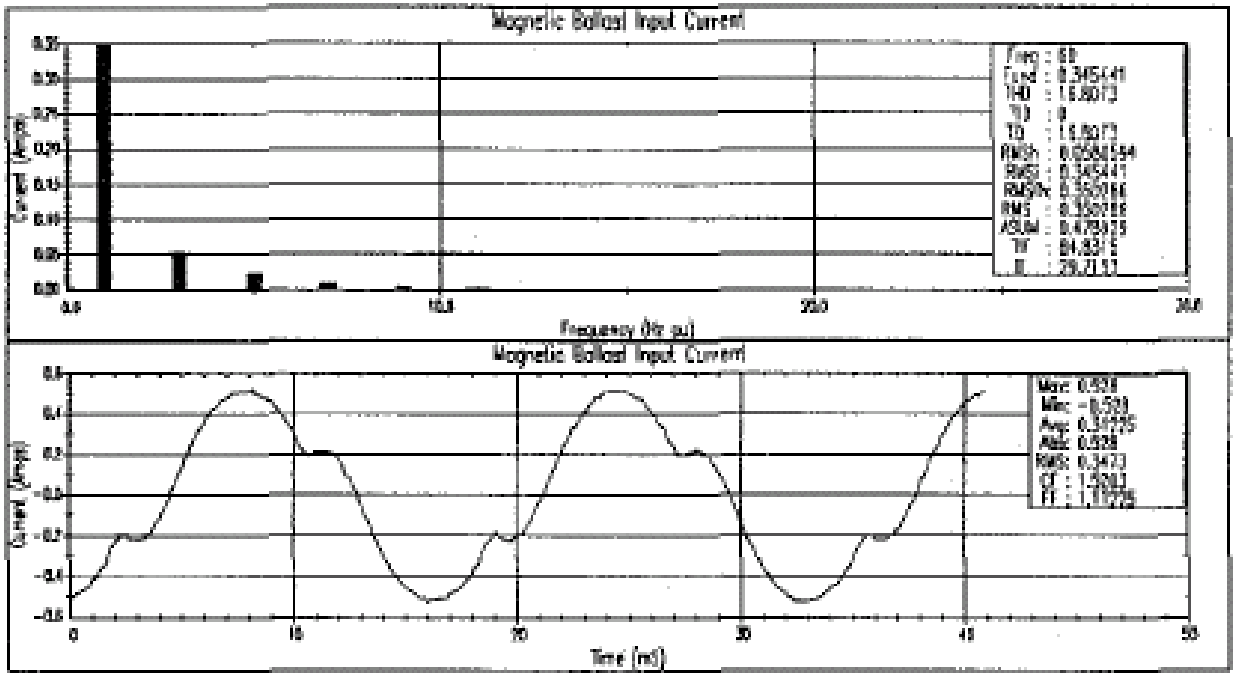


Figure 9: Magnetic Ballast Input Current Spectrum and Waveform.

Reference: C. J. Melhorn et. al., "Effect of High Efficiency Lighting on Power Quality in Public Buildings," *Conference Record of the 1995 Industry Applications Conference*, October 8-12 1995, pp. 2069-2075

Electronic Ballast Input Current

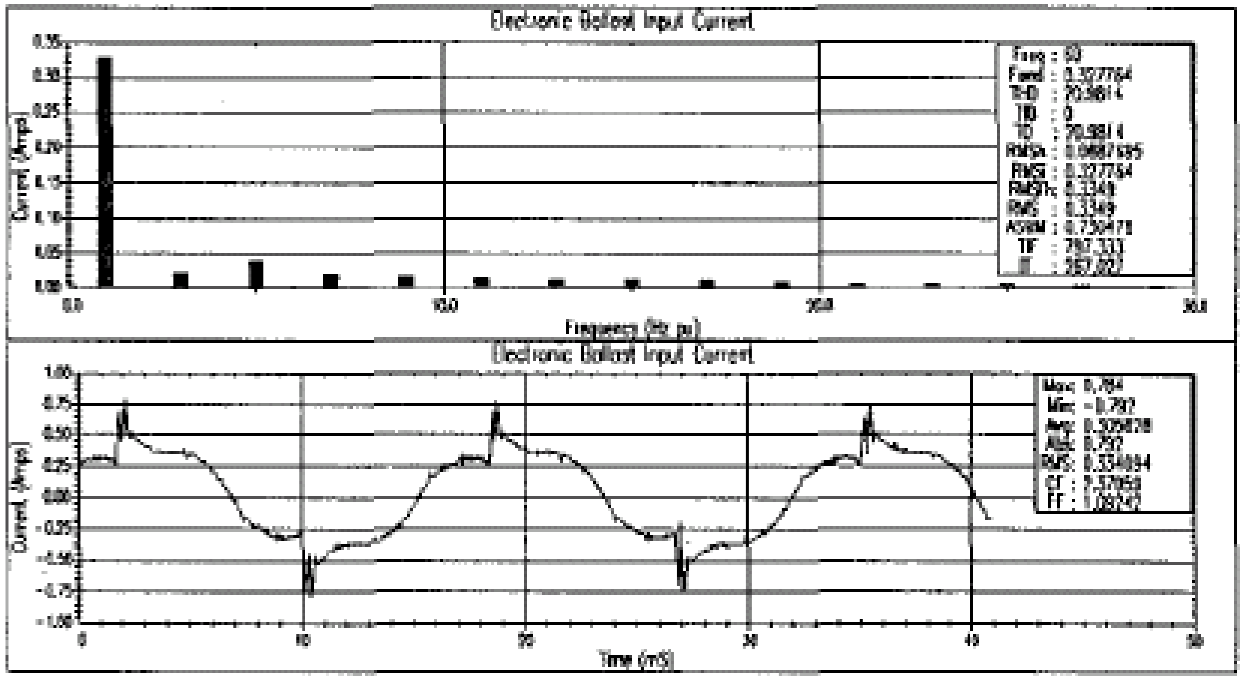


Figure 8: Electronic Ballast Input Current Spectrum and Waveform.

Reference: C. J. Melhorn et. al., "Effect of High Efficiency Lighting on Power Quality in Public Buildings," *Conference Record of the 1995 Industry Applications Conference*, October 8-12 1995, pp. 2069-2075

Case Study 4: Effects of Measurement Accuracy on Power Quality Measurements

- Study to determine effects of of non-ideal measurement components (CTs, voltage transformers) on power quality measurements on an arc furnace
- Authors added compensation filters to correct for nonideal frequency response of measurement components

Reference: B. Boulet et. al., "The Effect of Measurement System Accuracy on Power Quality Measurements in Electrical Arc Furnaces," *IEEE Industry Applications Society Annual Meeting*, October 5-9 1997, pp. 2151-2155

Power Quality Measurement System

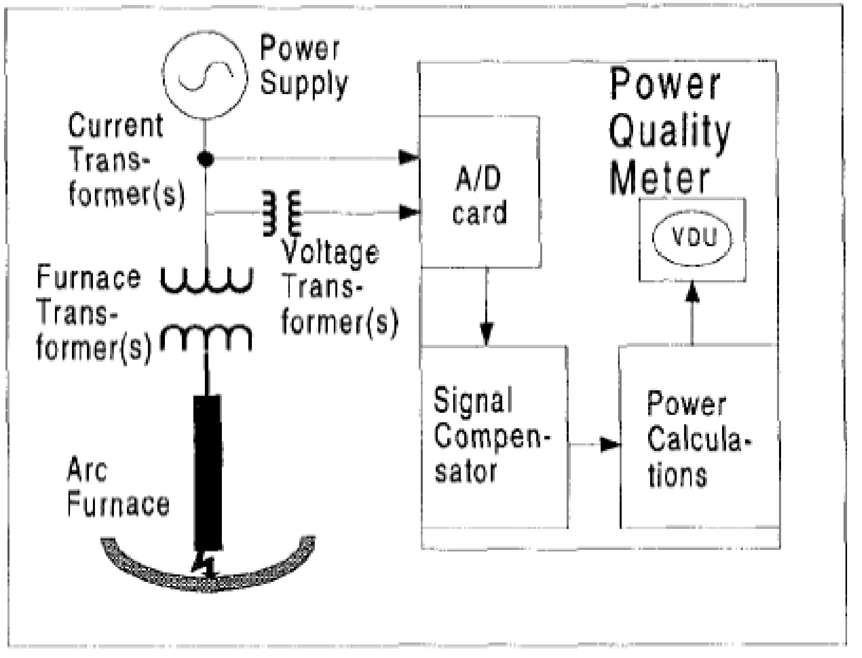


Figure 1: Power quality measurement system

Reference: B. Boulet et. al., "The Effect of Measurement System Accuracy on Power Quality Measurements in Electrical Arc Furnaces," *IEEE Industry Applications Society Annual Meeting*, October 5-9 1997, pp. 2151-2155

Accuracy of Instrument Transformers

- Standards (e.g. IEEE Std. C12.1 -1988 “American National Standard Code for Electricity Metering and IEEE Std C57.13-1993 “Standard Requirements for Instrument Transformers”) specify only accuracy of 60 Hz measurement
- At frequencies higher than 60 Hz, there will be gain and phase errors

Reference: B. Boulet et. al., “The Effect of Measurement System Accuracy on Power Quality Measurements in Electrical Arc Furnaces,” *IEEE Industry Applications Society Annual Meeting*, October 5-9 1997, pp. 2151-2155

Accuracy of Instrument Transformers

- Measured freq. response of a voltage instrument transformer shows phase lead

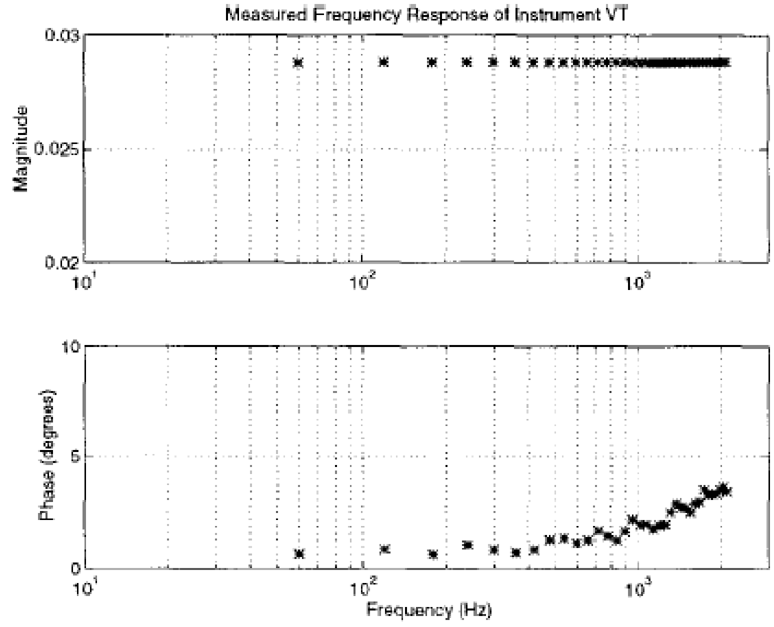


Figure 2: Measured frequency response of an instrument voltage transformer

Reference: B. Boulet et. al., "The Effect of Measurement System Accuracy on Power Quality Measurements in Electrical Arc Furnaces," *IEEE Industry Applications Society Annual Meeting*, October 5-9 1997, pp. 2151-2155

Other Causes of Error in PQ Measurement Systems

- Sampling adds phase shift
- Nonlinear phase response of antialiasing filters
- Phase shift doesn't affect RMS measurements
  – Phase shift can significantly affect power calculations

Reference: B. Boulet et. al., "The Effect of Measurement System Accuracy on Power Quality Measurements in Electrical Arc Furnaces," *IEEE Industry Applications Society Annual Meeting*, October 5-9 1997, pp. 2151-2155

Effects of Nonideal Transformers

- Comparison of results with and without compensation filters

Table 1: Unbalance calculation results

unbalance parameter	without filters	with filters	difference (%)
pos. seq.	193.6307	193.5505	0.0414
neg. seq.	25.3534	25.5983	-0.9567
zero seq.	26.7959	27.0302	-0.8668
% unbalance	13.1261	13.2586	-0.9994

Reference: B. Boulet et. al., “The Effect of Measurement System Accuracy on Power Quality Measurements in Electrical Arc Furnaces,” *IEEE Industry Applications Society Annual Meeting*, October 5-9 1997, pp. 2151-2155

Effects on Power Factor Calculations

- This waveform has 0.47 power factor

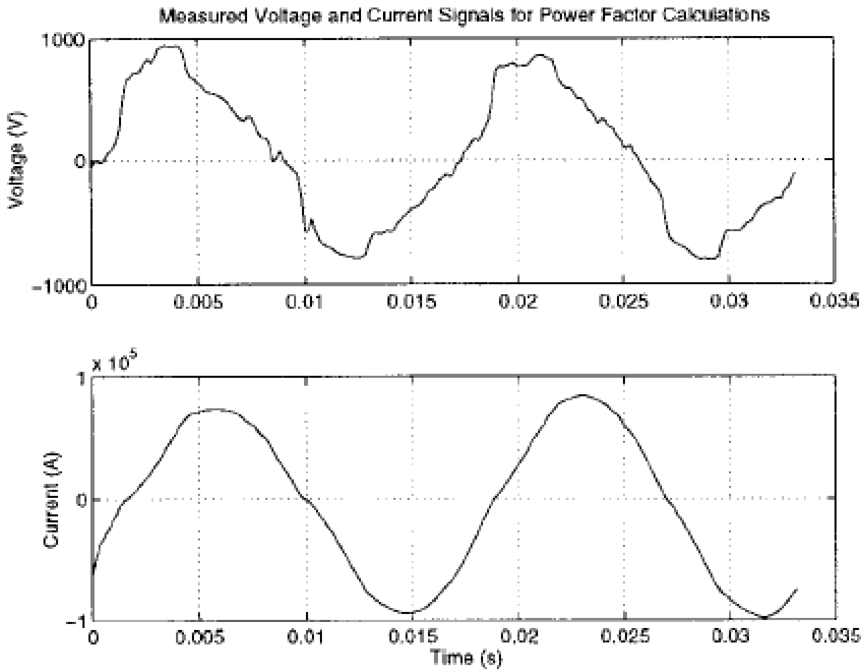


Figure 6: Voltage and current waveforms used for power and power factor measurements

Reference: B. Boulet et. al., "The Effect of Measurement System Accuracy on Power Quality Measurements in Electrical Arc Furnaces," *IEEE Industry Applications Society Annual Meeting*, October 5-9 1997, pp. 2151-2155

Effects on Power Factor Calculations

- With and without compensation filters

Table 2: Calculation results for 0.47 power factor

power calculation	without filters	with filters	diff. (%)
power factor	0.47468	0.46555	1.9611
active power (MW)	11.9858	11.7535	1.9764
react. power (MVAR)	21.9551	22.0741	-0.5391
app. power (MVA)	25.0137	25.0082	0.0220

Table 3: Calculation results for 0.75 power factor

power calculation	without filters	with filters	diff. (%)
power factor	0.75819	0.75196	0.8285
active power (MW)	25.1472	24.9377	0.8401
react. power (MVAR)	20.8277	21.0769	-1.1823
app. power (MVA)	32.6523	32.6516	0.0021

Table 4: Calculation results for 0.83 power factor

power calculation	without filters	with filters	diff. (%)
power factor	0.84045	0.83499	0.6539
active power (MW)	16.9889	16.8757	0.6708
react. power (MVAR)	10.7982	10.9729	-1.5921
app. power (MVAR)	20.1302	20.1294	0.0040

Reference: B. Boulet et. al., “The Effect of Measurement System Accuracy on Power Quality Measurements in Electrical Arc Furnaces,” *IEEE Industry Applications Society Annual Meeting*, October 5-9 1997, pp. 2151-2155