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Harmonics: When Considering Critical Power Loads

Eric Bibby

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Agenda

- Definition of Harmonics
- Sources of Harmonics
- Symptoms of Harmonics
- Harmonic Mitigation

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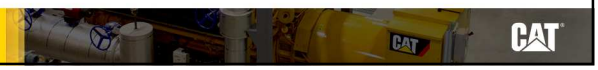

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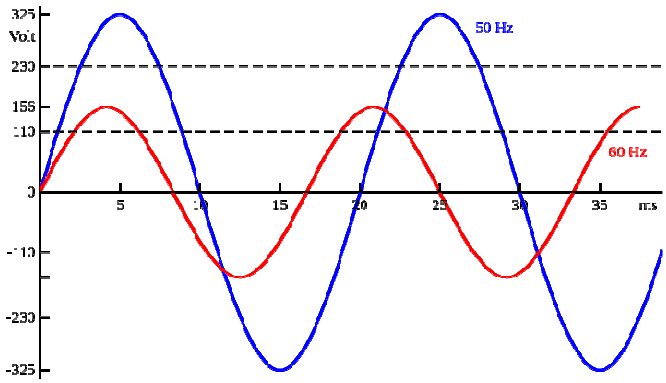
Definition of Harmonics

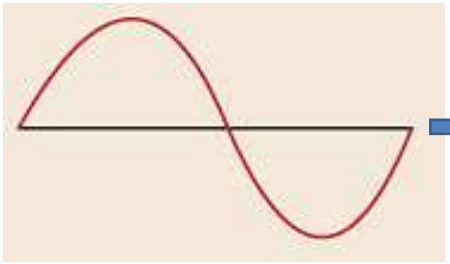
- "Normal" AC voltage wave shape is sinusoidal in time



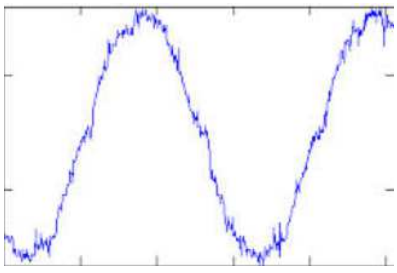
Definition of Harmonics

- If the wave form is not a perfect sinusoidal wave, we refer to it as being distorted, and the extent to which it deviates is called distortion.

Fundamental Sine Wave

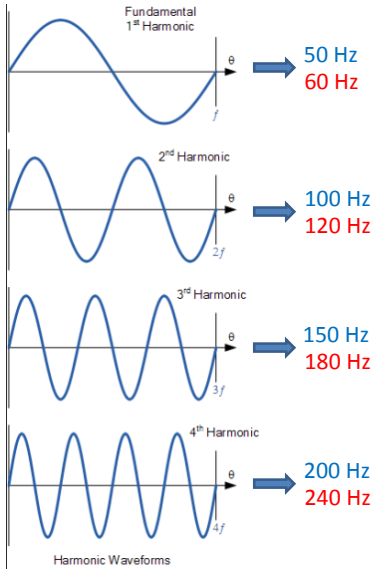


Distorted Sine Wave



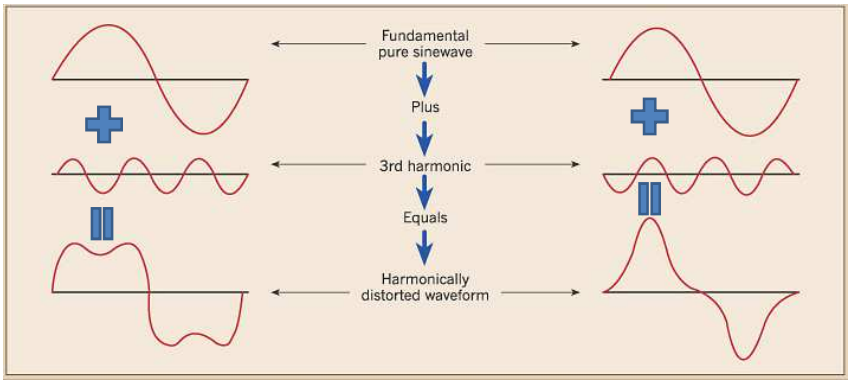
Definition of Harmonics

- Harmonics - multiples of the fundamental wave form
- Harmonic Content – measure of the harmonics in a waveform



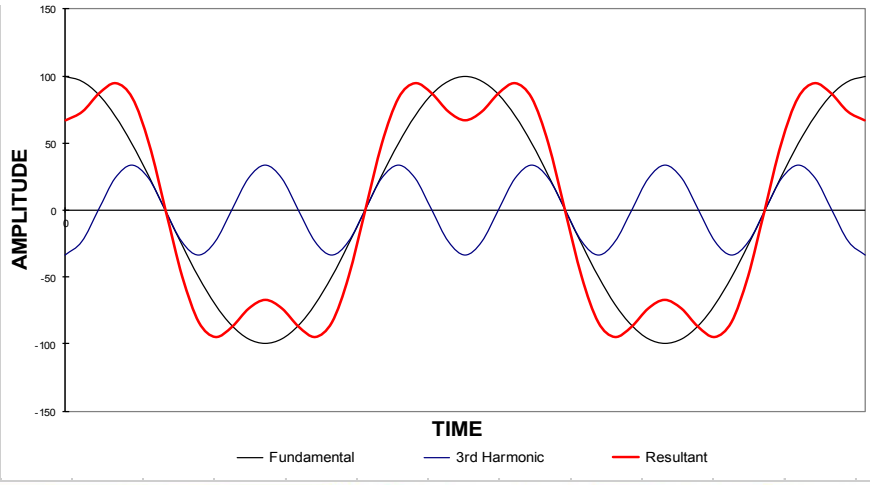
Definition of Harmonics

- The resultant waveform is the combinations of the fundamental waveform and all harmonic waveforms



Effect of Third Harmonic

Superimposed on Fundamental



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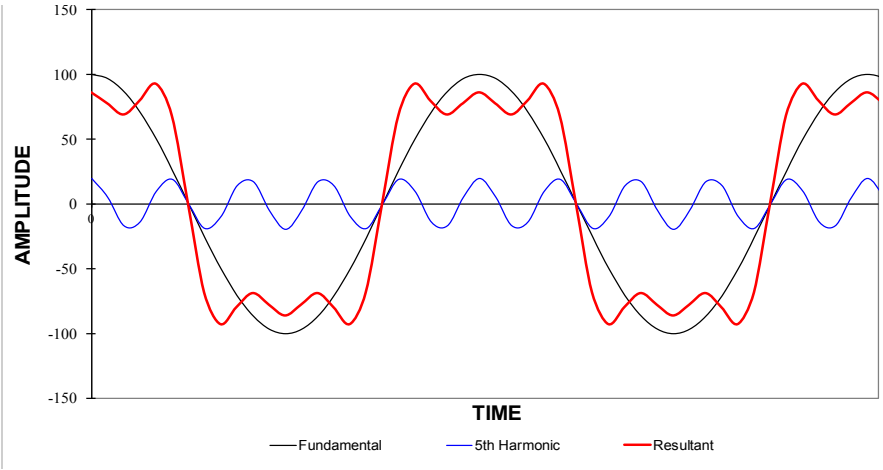
Waveform Distortion

Effect of 3rd and 5th Harmonics



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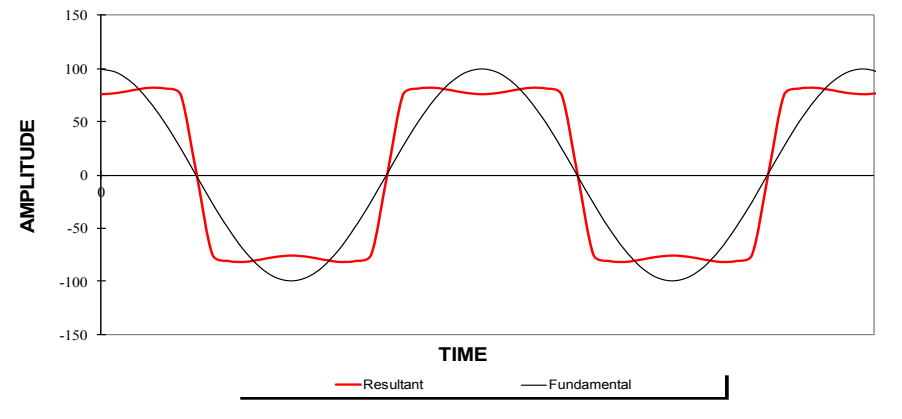
Waveform Distortion

Effect of 3rd through 19th Harmonics



THD = Total Harmonic Distortion $\frac{\sqrt{(20^2+15^2+....)}}{220} x100\% = 11.36\%$

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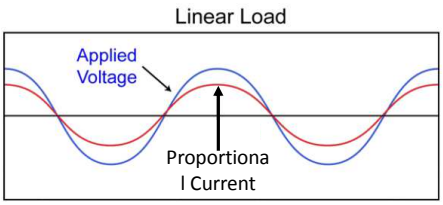
Sources of Harmonics

- Linear Load – Current draw is proportional to voltage and does not produce harmonics



- Linear Loads Examples
  - Resistance heaters
  - Load banks
  - Incandescent lighting
  - Transformers (unsaturated)
  - Induction and Synchronous Motors
  - Electromagnetic Devices

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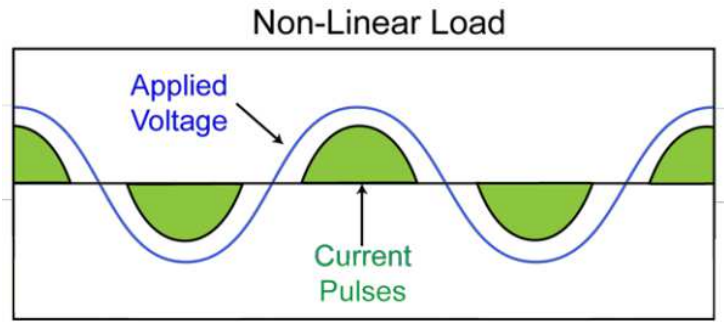
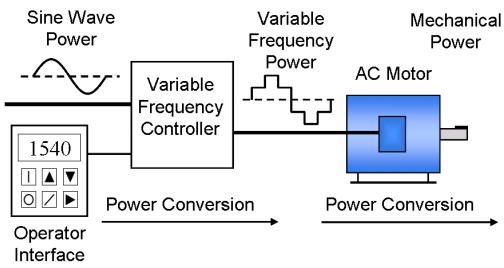
Sources of Harmonics

- Non-Linear Loads - current draw is disproportional to voltage



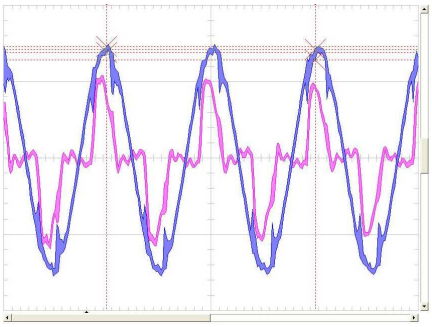
Sources of Harmonics

- Non Linear Load Examples
  - Variable Voltage AC Controls
  - Saturating Reactors and Transformers
  - Radar Stations
  - Variable Frequency Drive (VFD)



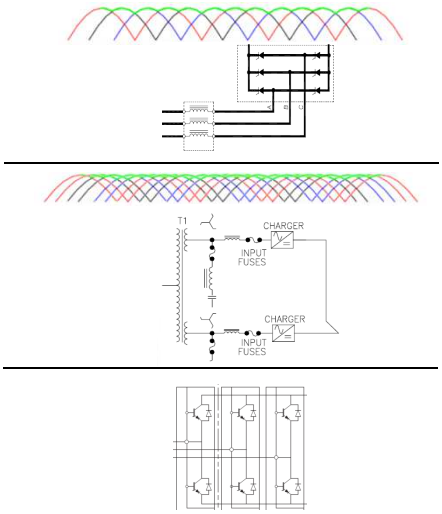
Sources of Harmonics

- Additional Non-Linear Loads
  - Computers (SMPS)
  - X-Ray Machines
  - Fluorescent & Gas Discharge Lighting
  - Uninterruptible Power Supply (UPS)
  - Silicon Controlled Rectifiers (SCR)
  - LED Lighting



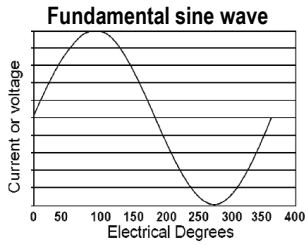
Sources of Harmonics

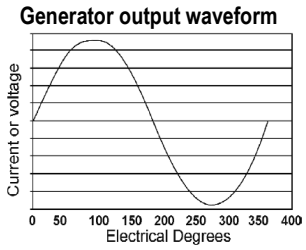
- SCR Rectifiers
  - 6 Pulse
    - 6 SCR's
    - THDI 27% - 30%, no Filter
  - 12 Pulse
    - 2 x 6 SCR's
    - THDI 16%, no Filter
- IGBT Rectifiers & PFCs
  - IGBT technology
  - THDI 3%, no Filter



Sources of Harmonics

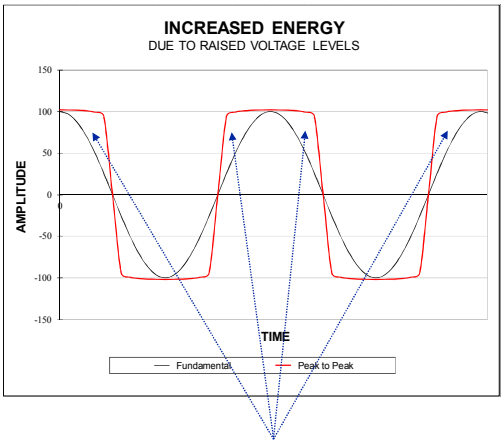
- Generator Design
  - Minimal harmonic distortion is produced by the generator
  - Cat® Design Criteria
    - Less than 3% Individual Harmonic
    - Less than 5% Total Harmonic Distortion (line to line)





Symptoms of Harmonics

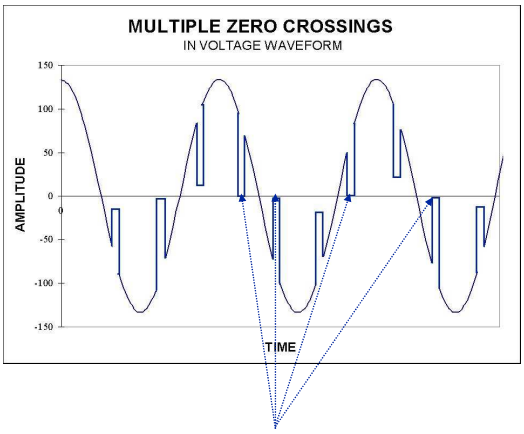
- Generator heating
- Motor heating
- Transformer heating
- Tripping Thermal Breakers



These areas represent 41% more energy in Square wave compared to standard Sine wave

Symptoms of Harmonics

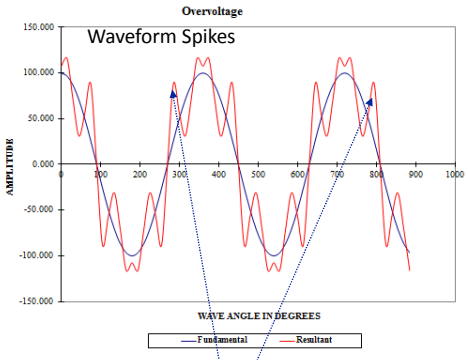
- System stability
- Voltage regulator stability
- False metering readings



Multiple zero crossings

Symptoms of Harmonics

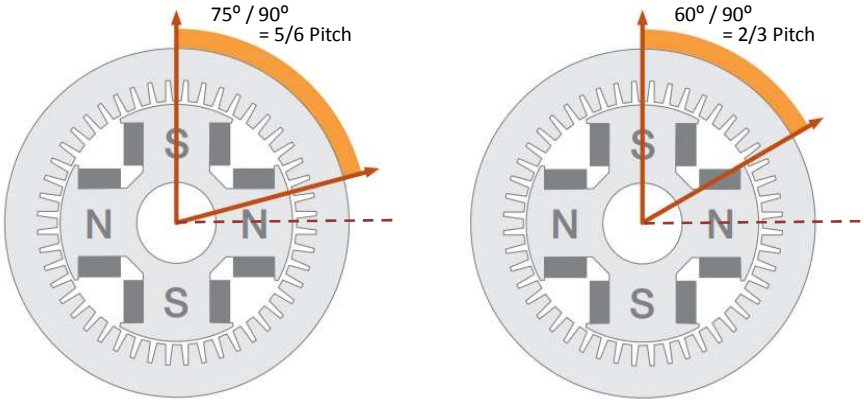
- False triggering
- Blown fuses
- Blinking lights
- Capacitor failure
- Computer malfunction
- Conductor failure



Spikes

Harmonic Mitigation

Fundamental & Harmonic Voltage verses Generator Pitch



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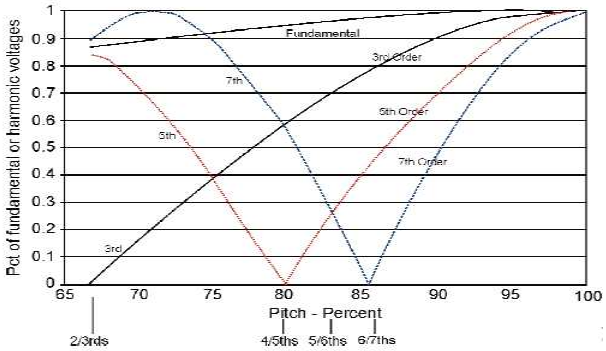
Harmonic Mitigation

Fundamental & Harmonic Voltage verses Generator Pitch



Pitch	Fund	3rd	5th	7th
2/3	0.866	0	0.866	0.866
4/5	0.951	0.588	0	0.588
5/6	0.966	0.707	0.259	0.259
6/7	0.975	0.782	0.434	0

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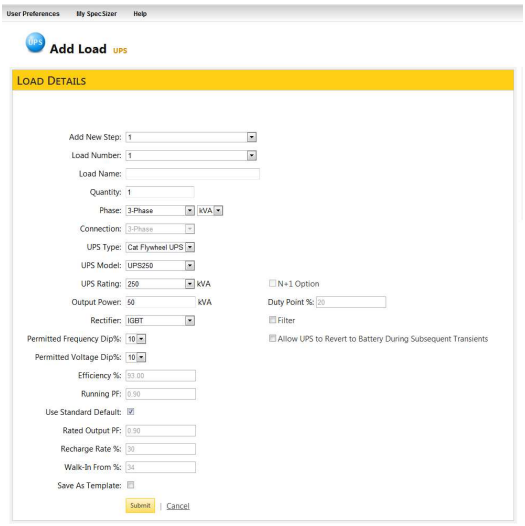
Harmonic Mitigation

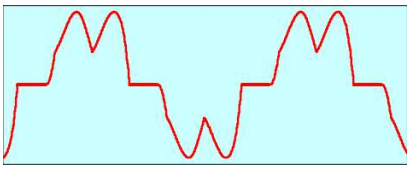
- Generator Sizing



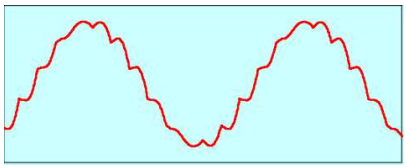
Harmonic Mitigation

- Transformers
  - K-factor Transformers
    - Designed to handle the heat generated by harmonics
  - Phase Shifting Transformers
    - Loads are phase shifted to cancel harmonics

Without Transformer

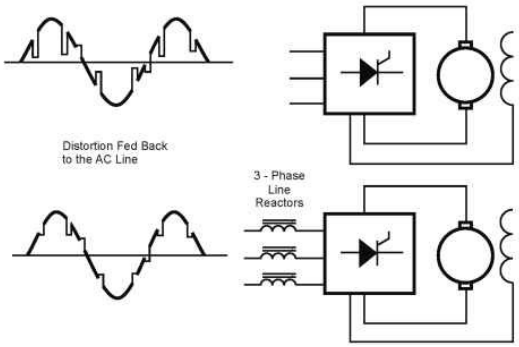


With Transformer



Harmonic Mitigation

- Filters - Line Reactors
  - Simple, Low Cost Solution
  - Typically used on Motor Drives



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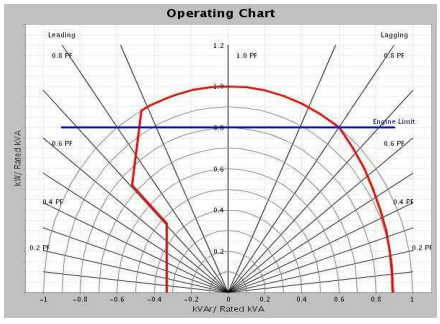
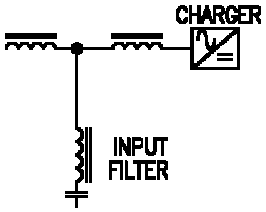
Harmonic Mitigation

- Filters – Passive Tuned
  - Tuned to eliminate specific harmonics
  - Can be Capacitive or Inductive
  - Can appear as leading pf on lightly loaded systems





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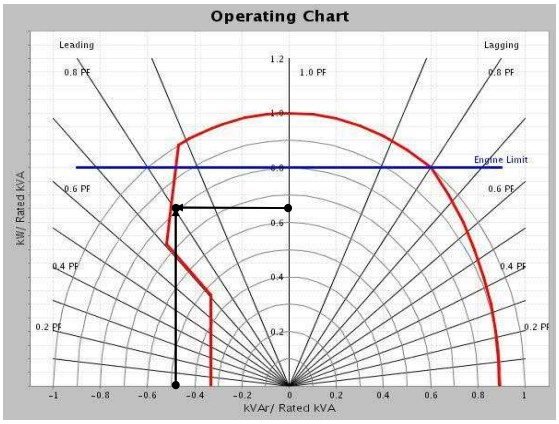
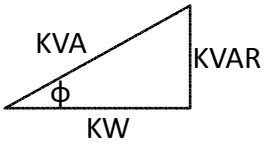
Harmonic Mitigation

- Location on the Curve



Given
Genset rating = 2000 KVA
pf = 0.80 leading
reading = -975 KVAR



cos ϕ = pf = .80
ϕ = 36.87°

KVA = KVAR / sin ϕ = 1625

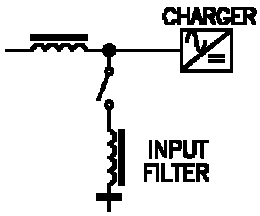
KW = KVA x pf = 1300

KVAR / rated KVA = 0.4875

KW / rated KVA = 0.65

Harmonic Mitigation

- Filters – Switched Passive Tuned
  - Utilizes Passive filter with contact
  - Filter disengaged at low loads
    - Disconnects at 30%
    - Reconnects at 40%

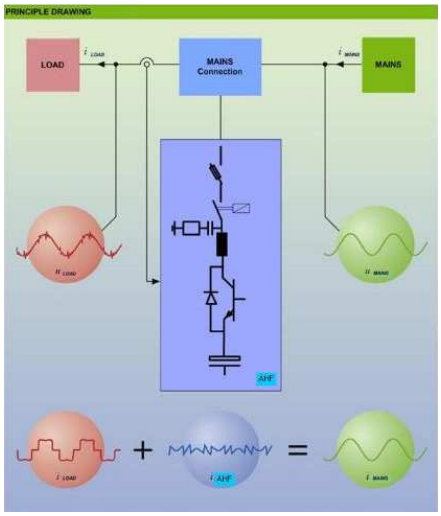


  - As load decreases, the harmonics as a percentage of load will increase

	25% Pn	50% Pn	75% Pn	100% Pn
THDI (in %)	12%	9%	6%	4%

Harmonic Mitigation

- Filters – Active or Dynamic
  - Monitor and measure harmonic current
  - Cancel harmonics produced by the load
  - Power factor correction



Harmonic Mitigation

Reference:

- Caterpillar A&I Guides
  - Generator Systems - LEBW4993
  - EP Applications, Engine & Generator Sizing – LEBW5294
- SpecSizer

Conclusion

- Harmonics are a distorted multiple of the fundamental sine wave
- Harmonics can cause various system related issues
- Obtain complete load details when sizing generator and generator set
- Proper system design can help avoid or eliminate problems

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