University of Idaho
College of Engineering

ECE 528 – Understanding Power Quality

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

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

Lecture 22

Today…

- Homework 4 pointers
- Harmonic analysis PSQ Ch. 6, FPQ Ch. 7
  - PCC
  - Harmonic distortion evaluations
  - Controlling harmonics
    - Principles
    - Utility control
    - End-user control

University of Idaho

HW4, Prob. 2

- (See PSQ section 5.7.3.(pg. 225))
- Saturable reactance is not linear
  - Relationship between V and I changes
  - Effect may be pronounced during primary overvoltages
  - An interesting paper on the subject:

  Modeling of Harmonic Sources – Magnetic Core Saturation, by Yilu Liu and Zhenyuan Wang

  http://www.calvin.edu/~pribeiro/IEEE/ieee_cd/chapters/pdffiles/c4pdf.pdf

University of Idaho

HW4, Prob. 3

- Note fundamental currents of drive and total load are different.
- Table only includes drive current
- Assume the rest of the current is only 60Hz.
  - 3.1 – THD for the drive ONLY
  - 3.2 – TDD is for the whole load
  - 3.3 – ALL harmonics, in amps. Percent is O.K. in addition but not instead, and percent of what? (Also, don't forget evens)
  - 3.4 – Comply with IEEE-519? Yes or no, and if not, include a list of non-compliant harmonics

HW4, Prob. 4

- Same drive load as prob. 3. Extra linear load is removed.
- See lecture 21, slides 9 – 21
- 4.1 - Could use table to calculate per-unit K-factor and then convert that to K-factor for rated current.
- See text for actual available K-factor ratings.
- 4.2 – Be conservative in choice of P_{EC-R}
- F_{HL} can be calculated from a table

Harmonics - Division of responsibility

- Utility
  - Limit voltage distortion: IEEE 519-2014, Table 1
    - Individual harmonic limits (% of nominal fundamental)
    - THD limits
      - IEEE-519-2014 allows more voltage distortion than 1992 edition.
    - How:
      - Monitor system and users
      - Avoid resonances
      - Educate users

University of Idaho

Division of responsibility

- End-users
  - Limit current distortion: IEEE 519-2014, Tbl. 2-4
    - Individual harmonic limits (% of maximum fundamental demand current)
    - TDD limits
      - Limits based on short-circuit ratio (I_{SC}/I_L) and service voltage
    - How:
      - Notify utility of new non-linear load, and install filters if necessary
      - Report possible harmonic problems
      - Notify utility of capacitor bank installations

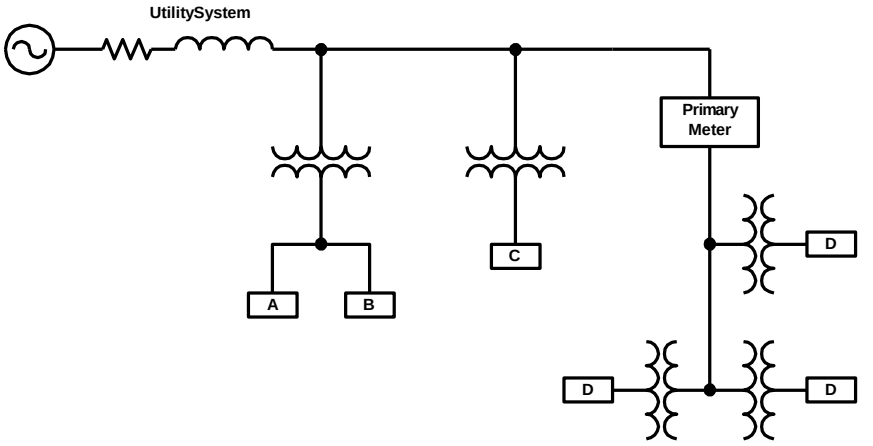
University of Idaho

The point of common coupling (PCC)

- Most downstream point in the system where another customer can be served
- Each PCC has, or could have at least two customers
- Point where harmonic limits apply
- Applying limits at the PCC benefits customers
  - Prevents interference with other customers
  - Only requires mitigation necessary to limit interference with others
- Utilities may apply certain limits downstream of the conventional PCC

University of Idaho

Some PCC examples



University of Idaho

Utility system harmonic evaluations Voltage distortion

- IEEE 519 table 1 (PSQ table 6.1, FPQ table 7.1 based on IEEE-519-1992 are similar)
  - Two factors drive voltage distortion
    - Harmonic current injection from non-linear loads
    - System response to harmonic frequencies

$$THD = \frac{\sqrt{\sum_{2} V_h^2}}{V_1}$$

Standard definition

$$THD = \frac{\sqrt{\sum_{2} V_h^2}}{V_{nominal}}$$

IEEE-519 definition for voltage distortion limits

University of Idaho

Utility system harmonic evaluations
Voltage distortion

- If the utility system impedance does not contain resonances near common harmonic frequencies, and end-user loads do not inject excessive harmonic current into the system, voltage distortion problems are unlikely.
- Utility engineers include system frequency response in design decisions
  - Avoid resonances near common harmonic frequencies
  - Primarily affects capacitor size and location

University of Idaho

Utility harmonic evaluations
Limiting harmonic current injection

- Process for existing loads
  - Isc from system simulations
  - Peak demand from billing data
    - Determine limits on TDD and individual harmonics
  - Monitor for 1-week (ideally near normal peak)
  - Statistical analysis:
    - Daily 99th percentile limits: 2 times limits in table
    - Weekly 99th percentile limits: 1.5 times limits in table
    - Weekly 95th percentile limits: limits in table
  - Report results to customers
  - Discuss mitigation plan if necessary

University of Idaho

Utility harmonic evaluations
Limiting harmonic current injection

- Process for proposed loads
  - Isc from system simulations
  - Peak demand from calculations
  - Provide information to customer
    - System impedance information
    - Requirements/limits
  - Customer education
  - Follow-up: check load when installed

University of Idaho

Harmonic evaluations in end-user facilities

- Highest distortion levels are in end-user facilities
- IEEE 519-2014 applies distortion limits at the PCC - distortion may be higher downstream
- Meeting IEEE 519-2014 may be difficult for isolated loads

University of Idaho

End-user harmonic evaluations

- Generally in response to harmonic problem
  - Failed capacitors
  - Interference
  - Failure to meet IEEE-519 at PCC
- May be conducted by utility
  - Identify sources
  - Recommend mitigation

University of Idaho

Principles of harmonic control

- Determine a "problem" level – usually IEEE 519 thresholds
- Causes
  - High harmonic currents
  - Path impedance
    - Distorted current through system impedance creates voltage distortion
    - System response may magnify impact of certain harmonics (resonances or near-resonances)

University of Idaho

Principles of harmonic control

- Solutions
  - Reduce harmonic currents
    - Use ASD for variable load only
    - Add inductance
    - Convert to 12-pulse with transformers
    - Specify IEEE 519 compliance in requirements
  - Filter
    - Shunt – provide low-impedance path away from rest of system
    - Series – increase impedance to harmonic currents near load
    - Active – Provide harmonic currents from another source

University of Idaho

Principles of harmonic control

- Solutions continued...
  - Modify system response
    - Remove a capacitor
    - Move a capacitor
    - Change a capacitor's size
    - Add a reactor
    - Add a shunt filter

Utility system harmonic control

- Emphasis is on recognizing and avoiding potential problems
  - Frequency response should be checked at every capacitor bank
  - Spot measurements should be used to check/verify computer simulations
  - Harmonic distortion can be included in other power quality recordings
  - It's possible to turn power factor correction capacitors into shunt filters

End-user harmonic control

- Prevention is key
  - Know your sources
  - Check for resonance
  - Filter near the sources
  - Put PF correction capacitors near the loads that need them
  - Check wiring
    - Adequate size given true RMS current?

Next time…

- Harmonic studies
- More Examples