6/1/05

Outline

Power Quality in Electrical Systems

by

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Authors

- Alexander Kusko, Sc.D, Corporate Vice President, Exponent Failure Analysis Associates, Natick, MA. Forty years experience on UPS, power-system design, and power quality. Former associate professor of Electrical Engineering at MIT, Author, co-author, 150 papers, 7 books; IEEE Life Fellow.

- Marc Thompson, Ph.D, President, Thompson Consulting, Inc., Harvard MA and Adjunct Associate Professor of Electrical Engineering, Worcester Polytechnic Institute. Teaches graduate-level power electronics and analog circuit design; twenty years industrial experience in analog and power electronics design; author, co-author, 10 papers; 7 US Patents.

Overview

- Tremendous requirement for reliable, uninterruptible electric power service for all consumers, particularly manufacturing facilities, data-processing centers, and other locations with critical and sensitive loads.
- Power Quality is a measure of the reliability of electric power service.
- Multi-million dollar industry to provide engineering and equipment to resolve Power Quality problems.
- Book is based on a professional course sponsored by IEEE and taught by the authors.
- Book is directed toward real problems and solutions, rather than a total theoretical treatment.
- Book can be used as the text for a course and as a reference.
- Dr. Kusko wrote early book in field in 1989 entitled "Emergency/Standby Power Systems", published by McGraw Hill.
- Book will include treatment of switch-mode power supplies and other loads that produce conducted and radiated interference. Levels are regulated by FCC and other codes.
- Book will include description of standby power systems for emergency and independ operation to solve Power Quality problems.

Market

- Managers, concerned with reliable electric power service
  - Computers/Date Centers
  - Manufacturers
  - Manufacturing facilities
  - Office buildings
  - Electric utility companies
  - Government/Military agencies
  - Healthcare facilities

- Engineers concerned with standards compliance and reliable operation of equipment and systems
  - Electrical design
  - Electric and telecom utilities

- Transportation
- Computer/Telecom
- Unconventional power (e.g. wind)

- Students seeking knowledge and entrance to an active field
  - Fourth year and graduate engineer
  - Two-year associate engineer
  - Professional engineer

Focus

- Identification and correction of power quality problems.
- Listing of definitions and standards
- Case studies from authors' experience and in references of power quality problems and solutions.
- References to significant articles in the professional and trade journals.

Organization of Book

- See Table of Contents
- Based on original six lectures expanded to 12 chapters.
- Figures suitable for PowerPoint presentation; can be emailed to students prior to each class.
- Preface of book will describe how the book can be used, for example, for a six- lecture professional course or for an 18-plus lecture academic course.
- Estimated length of book, 400 pages, including up to 100 figures (already done). See Attachment A for some representative figures.

Competitive Books

- "Power Quality Analysis", Dranetz – Bmi, Edison, N.J. 2003
- J. Arillaga, N.R. Watson, S. Chen, "Power Quality Assessment", John Wiley, 2000.
- A. Ghosh, G. Ledwich, "Power Quality Enhancement Using Custom Power Devices", Kluwer, 2002.
- R. C. Dugan, M. F. McGranayhan, and H. W. Beaty, "Electrical Power Systems Quality," McGraw Hill, New York, 1996

TABLE OF CONTENTS

- Utility, state and federal standards
- EMI standards
    - US: FCC Class A and B
    - International: CISPR 16-1, EN 61000

Chapter 3. Voltage Distortion

- Definitions
    - Amplitude, sags, swells, transients
    - Harmonic distortion
    - Interruptions
- Causes, External to Facility
    - Utility outages
    - Lightning
    - Utility switching
- Causes, Internal to Facility
    - Converters
    - Non-linear loads
    - Motor starts
- Impact on Connected Equipment
    - Compliance with CBEMA Curve
    - Erratic operation and shutdown of equipment
    - Damage

Chapter 4. Harmonics

- Definitions
    - Multiples of line frequency, characteristics.
    - Non-characteristic
- Fourier Analysis
    - Combined waveforms
- Total harmonic distortion, THD
- IEEE Std. 519
- Effects on equipment; case study

Chapter 5. Harmonic Current Sources

- Converters, definitions
  - Single–phase rectifiers
  - Multi-phase rectifiers
  - Controlled rectifiers
- Single-phase rectifiers
  - Inductor filter
  - Capacitor filter
  - Commutation, waveform notching
  - Voltage effect
- Multi-phase rectifiers, applications
  - Motor drives
  - UPS
  - Industry, transit, electrochemical
- Three-phase rectifiers
  - Operation
  - Control
  - Waveforms
  - Line current
  - Harmonics
- Three-phase rectifiers
- Analysis
  - IEEE Std. 519 Method
  - Harmonic sources, assumptions
- System Effects
  - Line and neutral current
  - Harmonic voltage
- IEEE Std. 519
  - Individual Harmonics
  - Total Harmonics, THD

- Case study

Chapter 6. Power Capacitors

- Purpose
  - Utility, facility, location
  - Power factor correction
  - Power harmonic filter
  - Switching
- Ratings
  - Reactive power, kvar
  - Voltage, current
- Resonance
  - Circuit
  - Calculation
  - Prevention

Chapter 7. Corrections for Power Quality Problems

- Converters
  - 12 pulse
- Power Harmonic Filters
  - Passive
  - Active
- Uninterruptible Power Supplies, UPS
  - Static
  - Rotating
- Transformers
  - Harmonic Cancellation
  - Saturable Magnetic, SOLA
- Standby Power Systems

Chapter 8. Switch-Mode Power Supplies

- Applications
- Sources of EMI
- Standards
    - US and European
- Measurements
    - LISN method
- Mitigating strategies
    - EMI filters

Chapter 9. Uninterruptible Power Supplies

- Purpose
    - Provide uninterruptible power
    - Isolate load from line
    - Features
- Types
    - Static
    - Rotary
- Systems
    - Engine-generator sets
    - Batteries
    - Maintenance, 24/7 concept

Chapter 10. Power Quality Events

- Effects on equipment
    - Utility equipment
    - Motors
    - Transformers
- 12-Pulse Motor Drives, Examples
    - Elevators
    - Power plant boiler feed pump
- Resonance, Example

- Extruder plant

Chapter 11. Standby Power Systems

- Purpose
  - Emergency power, long time outages
  - Economic, rate supplement, peak power
  - Back up UPS, batteries
  - Independent supply
- Types of power sources
  - Diesel/gas engine-generator sets
  - Combustion-turbine generator sets
  - Batteries
- Typical systems
  - Single E/G set, emergency power
  - Multiple E/G sets
  - Combined cycle
  - Battery

Chapter 12. Power Quality Measurement

- Purpose
  - Trouble analysis
  - Contractual
- Commercial equipment
  - Power factor
  - Harmonics
- Recorders
  - Sampling
  - Presentation

Attachment A
Representative Figures

Typical Lightning-Induced Transient

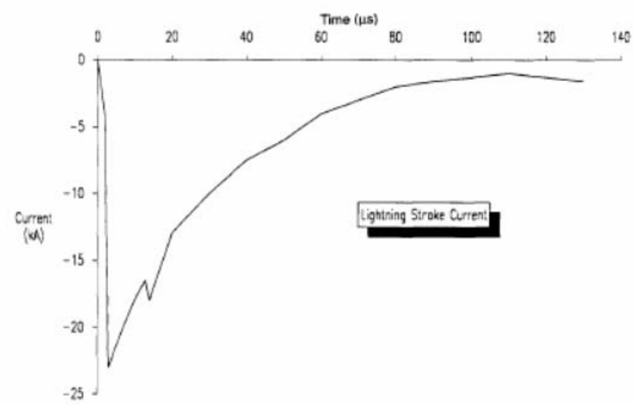


Figure 1—Lightning stroke current that can result in impulsive transients on the power system

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

UPS: Static Inverter

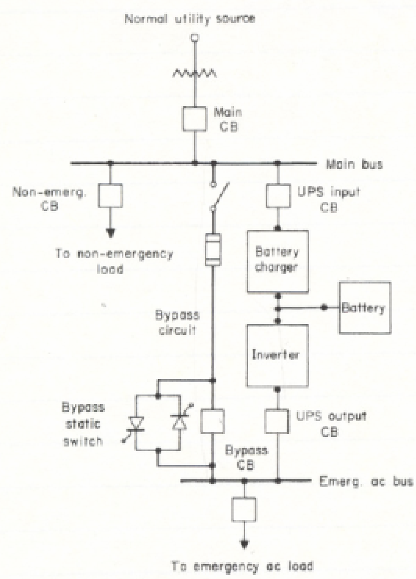


Figure 2.3 Emergency system with a static UPS.

Reference: A. Kusko, *Emergency Standby Power Systems*, McGraw Hill, 1989

Phase Current and Voltage

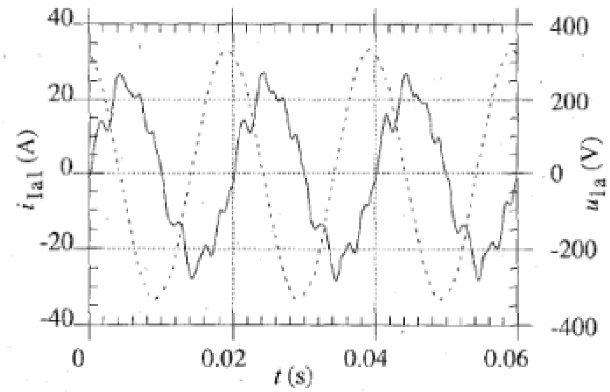


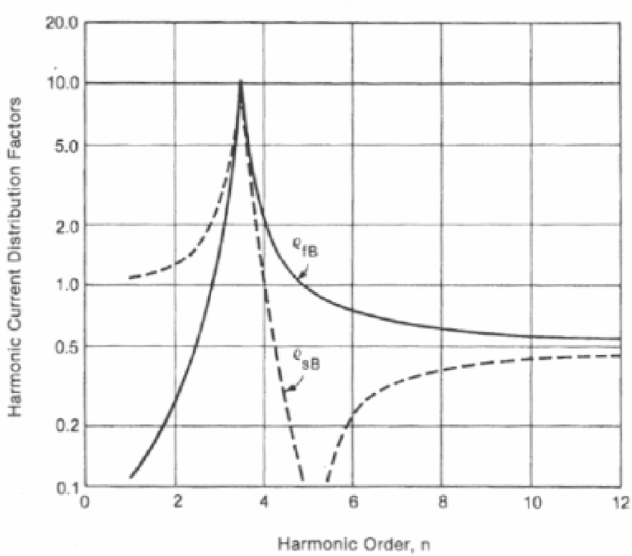
Fig. 9. Measured current (solid) and voltage (dashed) at 5 m/s.

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

Resonance: Distribution Factor, with Reactor



$\rho_{fB} \rightarrow 1$ at $n = 5$

$\rho_{sB} \rightarrow 0$ at $n = 5$

Reference: T. J. E. Miller, *Reactive Power Control in Electric Systems*, John Wiley, pp. 341