Effects of Power Quality On Metering

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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
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
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

RMS Voltage

Time

Voltage

120
119
118
117
116
115
114
113
112
111

11:59:17  12:00:00  12:00:43  12:01:26  12:02:10  12:02:53  12:03:36  12:04:19
Power Quality Issues

New Holstein (Miller)

[Graph showing voltage and current waves]
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
Power Quality Issues

• Voltage Regulation
  ▪ Long term variations in voltage
  ▪ ANSI C84.1 defines two **service** 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
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
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
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

\[ V(t) = \sqrt{2} \sum_{n=1}^{\infty} (V_n \sin(n \omega_0 t - \alpha_n)) \]
Harmonics Theory

\[ V(t) = \sqrt{2} \sum_{n=1}^{\infty} (V_n \sin(n \omega_0 t - \alpha_n)) \]
Even a square wave can be represented as a series of harmonics.
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
## Past Harmonic Sources

<table>
<thead>
<tr>
<th>SOURCE</th>
<th>TYPE</th>
<th>LEVEL</th>
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</thead>
<tbody>
<tr>
<td>Transformer</td>
<td></td>
<td></td>
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<tr>
<td>▪ Saturation</td>
<td>Current Harmonics</td>
<td>1 to 85%</td>
</tr>
<tr>
<td>▪ Energization</td>
<td>3,5,7… &amp; 2,4…</td>
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<tr>
<td>Arc Furnace Welders</td>
<td>Voltage Harmonics</td>
<td>2.5 to 8%</td>
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<td>5 &amp; 7</td>
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<tr>
<td>Line Commuted Converters</td>
<td>Volt. &amp; Cur. Harmonics</td>
<td>10 to 30%</td>
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<td>$H = np \pm 1$</td>
<td></td>
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<tr>
<td>Static VAR Compensators</td>
<td>Current Harmonics</td>
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<td>$H = np \pm 1$</td>
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<tr>
<td>Saturable Reactors</td>
<td>Current Harmonics</td>
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# New Harmonic Sources

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<tr>
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<tbody>
<tr>
<td>Fluorescent Lighting</td>
<td>Current Harmonics 3,5,7… up to &gt; 49</td>
<td>&gt; 400%</td>
</tr>
<tr>
<td>Electronic Power Supplies</td>
<td>Current Harmonics 3,5,7… up to &gt; 25</td>
<td>&gt;100%</td>
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<td>Especially Computers</td>
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</table>
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%
Harmonic Theory
An Alternate Approach

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

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<td>360</td>
<td>420</td>
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Harmonic Theory
An Alternate Approach

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Positive (+)
- If fundamental rotation is ABC then positive (+) sequence harmonics have ABC rotation
Harmonic Theory
An Alternate Approach

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Current Waveforms

Negative (-)
- If fundamental rotation is ABC then negative (-) sequence harmonics have CBA rotation
Harmonic Theory
An Alternate Approach

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<td>-</td>
<td>0</td>
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ZERO (0)
- If fundamental rotation is ABC then zero (0) sequence harmonics have NO rotation.
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
Harmonics & Metering Accuracy

• UPDATE: Latest ANSI C12 standards 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
Harmonics & Metering Accuracy

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

Waveform #6 – Multiple Zero Crossing Voltage Waveform
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
Power Quality Issues

• Sub Harmonics (Freq < Fundamental)
  ▪ Not addressed in any standard
  ▪ Not measured by FFT based approaches

• Non-Harmonic High Frequency Disturbances
  ▪ Not addressed in any standard
  ▪ Not measured by FFT based approaches

• Sudden Load Changes
  ▪ Not addressed in any standard
  ▪ Not measured by FFT based approaches
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
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
Questions?

Comments?

Thank you for your time!