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College of Engineering

ECE 528 – Understanding Power Quality

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

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Today…

- Midterm overview
- Harmonic studies
- An example
- Communicating results

Harmonic studies (PSQ section 6.4)

- Why?
  - Solve or prevent problems
    - Voltage distortion
    - Damaged equipment
  - Evaluate changes
    - New capacitors
    - New non-linear loads
  - Study solution alternatives
    - Filters
    - Relocating capacitors

Harmonic study procedure

- Define the goal, problem, or question
  - Why do fuses on a capacitor bank keep blowing?
  - The phone company is reporting 540Hz interference.
  - Can we add an 1800kVAR capacitor bank near this industrial customer?
  - A customer wants to install a 300Hp motor with a variable speed drive.

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Harmonic study procedure

- Measure/record
  - Existing issue? – measure or record it directly
  - Proposal? – get "before" conditions – existing voltage or current distortion.
- Simulate the system
  - Computer models - include system variations
  - Proxy loads – Extrapolate from other nearby loads with similar characteristics
- Check computer simulation with measurements
- Evaluate solutions
  - economics, effectiveness, side-effects
- Verify solution
  - more measurements/recordings

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A few general notes on engineering analysis

- Develop some instinct about the problem
  - Explore relationships between variables and unknowns
- Make the question easier
  - Make some assumptions
  - Find the range the answer is in
- Only answer the question
  - Real questions are often "a or b", or "is a>b"
  - Two options? – only do enough analysis to pick one and exclude the other
- Start with the answers
  - Know what constitutes "normal"
  - Just make a "guess" and see what analysis of that possible solution suggests
- Check the result
  - Plug in your solutions

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Modeling harmonic sources

- Computer simulation is now the norm
  - Harmonic studies, load flow, fault studies
- Impacts of simulation characteristics
  - Harmonic loads modeled as fixed-spectrum current sources
    - Voltage distortion is affected by current distortion.
    - Current distortion is affected by voltage distortion.
      - Is the assumption that the harmonic spectrum is fixed a conservative assumption?

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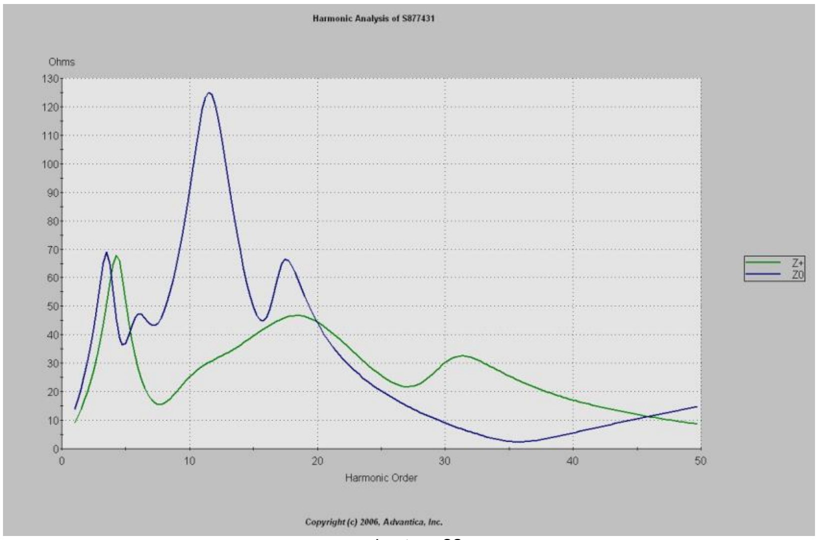
Computer modeling – frequency scan



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Modeling harmonic sources

- Sources of data
  - Measure the current directly
    - Existing loads
  - Use manufacturer's data
    - Proposed loads
  - Make assumptions
    - Table 6.3 from PSQ

$$I_h = \frac{I_1}{h}$$

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A real-world example

- Question:
  - Does the customer meet IEEE-519?
- Data needed:
  - PCC – define it
  - Demand current
  - Short-circuit current
  - Voltage
  - Harmonic spectrum of the load current

Example data

- Customer is primary-metered at $12.47kV_{L-L}$ (3-phase AC RMS)
  - PCC is at primary meter on high voltage side of the transformers at the facility
- From revenue metering, or recording
  - Demand current I_L, is: 244A
- From computer fault analysis
  - Short circuit current, I_{SC}, is: 3,555 A
  - Which row of IEEE-519, table 2 applies?
    (Table 7.2, pg 241 of FPQ is the same.)

IEEE 519 current distortion limits (from 2014 edition, Table 2)

Maximum harmonic current distortion in percent of I_L						
Individual harmonic order (odd harmonics)[a, b]						
I_{SC}/I_L	$3 \le h < 11$	$11 \le h < 17$	$17 \le h < 23$	$23 \le h < 35$	$35 \le h \le 50$	TDD
< 20[c]	4.0	2.0	1.5	0.6	0.3	5.0
$20 < 50$	7.0	3.5	2.5	1.0	0.5	8.0
$50 < 100$	10.0	4.5	4.0	1.5	0.7	12.0
$100 < 1000$	12.0	5.5	5.0	2.0	1.0	15.0
> 1000	15.0	7.0	6.0	2.5	1.4	20.0

[a]Even harmonics are limited to 25% of the odd harmonic limits above.

[b]Current distortions that result in a dc offset, e.g., half-wave converters, are not allowed.

[c]All power generation equipment is limited to these values of current distortion, regardless of actual I_{sc}/I_L.

where

I_{sc} = maximum short-circuit current at PCC

I_L = maximum demand load current (fundamental frequency component) at the PCC under normal load operating conditions

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Analyzing the recorded harmonic data

- The power quality recorder can only measure actual current and voltage
  - We need to calculate values involving I_L separately
  - Spreadsheet – Calculate:

$$\%I_L = \frac{I_h}{I_L} \cdot 100\% \qquad TDD = \frac{\sqrt{\sum_2 I_h^2}}{I_L} \cdot 100\%$$

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Harmonic testing: non-peak conditions

- Use current harmonic limits in Amps based on $I_{L,}$; the maximum normal (fundamental) load current

Harmonics > limits

- More load won't change the result, regardless of the nature of that additional load.

Harmonics < limits

- More linear load won't change that
- Adjust for missing non-linear load if necessary
  - Compare amount of missing non-linear load to test results
  - May use multiplier on recorded harmonic current to account for missing load

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Analyzing the data – 1-week 95th percentile values

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h	Amps	%	h_pu^2
1	244	100	1
3	3.172	1.3	0.000169
5	22.936	9.4	0.008836
7	7.808	3.2	0.001024
9	1.22	0.5	0.000025
11	5.124	2.1	0.000441
13	4.148	1.7	0.000289
15	0.732	0.3	0.000009
17	0.732	0.3	0.000009
19	0.488	0.2	0.000004
21	0.488	0.2	0.000004
23	0.244	0.1	0.000001
25	0.244	0.1	0.000001

$$TDD = \frac{\sqrt{\sum_{2} {I_h}^2}}{I_L} \cdot 100\%$$

$$TDD = 10.4\%$$

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Conclusions of this analysis

- This customer exceeds the IEEE 519 current harmonic distortion limits for the 5th, and 11th harmonics, and for the TDD.
- Now we have to tell the customer
  - Explain your analysis
  - Help them reach the same conclusion
  - Explain their options and why action is important

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Next time…

- Harmonic control devices
- Filters
- Filter design example