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# ECE 528 – Understanding Power Quality

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Lecture 19





## Today…

- Harmonics fundamentals
  - Harmonic Distortion
  - Voltage and Current Distortion
  - Power system quantities with harmonics
  - Harmonic Indices
  - Texts
    - FPQ chapters 6 and 7
    - PSQ chapters 5 and 6

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# Text updates and announcements

- Both texts mention IEEE-519-1992: *IEEE Recommended Practice and Requirements for Harmonic Control in Electric Power Systems.* The latest version of this standard is IEEE-519-2014.
  - Get a copy of this standard from the IEEEXplore site via the UI library web site.
- There is a facebook page for UI EE Power students.
  "uidaho-ece graduate power courses"



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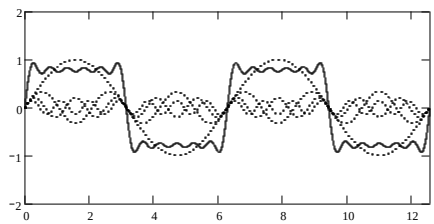
# Harmonics – quick review

- Any repetitive waveform can be expressed as a sum of sine waves at frequencies that are integer multiples (HARMONICS) of the fundamental frequency of the waveform.
- This allows us to use superposition in analysis



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# General Principles

- Harmonic problems are often continuous in nature
  - Heating
  - Interference
- Some harmonic distortion in the supply voltage may be found almost everywhere
- Actual problems due to harmonics are not as common as problems due to voltage sags
- Percentage of nonlinear load is growing



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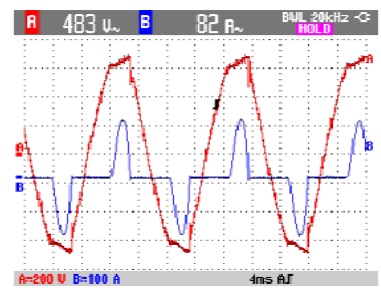
# Harmonic distortion

Cause: "non-linear" loads

Current is not a linear function of the applied voltage at a given frequency, and is therefore distorted




Result:

Distorted current passing through frequency-dependent system impedances → distorted voltage

Distorted voltage supplied to linear loads → distorted currents in other parts of the electrical system

If load is frequency-dependent (inductive, capacitive, both) current distortion may be higher than voltage distortion even for linear loads

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## Harmonics in power systems - overview

- Analysis range – usually up to 25th or 50th
- Most non-linear elements in the system are end-user loads - power electronics
- When referring to "harmonics" we may need to specify current or voltage
- Because voltage distortion depends on system impedance, harmonic analysis is location-specific



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## Power system quantities with harmonics

- Apparent power (S) – Volt-Amps, VA

$$S = V_{rms} \cdot I_{rms}$$

  - Not harmonic-specific or dependent
    - Could have voltage and current waveforms made up of different harmonics

$$V_{rms} = \sqrt{\sum_{h=1}^{h_{max}} \left( \frac{1}{\sqrt{2}} \cdot V_h \right)^2}$$

$V_h$ is the peak magnitude of the individual harmonic voltages.

FPQ includes several apparent power and distortion power values; see pgs. 208-212.

## Power system quantities with harmonics

- Active power (P) – Watts, W

$$P = \frac{1}{T} \cdot \int_0^T v(t) \cdot i(t)\, dt \qquad P = \sum_h \left( V_{h\_rms} \cdot I_{h\_rms} \cdot \cos\theta_h \right)$$

  - Harmonic specific – only current in phase with, **and** at the same frequency as the voltage can deliver useful work: REAL power
  - All other combinations (different frequencies and/or phase shift) create apparent or distortion power only
    - ALL current contributes to system losses though: $I^2R$
  - Some instruments or software distinguish fundamental frequency power from harmonic contributions
  - It is usually accurate enough to only use fundamental values when calculating active power (P)
  - ***Download and experiment with PF Teaching Tool and Power Quality Teaching Toy via class website.***





## Power system quantities with harmonics

- Our texts don't agree on the definition of some power values under nonsinusoidal conditions.
  - Distortion power as shown on PSQ page 206 is no longer used.
  - See IEEE standard 1459-2010: *IEEE Standard Definitions for the Measurement of Electric Power Quantities Under Sinusoidal, Nonsinusoidal, Balanced, or Unbalanced Conditions*
  - More common terms will be described in class

## Power system quantities with harmonics

- Note that S, the apparent power was not harmonic specific
- It is possible, in theory, to have apparent power (S), without real power (P) or reactive power (Q)
- "Distortion Power" resolves this issue





## Power Factor

Displacement power factor -Due to phase shift between V and I at fundamental frequency

$$DPF = \cos\theta$$

True Power Factor – includes harmonics

$$PF = \frac{P}{S} = \frac{Active\_power}{Apparent\_power}$$

True Power Factor may also be called "Power Factor" or "Total Power Factor"

# Total harmonic distortion

- THD – common measure of harmonic distortion

$$THD = \frac{\sqrt{\sum_{h=2}^{h_{max}} M_h^2}}{M_1} = \frac{\sqrt{M_2^2 + M_3^2 + .. + M_{hmax}^2}}{M_1}$$





# Distortion Power Factor

- Relates RMS of the distorted current, including the fundamental current, to RMS of the fundamental current only (not in texts)

$$\frac{I_1}{I_{RMS}} = PF_{dist} \qquad I_{RMS} = \sqrt{\sum_{h=1}^{h_{max}} I_h^2} = I_1 \cdot \sqrt{1 + THD_I^2}$$

$$PF_{dist} = \frac{1}{\sqrt{1 + THD_I^2}}$$

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# The impact of harmonic current on true power factor

- Typical power systems:
  - $P_1 \approx P_{total}$ : nearly all real power flow is at the fundamental frequency
  - Voltage distortion is low
- Using these generalities, we can say:

$$PF_{.true} = \frac{P_{.1}}{V_{.1rms} \cdot I_{.1rms}} \cdot \frac{1}{\sqrt{1 + THD_{.I}^{2}}} = PF_{.disp} \cdot PF_{.dist}$$

Therefore current distortion results in a lower true power factor



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# Total demand distortion

- TDD – addresses the fact that very small and very distorted currents are not normally a problem

$$TDD = \frac{\sqrt{\sum_{h=2}^{h_{max}} I_h^{2}}}{I_L}$$

$I_L$ = peak demand load current (RMS) at fundamental frequency

# Next time…

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

References:
[1] "Harmonics and how they relate to Power Factor", W. Mack Grady and Robert J. Gilleskie, 1993
http://users.ece.utexas.edu/~grady/POWERFAC.pdf