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Interharmonics: What They Are, Where They Come From and What They Do

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Presentation Outline

- What are Interharmonics? - Definitions
- Where Do They Come From? - Sources
- What Do They Do? – Effects
- How are They Measured? – Metering
- What Levels are Acceptable? – Standards/Guidelines/Limits
- How are they Controlled? - Mitigation

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Introduction

- Improve Efficiency, Flexibility and Reliability
- Use Increasingly Sophisticated Power Electronics and Communication Systems
- Can Increase Interharmonic Levels and Sensitivity to Interharmonics
- Need to Prevent Interharmonics from Adversely Affecting Power Systems

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Interharmonic Definitions

- IEEE: “A frequency component of a periodic quantity that is not an integer multiple of the frequency at which the supply system is operating”
- IEC: “Between the harmonics of the power frequency voltage and current, further frequencies can be observed which are not an integer of the fundamental. They can appear as discrete frequencies or as a wide-band spectrum.”

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So, What are Interharmonics?

f_1 = fundamental frequency	
If n – Any Positive Integer	If m – Any Positive Non-Integer
nf_1 is the n^{th} Harmonic	mf_1 is the m^{th} Interharmonic
If $n = 0$, nf_1 is DC	If $m < 1$, mf_1 is a Subharmonic

- Periodic Waveforms: Only Harmonic Components
- Interharmonics not Periodic at Fundamental
  - All Non-Periodic Waveforms Contain Interharmonics
  - Interharmonics are a Measure of Non-Periodicity

Interharmonics Compared to Harmonics

- Both Add Signal(s) to the Power Frequency
- Both Can Be Magnified by Resonance(s)
- Usually Harmonics a Limited Number of Stable Frequencies, Interharmonics Varying Frequencies or Wide-Spectrum
- Interharmonics Provide More Opportunities for Undesirable Resonance

$$f = \frac{1}{2\pi\sqrt{LC}}$$

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Interharmonic Producing Phenomena

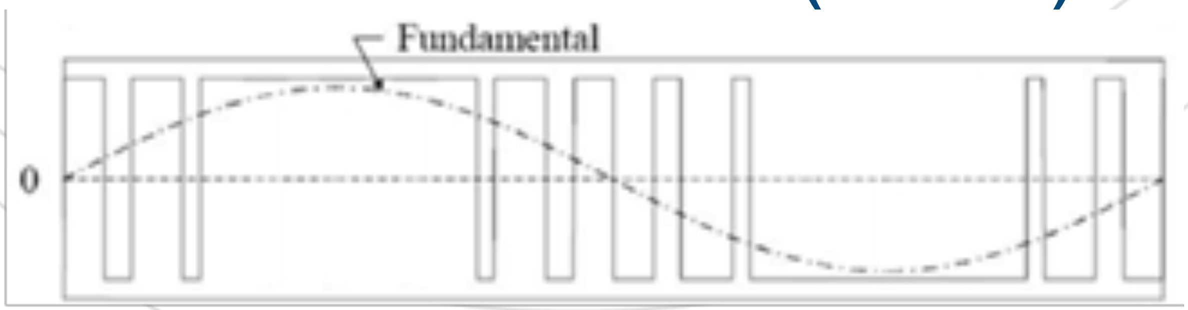
- Rapid Non-Periodic Load/Current Changes
  - Loads Operating in a Transient State
  - Voltage or Current Amplitude Modulation
- Asynchronous Switching Static Converters
  - Insulated Gate Bipolar Transistors (IGBT), Unlike Thyristors, Can Be Turned Off
  - Voltage Sourced Converters (VSC) Use IGBTs to Regulate Vars, Blackstart, etc.

Some Specific Interharmonic Sources

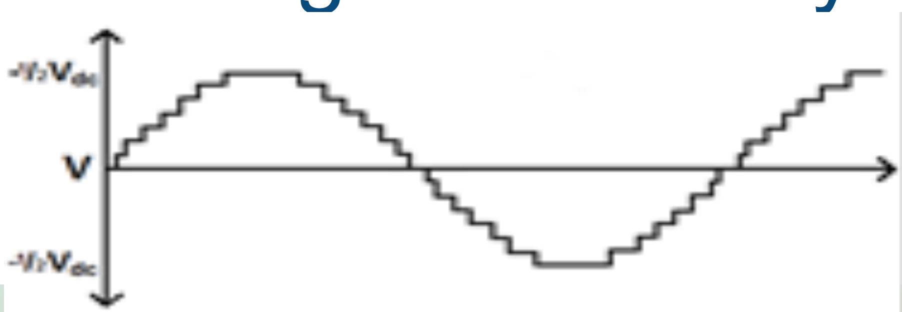
- Arcing Loads – Arc Furnaces, Welding
- Induction Motors – Saturation, Variable Torque, Asymmetry, etc.
- Electronic Frequency Converters – Filtering
- Traction Power Supplies – Fixed Frequencies
- VSCs – Wind Mills, HVDC, etc.
- Power Line Communications – Single or Multiple Interharmonic Frequencies

Voltage Sourced Converters

- Interharmonics Depend on Design (Pulse Number, Levels, etc.)
- Pulse Width Modulation (PWM) More



- Modular Multi-Level (MML) and Cascaded Two-Level Designs Generally Less Distortion



One Way Power Line Communications

- System Protection Communications
  - Usually a Limited Number of Frequencies
  - Limited Information to Few Receivers
  - Confined to Small Area by Wave Traps
  - Usually Only Sent During an Event (Rare)
- Ripple Control of Loads, Capacitors, etc.
  - Usually a Limited Number of Frequencies
  - Limited Information to Many Receivers
  - Signal Can Be Sent to a Wide Area
  - Signal Usually Sent Infrequently

Two Way Power Line Communications

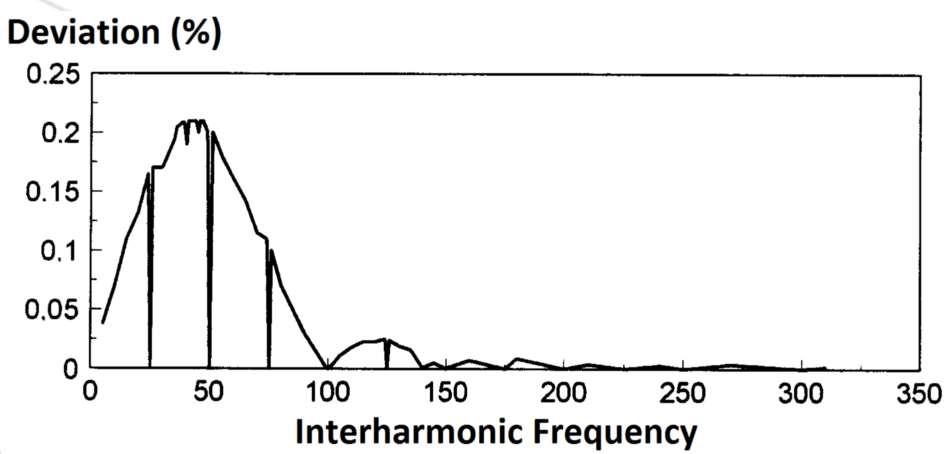
- Smart Meter Communications
- Various Levels of Data Intensity
  - Minimal – Monthly Usage for Billing
  - High Intensity – Time of Day Billing, Outage Information, etc.
- Communicates with Hundreds of Meters
- Voltage and/or Current Send Digital Bits
- Reliable: Multiple Attempts/Error Checking
- A Wide Range of Interharmonics

“Typical” Interharmonic Characteristics

- Generated and Transferred to Any Voltage
- Relatively Little Interharmonic Measurement Data Publically Available
- “Typical” Transmission Levels Below 0.02%
- Resonance Can Increase Levels to 0.5%
- Typically an Order of Magnitude Below Harmonic Distortion Levels

Interharmonic Effects

- Some Effects Similar to Harmonics
  - Overloads: Additional Losses, Heating and Saturation
  - Oscillations: Mechanical, Acoustic or Communications
  - Distortion: Affects Zero Crossing or Peak Magnitude
- Light Flicker – Magnitude & Frequency
  - RMS Voltage Variation for 0.2% Interharmonic
  - Interharmonics above 2nd Harmonic Not an Issue



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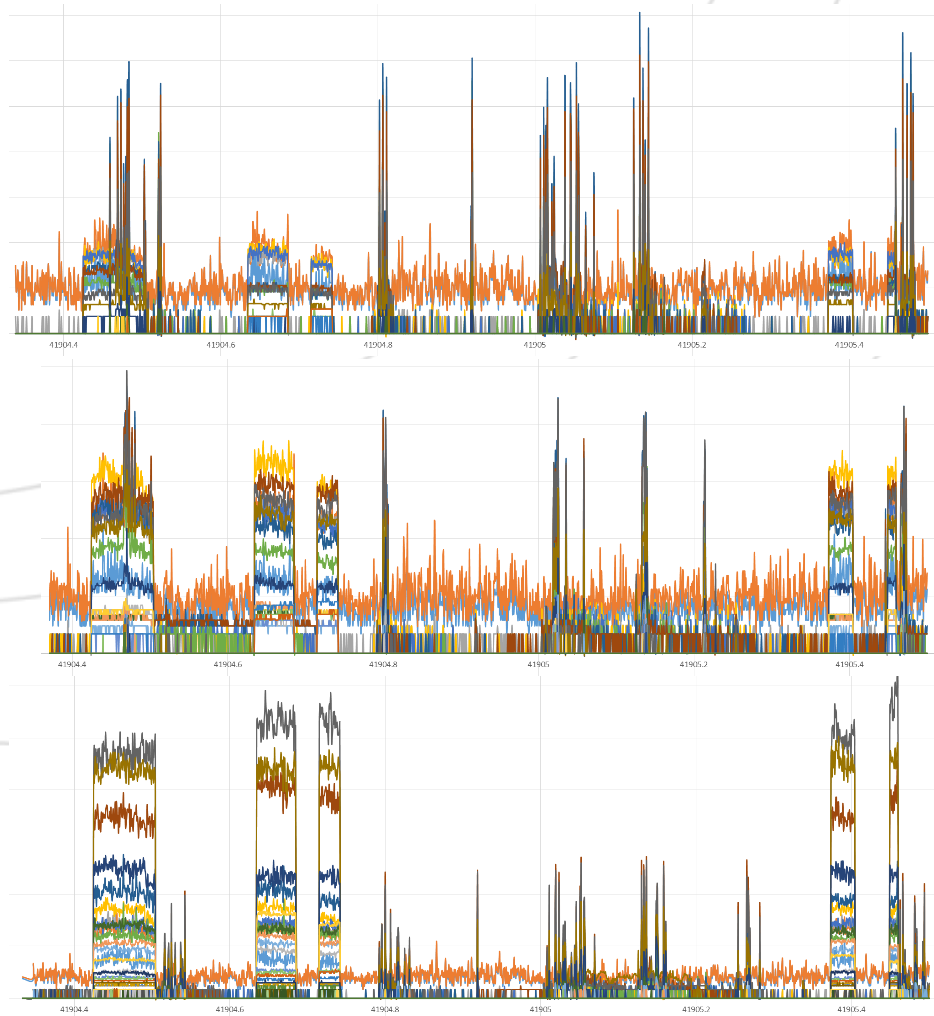
Power Line Communications Effects

- Communications are Non-Periodic (Interharmonics)
- A Single Frequency Might be Avoided
- Similar Frequencies Could Interfere
- Increasing Signal Could Cause Flicker



Interharmonic Measurement Requirements

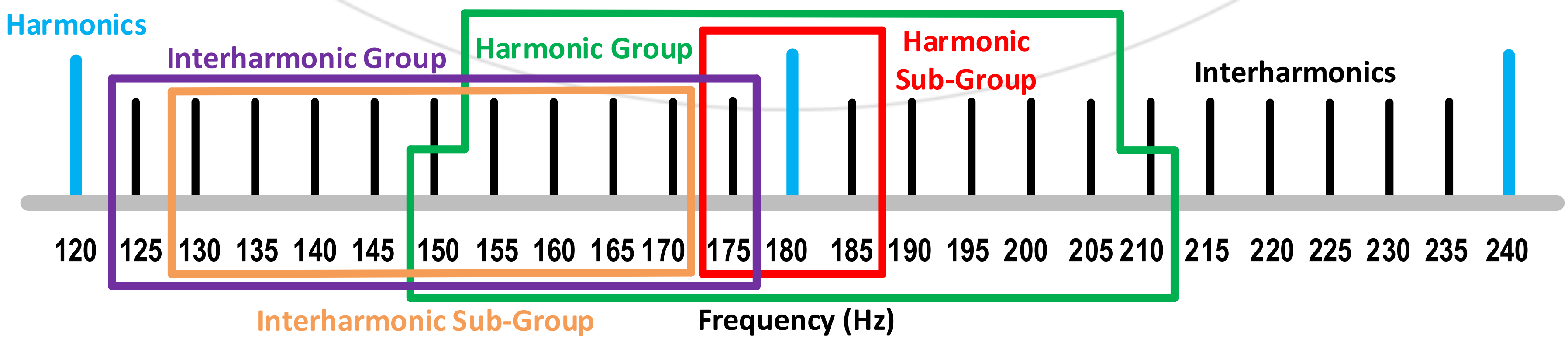
- More Data Intensive than for Harmonics
- Fourier Transform Example: 60 Hz, 50th Harmonic (3000 Hz), and 71.2 Hz Interharmonic
- Harmonic Only: Period = 16.67 msec (one Cycle), Min. Sample Freq. = 4 x 3000 Hz = 12,000 Hz

  Sample Size: 0.0167 Sec * 12,000 Hz = 200
- With Interharmonic: Period = 5 Seconds (0.2 Hz Fundamental Fourier Frequency), Same Minimum Sample Frequency (12,000 Hz)

  Sample Size = 5 Sec* 12,000 Hz = 60,000

Standardized Interharmonic Measurements

- IEC 61000-4-7:2002 General Guide on Harmonic and Interharmonic Measurements and Instrumentation
- For 60 Hz System: 12 Cycle Basis (5 Hz Resolution)
- Based on Concept of Grouping
- Magnitude is Square Root of Sum of Squares of Group Components) Note: Component Angle Information Lost and Waveform Can't be Reconstructed.



Interharmonic Measurement Definitions

- Same Harmonic/Interharmonic Group/Sub-Group Definitions Used for Voltage and Current
- Interharmonic Group Below Fundamental (Sub-Harmonic) is Interharmonic Zero (Usually)
- Interharmonic Group: All 5 Hz “Bins” Between Harmonics

$$IG_N = \sqrt{\sum_{k=1}^{11} Y^2_{(60Hz*N+5Hz*k)}}$$

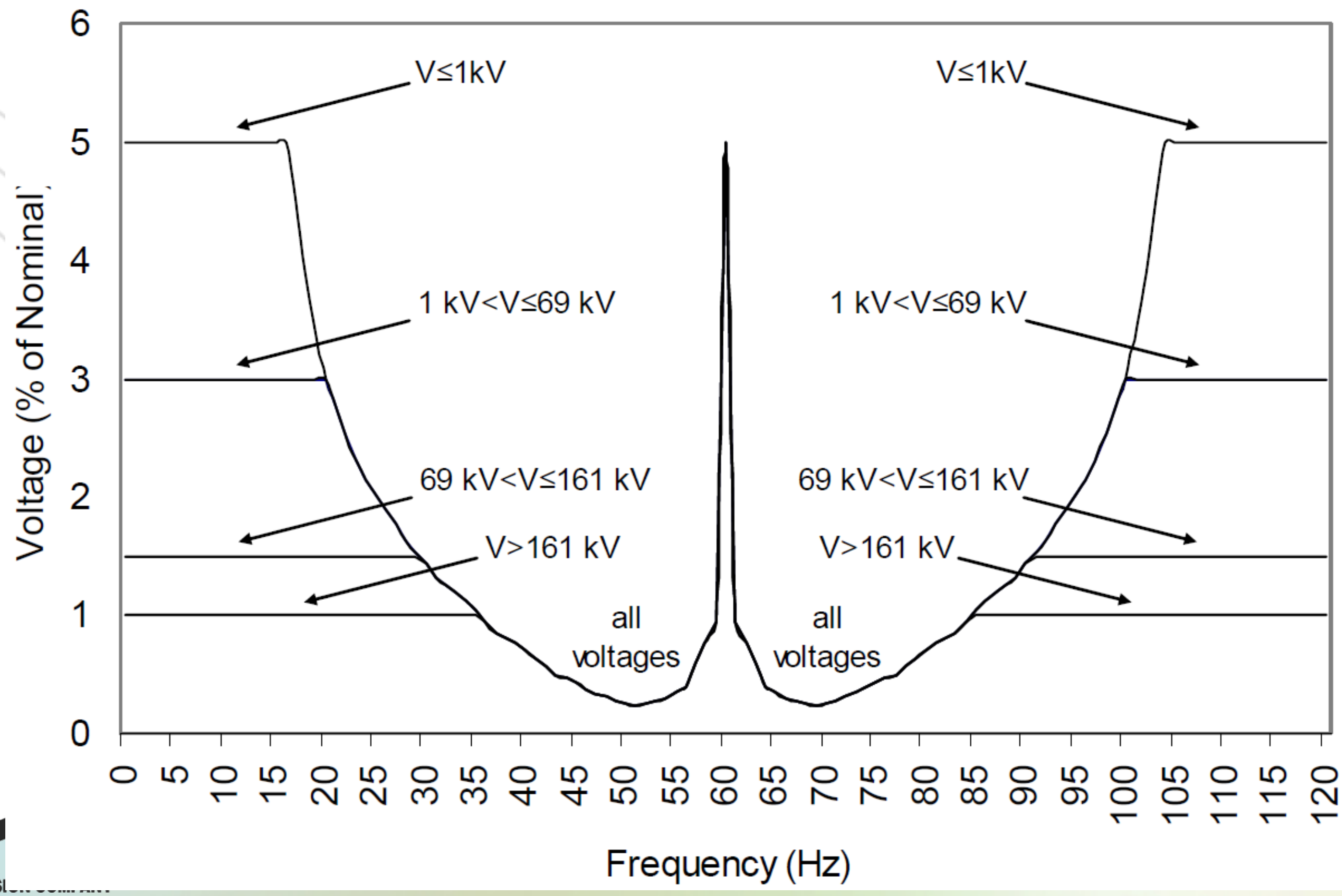
- ATC Combines (RSS) Interharmonic Groups to Give Total Interharmonic Distortion Magnitude

Standards, Guidelines and Limits

- Acceptable Level Depends on Concern: Flicker, Effects Similar to Harmonics or Communications
- IEEE 519-2014 - Informative Flicker Limits
  - Otherwise interharmonic effects should be given "due consideration" and "appropriate interharmonic current limits should be developed on a case-by-case basis."
- IEC 6100-2-2-2 – Very Similar Flicker Limits
  - Not enough knowledge of interharmonics for agreement on compatibility limits beyond those for flicker. Includes some discussion on what additional limits might look like.

IEEE Interharmonic Informative Flicker Limits

- From 0.23% to 5% based on Frequency. (Pst = 1.0)
- No Limits Above the 2nd Harmonic.



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IEC – What Additional Limits Might Be Like

- For Harmonic Like Issues Interharmonic Voltage
  - Equal to Next Higher Even Harmonic Limit
  - IEC Limits 2nd – 2%, 4th – 1%, 6th to 8th – 0.5%. 10th to 50th – (0.25*(10/h) + 0.25)%
  - IEEE Harmonic Voltage Limits: ≤ 69 kV - 3% Individual, 5% Total, 69.001 to 161 kV -1.5% Individual, 2.5% Total, >161 kV - 1% Individual, 1.5% Total
- Ripple Control Receivers (Limited Frequencies)
  - Voltage Limit to 0.2% Near Control Frequency

Interharmonic "Limits" Beyond Flicker

- For Wide Spectrum Communication Systems
- IEC Suggested "Reference" Level
  - 0.2% for Each Interharmonic Group Below 50^{th}
  - 0.3% (200 Hz Bandwidth) from 50^{th} to 9 kHz
- IEEE 519-2014
  - Effect on Communicates Recognized: Due Consideration Should be Given and Limits Developed Case by Case

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Status of Interharmonic Limits

- No Enforceable Limits
- No Consensus on what they should be
- Would Be Significantly Lower than Harmonic Limits
- Would Be Different for Different Phenomena
  - Much Lower for Power Line Communications
  - Do Communications Belong on Power Lines?
- Status Quo: Case By Case Best for Now?
- Difficult to Design Equipment that Produces or is Sensitive to Interharmonics

Interharmonic Mitigation

- Generally More Difficult than Harmonic Mitigation
- Reduce Emission Levels
  - Could Reduce Equipment Benefits
  - Converter Mvar Control, Arc Furnace Efficiency, etc.
- Reduce Load Sensitivity
  - Increase Equipment Ratings (Similar to Harmonics)
  - Timing Other than Power Frequency Synchronization
  - Remove Communication Signals from Power Lines
- Reduce Coupling Between Sources and Loads
  - May be Impractical for Multiple Interharmonics (Filters May Increase Other Frequencies)
  - Low Levels of Distortion May be Difficult to Achieve

Conclusions

- Presently Few Large Interharmonic Sources
  - Use of IGBTs is Increasing
- Standards for Measurement, But No Limits
- Interharmonic Distortion Lower than Harmonic
  - Newer SVC Designs Produce Lower Interharmonic
  - Will this Continue to be True?
- Power Line Communications Require Interharmonic Limits Much Lower than Existing Harmonic Limits
  - Should Power Lines be a Communication Medium?
- Continue Resolving Issues Case-by-Case?
  - No Guide for Equipment (or System) Designs

Questions?

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