

ECE 528 – Understanding Power Quality

<http://www.ece.uidaho.edu/ee/power/ECE528/>

Paul Ortmann
portmann@uidaho.edu
208-733-7972 (voice)

Lecture 20

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Today...

- Harmonics fundamentals
 - Harmonic phase sequence
 - Triplen harmonics
 - Harmonic sources
 - Locating harmonic sources

References:

- [1] "Fundamentals of Electric Power Quality" by Surya Santoso
[2] "Harmonics and how they relate to Power Factor", W. Mack Grady and Robert J. Gilleskie, 1993
<http://users.ece.utexas.edu/~grady/POWERFAC.pdf>

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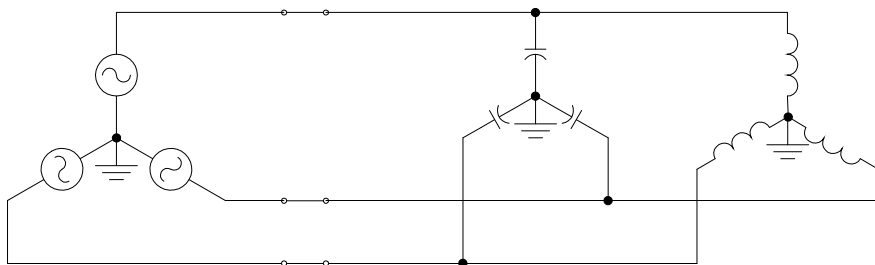
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Harmonic phase sequence

- Remember - unbalanced 60Hz voltages can be broken down into positive, negative, and zero-sequence components
- Harmonic voltages and currents, even if perfectly "balanced", are also classified as either positive, negative, or zero sequence

Harmonic phase sequence

- Harmonic phase sequence becomes important for motors and on grounded-wye systems

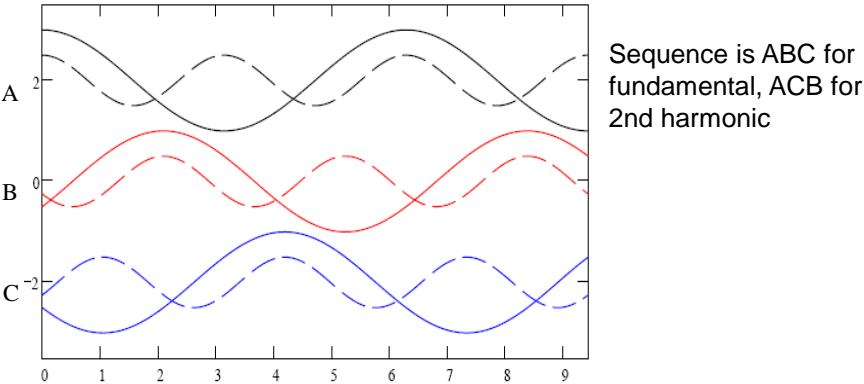


Harmonic phase sequence

Positive	Negative	Zero
1	2	3
4	5	6
7	8	9
10	11	12
13	14	15
16	17	18

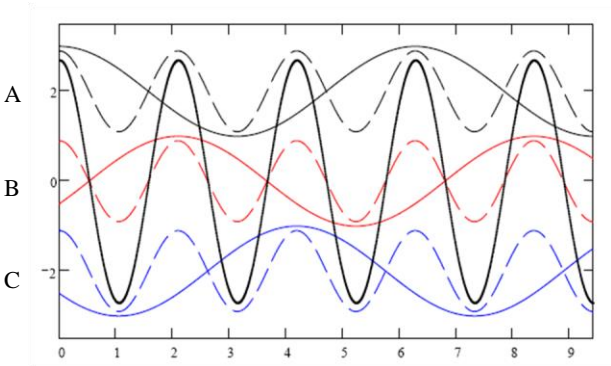
Harmonic phase sequence

- A graphical example of harmonic phase sequence
 - Three-phase fundamental and 2nd harmonic waveforms



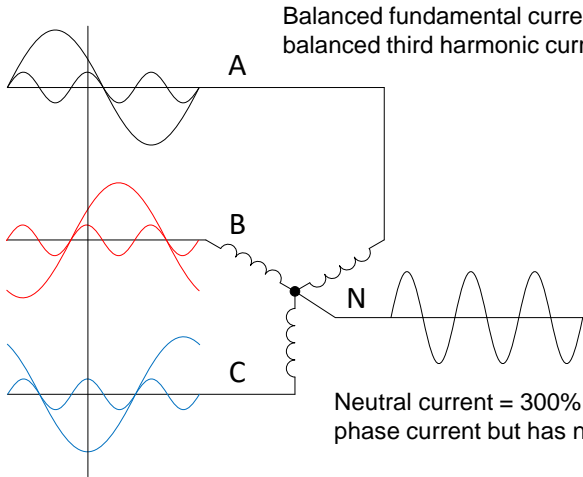
Triplen harmonics on three-phase systems

- Triplen harmonics in a three-phase system
 - Three-phase fundamental and 3rd harmonic waveforms



Third harmonic waveforms are in phase – they add in the neutral

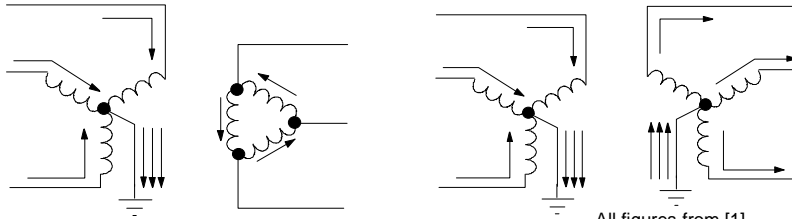
Triplen Harmonics: Odd multiples of the third harmonic



Balanced fundamental currents sum to zero, balanced third harmonic currents are in-phase

Neutral current = 300% of third harmonic phase current but has no fundamental current

Triplen harmonics:



- Balanced triplen harmonic currents are blocked by delta transformer windings
- Unbalanced harmonic currents and voltages may not produce the same effects as their balanced counterparts.
 - Unbalanced harmonic voltages and currents can be broken down into a set of positive, negative, and zero sequence harmonic symmetrical components – more complex analysis

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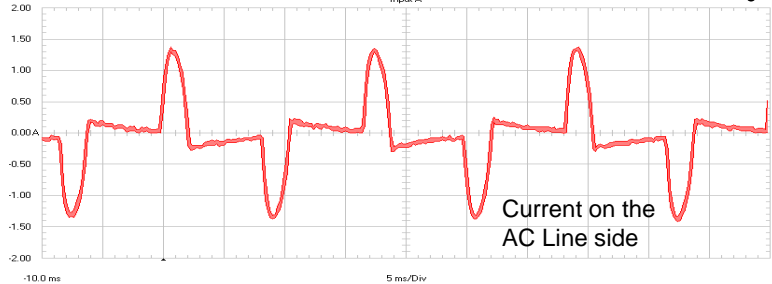
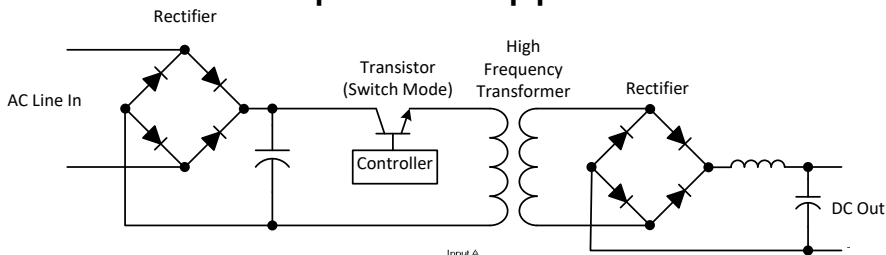
Harmonic sources: Commercial loads

- Single-phase power supplies
 - Older power supplies stepped down AC supply first with a transformer, then rectified it
 - What are the advantages and disadvantages of this approach?
 - Now most electronic devices use switched mode power supplies.
 - Advantages and disadvantages?

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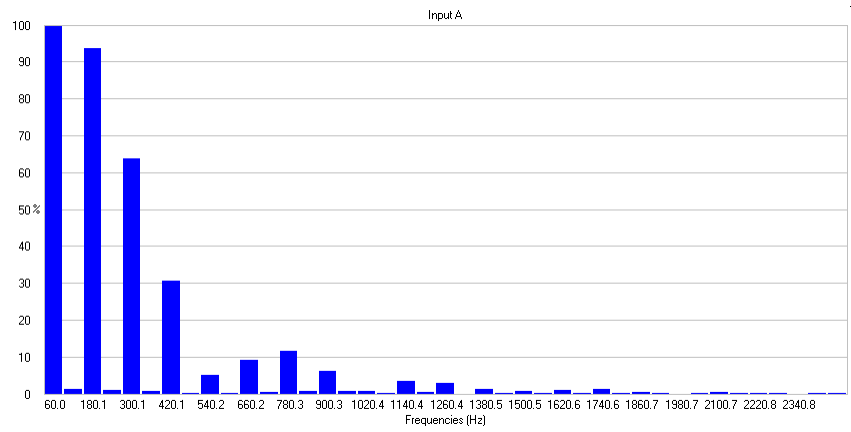
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Switch-mode power supplies



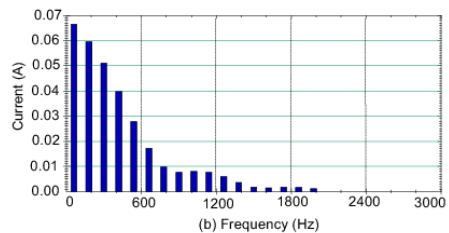
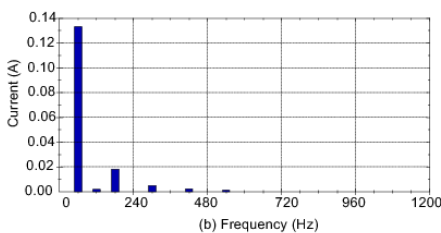
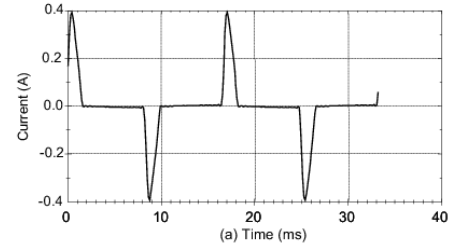
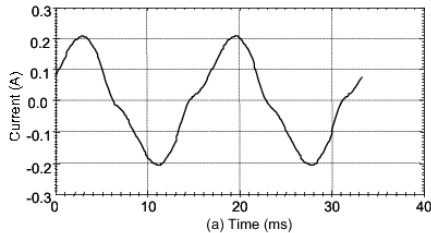
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Switch-mode power supply harmonic spectrum



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Other commercial-load issues: magnetic and electronic ballasts



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All figures from [1]

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Other commercial-load issues:

- Efficiency is driving the use of ASDs in HVAC systems
- Harmonic issues need to be considered in building electrical systems
 - Could be a significant problem when older buildings become home to computers and modern lighting systems

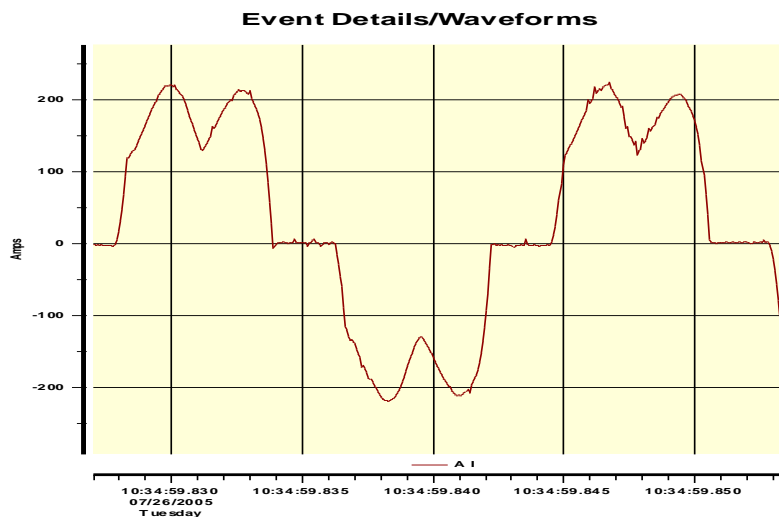
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Industrial loads

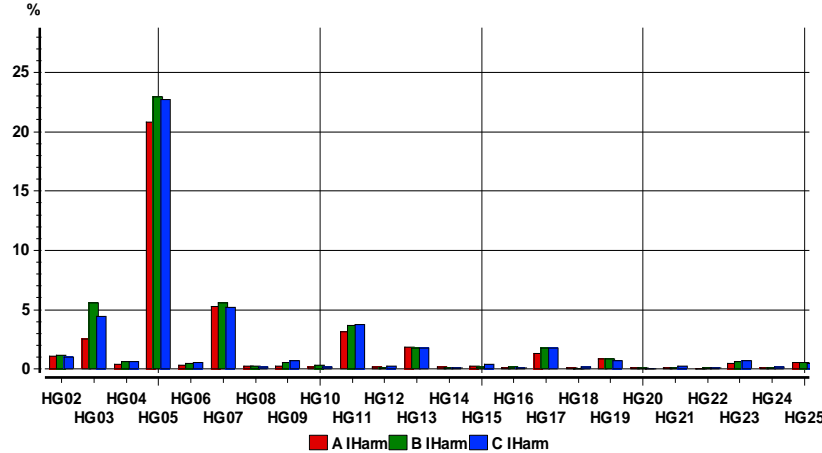
- Three-phase power converters
 - Variable speed drives, AC or DC, employing six-pulse rectifiers are generally the most common source of harmonics in industrial facilities
 - Triplen harmonics not a problem – three-phase drives don't produce them
 - PWM ASD is the most popular (Pulse-Width-Modulation)

Harmonic sources – Variable speed drive



Harmonic sources – variable speed drive

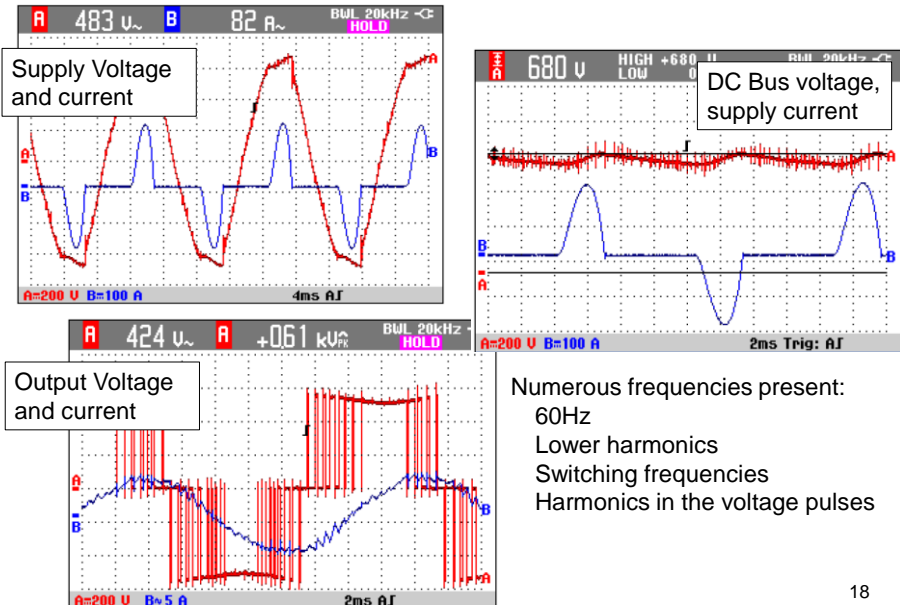
Waveform harmonics



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Some PWM drive waveforms

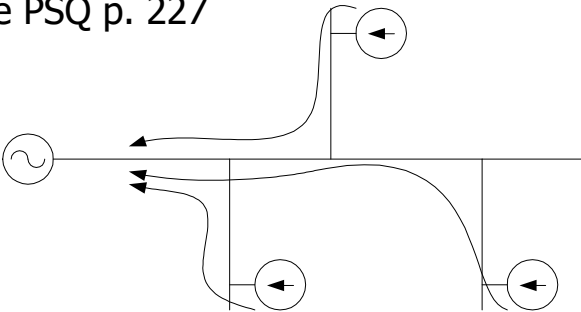


Numerous frequencies present:
 60Hz
 Lower harmonics
 Switching frequencies
 Harmonics in the voltage pulses

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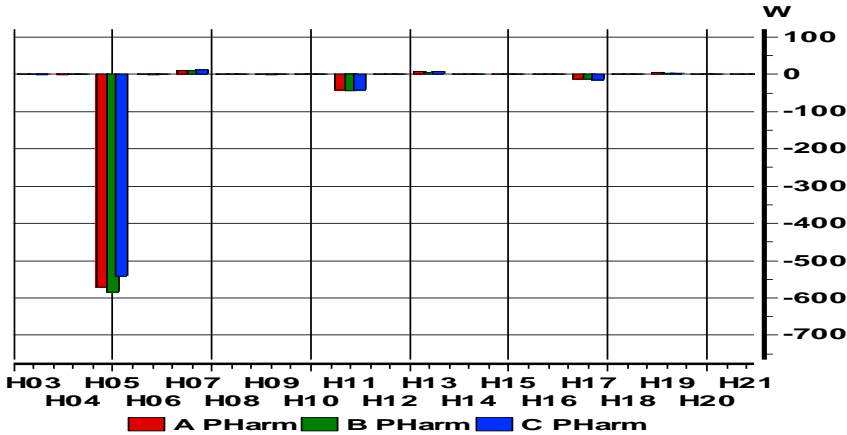
Locating harmonic sources

- Method described in the text:
 - Follow the current “downstream” to the load
 - See PSQ p. 227



Another way to find harmonic sources

Waveform harmonics



Next time...

- System response
- Effects of harmonic distortion
- Interharmonics