Outline

Power Quality in Electrical Systems

by

Alexander Kusko, Sc.D., P.E.
Marc T. Thompson, Ph.D.

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.
- 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 independent operation to solve Power Quality problems.

Market

- Managers, concerned with reliable electric power service
  - Computers/Data 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
TABLE OF CONTENTS

Chapter 1. Introduction

- Definitions of term, “Power Quality”
  - Voltage sag, swell, transients, flicker
  - Harmonics
  - Frequency Deviations
  - Interference

- Examples of poor power quality
  - Interruptions
  - Voltage distortion
  - Capacitor failures
  - Flicker
  - EMI, conducted and radiated

- Need for corrections
  - Customer needs
  - Standards and codes

- Scope
  - Events
  - Corrective measures

Chapter 2. Power Quality

- Factors causing poor power quality
  - Power outages
  - Inherent equipment design
  - Non linear loads, converters, arcing
  - Motor starts, utility switching
  - Standards non-compliance

- Relevant standards
  - IEEE Stds 519 and 1159
  - CBEMA curve
  - Engine-generator standards
  - UPS standards
- 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
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


UPS: Static Inverter

Phase Current and Voltage

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

Table 1. Relative harmonic content of the voltages.

<table>
<thead>
<tr>
<th>Order n</th>
<th>5</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>11</th>
<th>13</th>
<th>15</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency (Hz)</td>
<td>250</td>
<td>350</td>
<td>450</td>
<td>550</td>
<td>650</td>
<td>750</td>
<td></td>
</tr>
<tr>
<td>U(1m) (%)</td>
<td>1.1</td>
<td>0.72</td>
<td>0.11</td>
<td>0.072</td>
<td>0.0077</td>
<td>0.056</td>
<td>0.018</td>
</tr>
<tr>
<td>U(2m) (%)</td>
<td>1.0</td>
<td>0.54</td>
<td>0.09</td>
<td>0.048</td>
<td>0.047</td>
<td>0.016</td>
<td>0.008</td>
</tr>
</tbody>
</table>


Resonance: Distribution Factor, with Reactor

\[ \rho_{fB} \rightarrow 1 \text{ at } n = 5 \]
\[ \rho_{sB} \rightarrow 0 \text{ at } n = 5 \]