Power Quality
Notes 1-1 (MT)

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Course Overview: 3 Days, 6 Hours

- Day 1 - Hour 1: Course Overview, Objectives and Introduction (MT)
- Day 1 - Hour 2: Voltage Distortion (AK)
- Day 2 - Hour 1: Harmonic Current Sources (MT)
- Day 2 - Hour 2: Harmonic Current Effects (AK)
- Day 3 - Hour 1: Correction for Power Quality (AK)
- Day 3 - Hour 2: Power Quality Measurements (MT)

Objectives of this Course

- Familiarize the student with power quality issues such as sag, flicker, harmonic distortion, transients, etc.
- Overview of some mitigating strategies
- Measurements of power quality

Class #1 - Hour #1 (4/5/05) Introduction to Power Quality

- Background
- Definition of power quality
- Examples of poor power quality
  - Voltage distortion - sag, swell, transients
  - Harmonics
  - Flicker
  - Voltage Unbalance
  - High frequency conducted and radiated EMI
  - Notching

Background

- The increasing use of electronic equipment which can cause electromagnetic interference has heightened interest in “power quality.”

Some Definitions of Power Quality

- Power quality broadly encompasses the study of deviations in current and voltage waveforms from ideal sinewaves.
- IEEE 1519 definition: "*The concept of powering and grounding sensitive equipment in a manner that is suitable to the operation of that equipment.*"

Reference: IEEE Standard 1159-1995, "IEEE Recommended Practices for Monitoring Electric Power Quality," pp. 5

Some Definitions of Power Quality

3.1.47 power quality: The concept of powering and grounding sensitive equipment in a manner that is suitable to the operation of that equipment.[c]

NOTE—Within the industry, alternate definitions or interpretations of power quality have been used, reflecting different points of view. Therefore, this definition might not be exclusive, pending development of a broader consensus.

Reference: IEEE Standard 1159-1995, "IEEE Recommended Practices for Monitoring Electric Power Quality," pp. 5

Power Quality "Avoided Terms"

3.2 Avoided terms

The following terms have a varied history of usage, and some may have specific definitions for other applications. It is an objective of this recommended practice that the following ambiguous words not be used in relation to the measurement of power quality phenomena:

blackout

blink

brownout (see 4.4.3.2)

bump

clean ground

clean power

computer grade ground

counterpoise ground

dedicated ground

dirty ground

dirty power

frequency shift

glitch

interruption (when not further qualified)

outage (see 4.4.3.3)

power surge

raw power

raw utility power

shared ground

spike

subcycle outages

surge (see 4.4.1)

wink

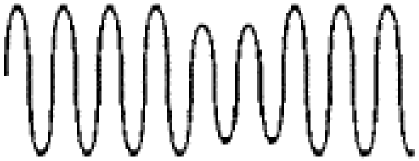
Reference: IEEE Standard 1159-1995, "IEEE Recommended Practices for Monitoring Electric Power Quality," pp. 7

PQ Measurable Quantities

- We'll go over a sampling of some power quality measurable quantities, including sag, swell, transients, harmonics, flicker, voltage unbalance and notching

Voltage Sag

- Also called "dip"
  - Reduction in RMS voltage for short duration (a few cycles)
  - Defined by IEEE Std. 1159 as duration of 0.5 cycles to 1 minute
  - Can be caused by varying load, short circuits, motor startup, etc.



Sag

References:
[1] J. Dougherty and W. Stebbins, "Power Quality: A Utility and Industry Perspective, *Proc. Of the IEEE 1997 Annual Textile, Fiber and Film Industry Technical Conference*, May 6-8, 1997, pp. 1-10
[2] IEEE Standard 1159-1995, "IEEE Recommended Practices for Monitoring Electric Power Quality"

Voltage Sag

- SLG (single line-ground) fault

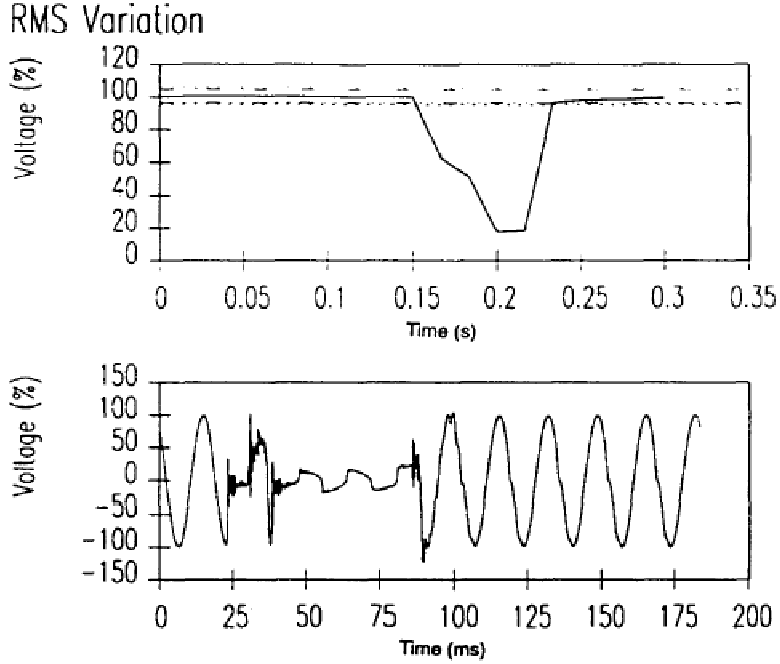


Figure 6—Instantaneous voltage sag caused by a SLG fault

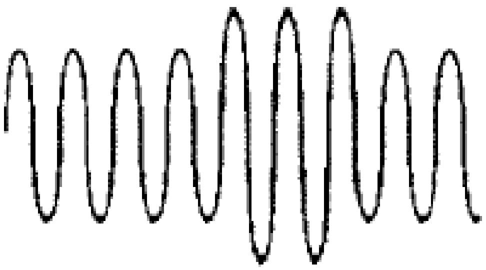
Reference: IEEE Standard 1159-1995, "IEEE Recommended Practices for Monitoring Electric Power Quality," pp. 17

Effects of Voltage Sag

- Consumer equipment can be interrupted
  - VCRs, furnace relays, computers, etc.
- Industrial equipment can be affected
  - Long-term voltage sag can interrupt factory processes

Reference: M. Bolen, "Voltage Sags: Effects, Mitigation and Prediction," *Power Engineering Journal*, vol. 10, no. 3, June 1996, pp. 129-135

Voltage Swell



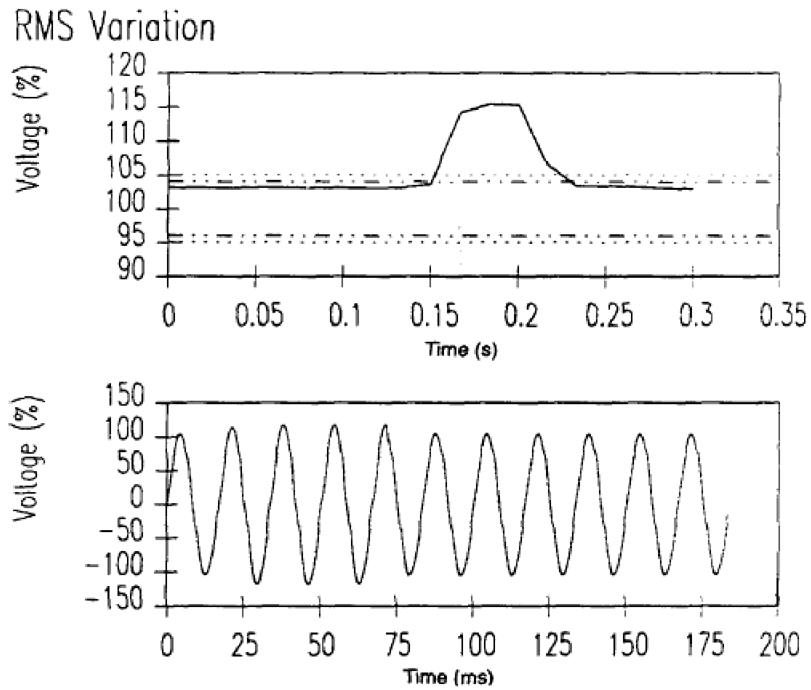


Figure 8—Instantaneous voltage swell caused by a SLG fault

Reference: IEEE Standard 1159-1995, "IEEE Recommended Practices for Monitoring Electric Power Quality," pp. 19

Transients

- Undesirable momentary deviation
- May be caused by lightning, energizing motors, etc.
- Maximum line transient in dwellings approximately 6 kV

References:
[1] J. Dougherty and W. Stebbins, "Power Quality: A Utility and Industry Perspective, *Proc. Of the IEEE 1997 Annual Textile, Fiber and Film Industry Technical Conference*, May 6-8, 1997, pp. 1-10
[2] IEEE Standard 1159-1995, "IEEE Recommended Practices for Monitoring Electric Power Quality," pp. 6

Typical Lightning-Induced Transient

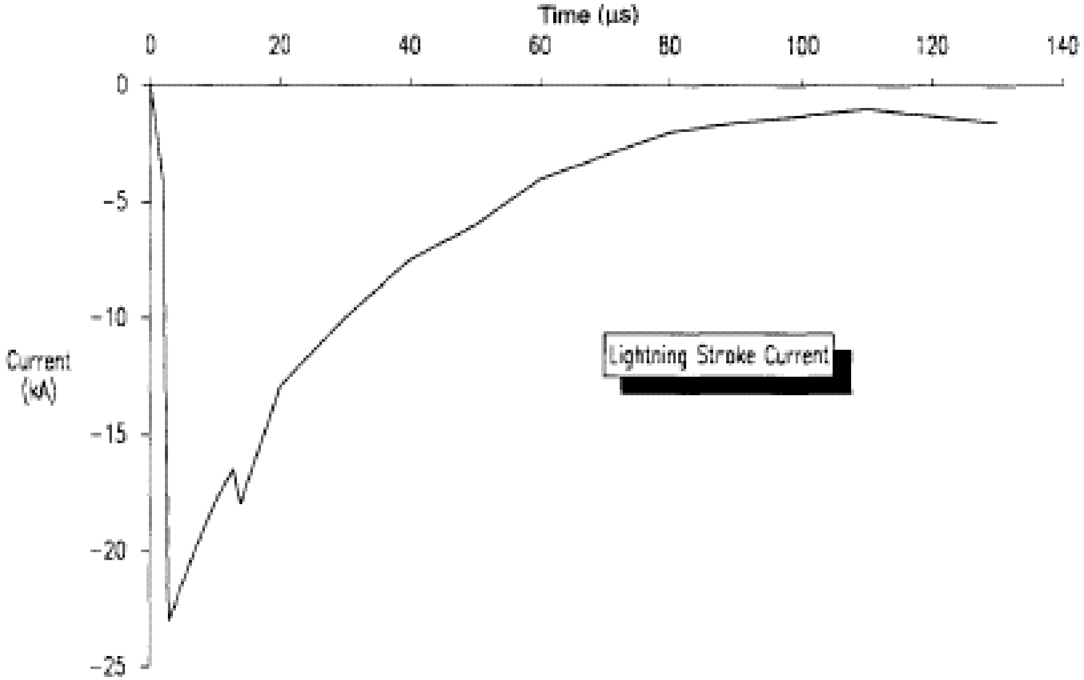


Figure 1—Lightning stroke current that can result in impulsive transients on the power system

References: IEEE Standard 1159-1995, “IEEE Recommended Practices for Monitoring Electric Power Quality,” pp. 7

Harmonics

- One measure is THD (total harmonic distortion)
  - Also known as "distortion factor"

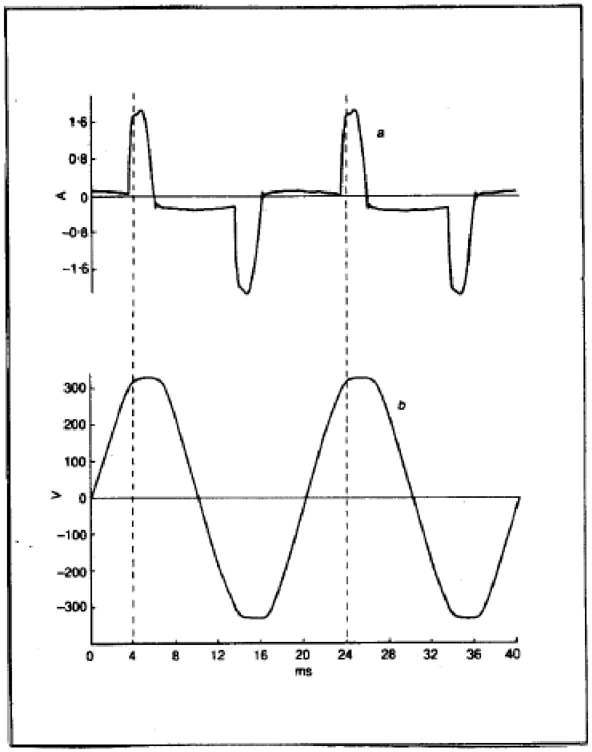
$$DF = \sqrt{\frac{\text{sum of squares of amplitudes of all harmonics}}{\text{square of amplitude of fundamental}}} \cdot 100\%$$

Harmonic Distortion

References:
[1] J. Dougherty and W. Stebbins, "Power Quality: A Utility and Industry Perspective, *Proc. Of the IEEE 1997 Annual Textile, Fiber and Film Industry Technical Conference,* May 6-8, 1997, pp. 1-10
[2] IEEE Standard 519-1992, "IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems," pp. 9

Example of Harmonic Source

- Single-phase full-wave rectifier
- Capacitor charges only near the peak of the line voltage
- High harmonics, poor power factor



Another Example of Harmonic Source

- Switching converters

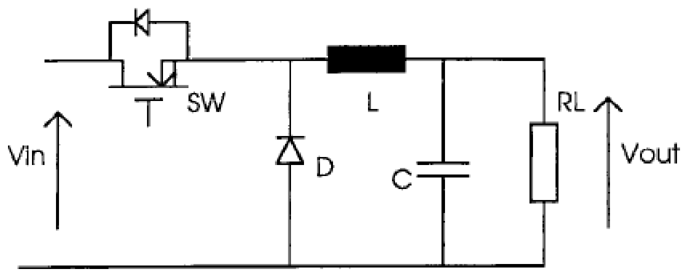
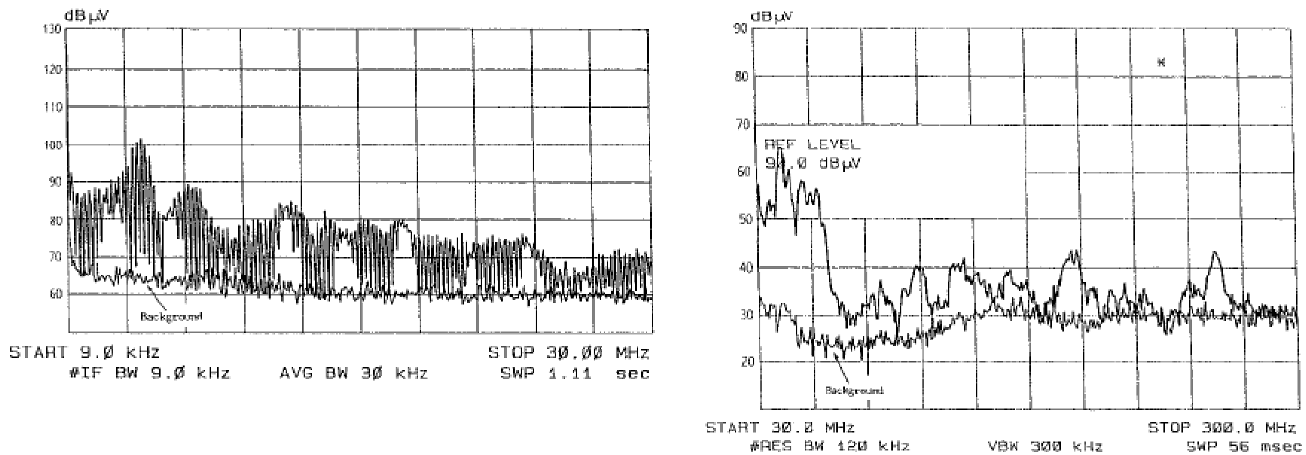


Fig. 1. Schematic of the hard-switched buck converter.



(a) (b)

Fig. 6. (a) Conducted EMI from hard-switched buck converter. (b) Radiated EMI from hard-switched buck converter.

Reference: H. Chung, et. al., “Reduction of Power Converter EMI Emission Using Soft-Switching Technique” *IEEE Transactions on Electromagnetic Compatibility*, vol. 40, no. 3, August 1998, pp. 282-287

Conducted EMI Testing Envelope

- Applied to offline witching converters

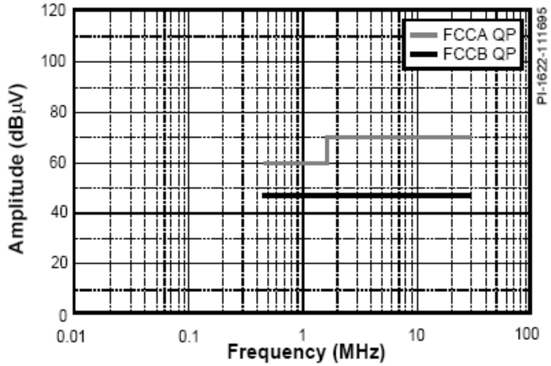


Figure 1. FCC Class A and B Limits (Quasi Peak).

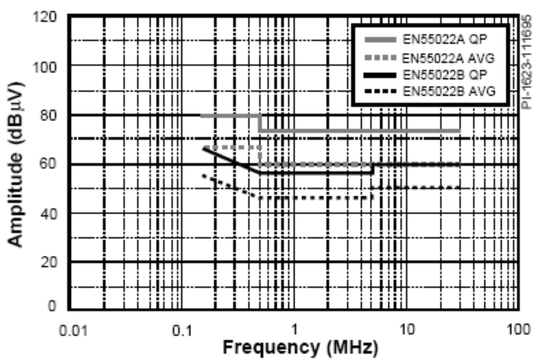


Figure 2. EN55022 Class A and B Limits (Average and Quasi Peak).

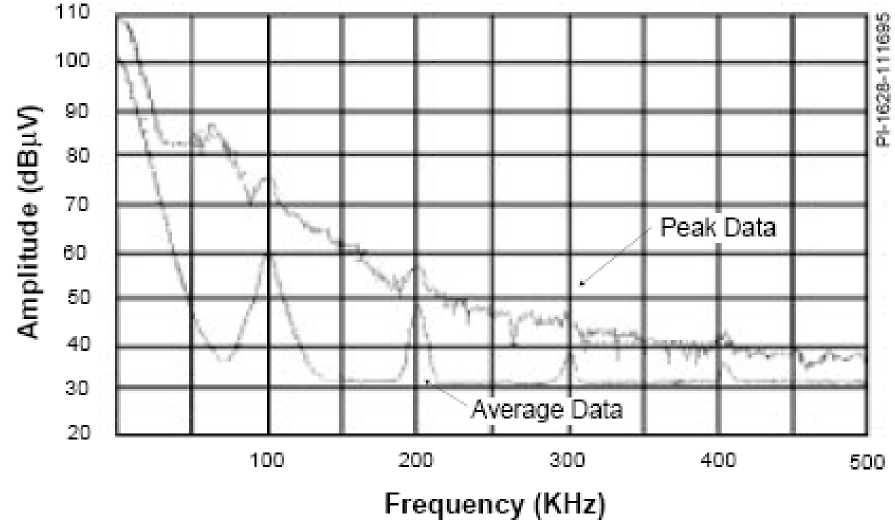


Figure 8. Peak Data vs Average Data.

Reference: Power Integrations, Inc., application note AN-15, "Techniques for EMI and Safety," from http://www.powerint.com/PDFFiles/an15.pdf

Flicker

- Visual effect of small voltage variations on electrical lighting
  - "Impression of unsteadiness of visual sensation induced by a light stimulus whose luminance or spectral distribution fluctuates with time"
    - - IEEE Std. 1159

Reference:
[1] W. Chang, et. al., "A Flexible Voltage Flicker Teaching Facility for Electric Power Quality Education" *IEEE Transactions on Power Systems*, vol. 13, no. 1, February 1998, pp. 27-33
[2] IEEE Standard 1159-1995, "IEEE Recommended Practices for Monitoring Electric Power Quality," pp. 3

Flicker

- Can be caused by load switching (compressor, arc furnace, etc.)

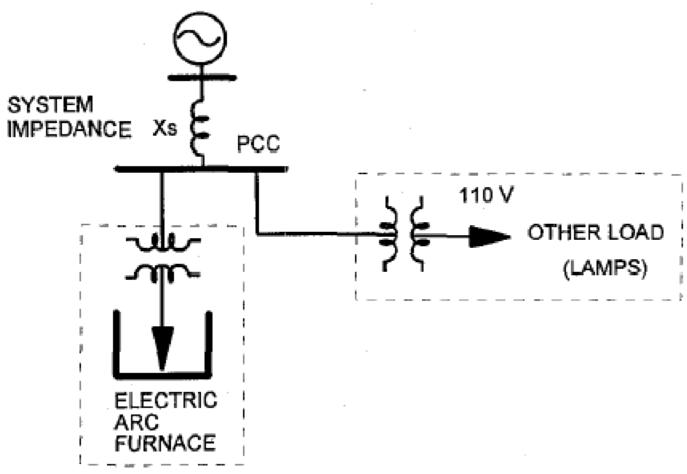


Figure 1. A simple power distribution system.

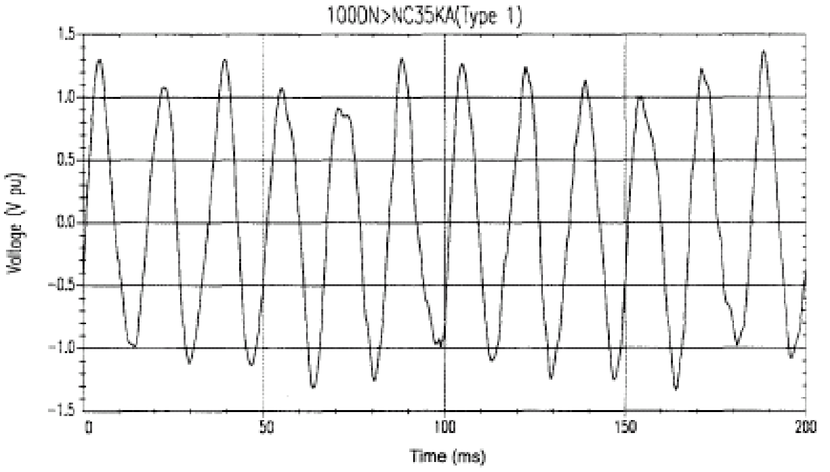


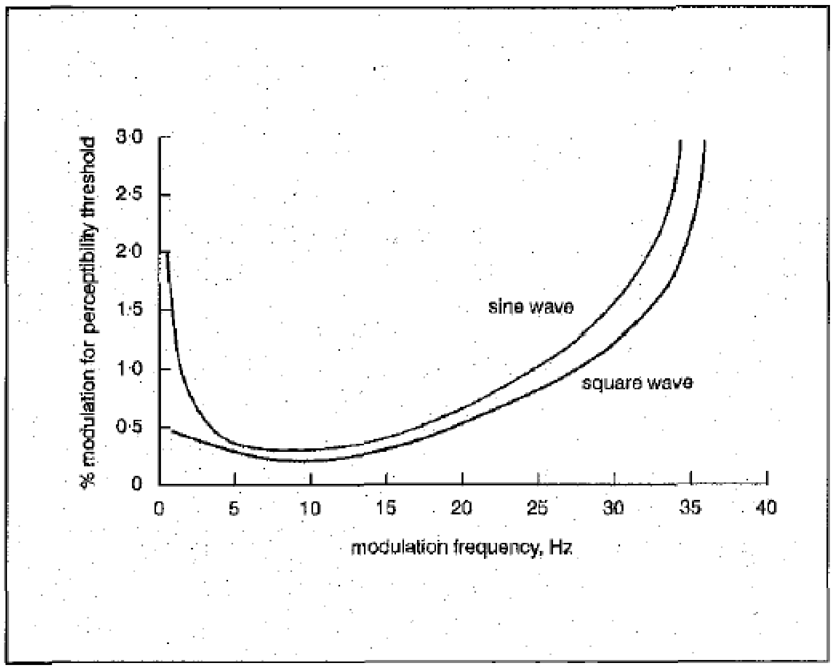
Figure 12—Example of voltage fluctuations caused by arc furnace operation

Reference:

[1] W. Chang, et. al., "A Flexible Voltage Flicker Teaching Facility for Electric Power Quality Education" *IEEE Transactions on Power Systems*, vol. 13, no. 1, February 1998, pp. 27-33

[2] IEEE Standard 1159-1995, "IEEE Recommended Practices for Monitoring Electric Power Quality," pp. 24

Flicker Perceptibility Curves



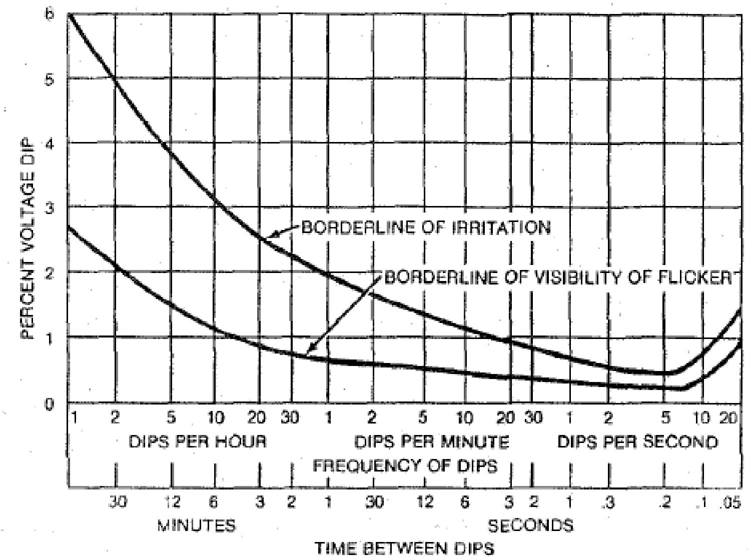


Figure 3. The perceptibility threshold of voltage flicker verse time.

References:

[1] P. Ashmole, “Quality of Supply - Voltage Fluctuations. I” *Power Engineering Journal*, vol. 14, no. 3, June 2000, pp. 113-119

[2] W. Chang, et. al., “A Flexible Voltage Flicker Teaching Facility for Electric Power Quality Education” *IEEE Transactions on Power Systems*, vol. 13, no. 1, February 1998, pp. 27-33\

Voltage Unbalance

- Deviation of magnitude and/or phase in 3-phase system
- Can result in heating of induction motors

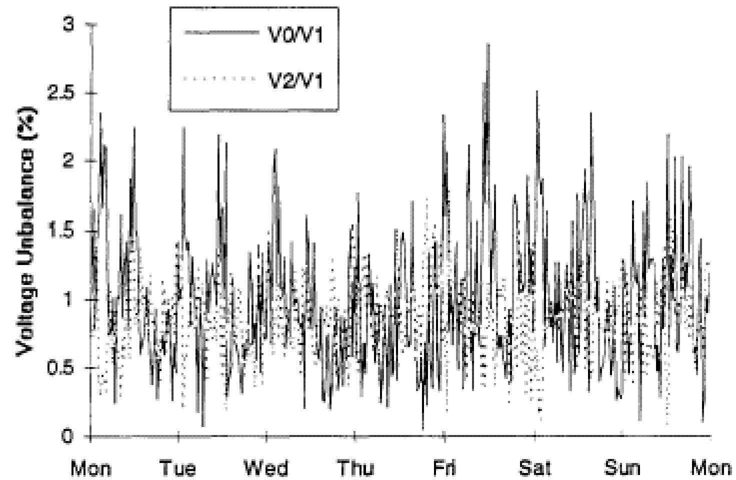


Figure 9—Imbalance trend for a residential feeder

References:
[1] IEEE Standard 1159-1995, "IEEE Recommended Practices for Monitoring Electric Power Quality," pp. 20
[2] NEMA, *Motors and Generators*, NEMA Standards No. MG 1-1988, pp. 14-10

Notching

- Caused by commutation in semiconductor converters

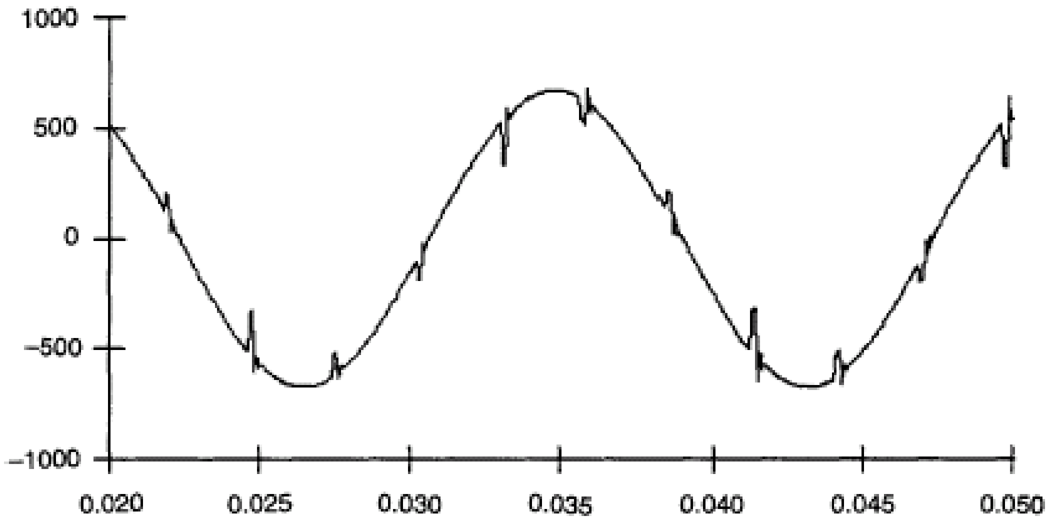


Figure 11—Example of voltage notching caused by converter operation

References: IEEE Standard 1159-1995, "IEEE Recommended Practices for Monitoring Electric Power Quality," pp. 23

PQ Acceptability Curves

- CBEMA: Computer Business Equipment Manuf. Assoc
- ITIC: Information Technology Industry Council
- SEMIF47: Semiconductor Processing Equipment

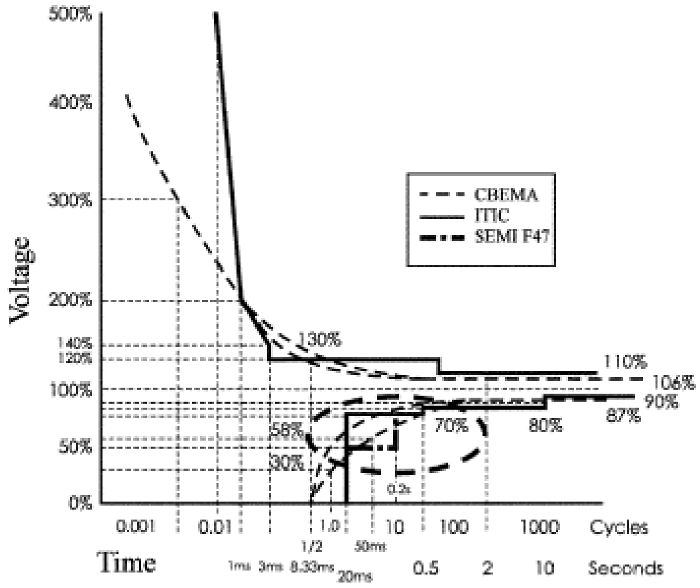


Fig. 2. Power acceptability curves—trends in recommended power acceptability.

Reference: Djokic, et. al., "Sensitivity of Personal Computers to Voltage Sags and Short Interruptions," *IEEE Transactions on Power Delivery*, vol. 20, no. 1, January 2005, pp. 375-383

Some Relevant Standards

- IEEE 519 --- Recommended Practices for Harmonic Control
- IEEE 1519 --- Recommended Practices for Monitoring Power Quality