ECE 528 – Understanding Power Quality

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

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

Lecture 24

Today…

- Harmonic control devices
  - In-line reactors (chokes)
  - Zigzag transformers
  - Passive filters
  - Active filters
  - Designing a harmonic filter

University of Idaho

In-line reactors (chokes)

- Simply a series inductance
  - Presents a series impedance that is directly proportional to frequency
  - Forces DC bus capacitor to charge more slowly
  - Additional benefit:
    - Reduces DC bus overvoltages due to capacitor switching transients – reduced nuisance tripping

University of Idaho

In-line reactors (chokes)

- Sizing the in-line reactor
  - Line reactors are typically described as "a 3% reactor", 3% to 5% are common
  - Size is based on the VA base of the drive

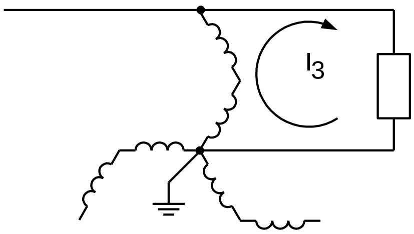
$$X_{L\_5\%} := 0.05 \frac{(V_{base})^2}{VA_{base}} \qquad L = \frac{X_L}{2\pi \cdot f}$$

  - Inductance in Henrys is based on X_L at the <u>fundamental</u> frequency

University of Idaho

Zigzag transformers

- Used for zero-sequence currents
- Commercial facilities – single-phase non-linear loads
- Provides a path for zero-sequence currents between the phase and neutral conductors
- Useful in existing facilities



University of Idaho

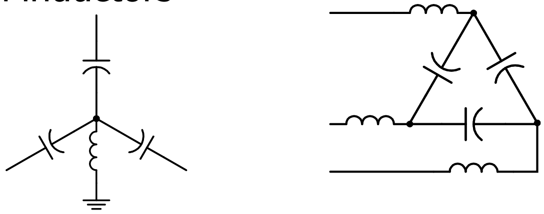
Passive filters

- Capacitors and inductors can be arranged to produce high or low impedances at certain frequencies
- Resistors can be added to provide damping
- Shunt passive filters – provide a low-impedance alternate path
- Series passive filters – increase the series impedance for certain frequencies

University of Idaho

Passive filters

- Shunt passive filters
  - Notch filter is the most popular
  - May employ delta or wye connected capacitors connected to the line or neutral through inductors



Lecture 24 7

University of Idaho

Passive filters

- Series passive filters
  - Provide a high impedance to the target harmonic
  - Must carry full load current
  - Not practical for multiple harmonics
  - Useful in single-phase applications

Lecture 24 8

Low-pass broadband filter

- Combines shunt and series elements
  - Low impedance for low frequencies
  - Hi impedance for high frequencies
  - (See PSQ p.287)
  - Several basic "building blocks" of the low-pass filter can be placed in series to produce a steeper slope in the frequency response

General approach with passive filters

- Start at the lowest harmonic of concern
- Tune filters slightly lower than the target harmonic
- Check for resonant points creating high impedances
- If system impedance changes, re-evaluate filter

University of Idaho

Active filters

- Use power-electronics to inject the missing current in the non-linear load's current waveform
- Results in minimal distortion on the source side
- No resonance concerns
- May also correct power factor and flicker

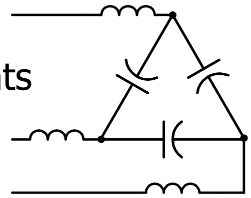
University of Idaho

Filter design example FPQ p. 259-266

- Goals – improve displacement power factor and filter 5^{th} harmonic
  - Load is 480V, 3-ph., 1600kVA, DPF=0.75 lag.
  - Load current has 20% 5^{th} harmonic
- We can address both the low power factor and the high 5^{th} harmonic current with a shunt filter
- Note – both texts contain this example. Both texts contain errors. Underlined material on slides is corrected or clarified from texts. References are to the FPQ text.

Filter design procedure

- Pick tuned frequency
- Calculate VAR requirements
- Calculate reactor size
- Determine filter duty requirements
  - Fundamental
  - Harmonic
  - RMS current and peak voltage
- Check capacitor ratings
- Calculate filter frequency response – check for resonance at other harmonics



Filter design example

- Notch picked at 4.7th harmonic or 282Hz
- VAR requirement to improve DPF to 98% is <u>814.63kVAR</u>
- Compute capacitive reactance (wye) of the FILTER based on VAR need: 0.2828 ohm. (eq. 7.21)
- Capacitive reactance of the filter's capacitors is higher because inductive reactance will cancel some (eq. 7.22)

University of Idaho

Filter design example

- Capacitive reactance: 0.2962 ohms (eq. 7.24)
- Capacitive reactance and voltage rating determines kVAR rating:
  - 777.75kVAR at 480V (eq. 7.25)
  - 1215.2kVAR at 600V
  - We'll use 750kVAR at 480V as a first try.
- Filter reactor's fundamental inductive reactance is calculated from capacitor size and harmonic number:

$$X_{cap} := \frac{(480V)^2}{kVAR_{cap}} = 0.307\,\Omega \qquad \text{(eq. 7.26)}$$

University of Idaho

Filter design example

- Inductance at fundamental:

$$X_L = \frac{X_{cap}}{h^2} \qquad L = \frac{X_L}{2\pi\, 60Hz} \qquad L = 0.0369mH$$

(for 480V capacitors) (from eq. 7.29)

- Duty requirements
  - We compute the fundamental and harmonic voltage and current for the capacitors separately, then add these values to get the total RMS current and peak voltage.

University of Idaho

Filter design example

- Eq. 7.34 - Fundamental VARs produced by the capacitor

$$Q_{cap\_fund} = \sqrt{3} \cdot I_{filt\_fund} \cdot V_{cap\_fund}$$

- This is **<u>not</u>** the fundamental reactive power produced by the filter. Fundamental reactive power produced by the filter is: (**<u>not in texts</u>**)

$$kVAR_{fund} = \sqrt{3} \cdot I_{filt\_fund} \cdot V_{LL\_Sys} \quad \text{or} \quad kVAR_{fund} = 3 \cdot I_{filt\_fund}^{2} \cdot X_{filt}$$

- Your filter design <u>must</u> produce enough reactive power at 60Hz to improve the power factor as required. PSQ's example does (it produces 565.6kVAR). <u>FPQ's example doesn't (it produces 785kVAR).</u>

University of Idaho

Filter design example

- Notes on duty calculations:
  - Fundamental duty is straightforward
    - Depends only on net filter reactance and the line voltage
  - Harmonic duty
    - Includes harmonic current from load AND source
    - Reactance calculations are at the harmonic frequency
  - "Total" duty
    - Sum of fundamental and harmonic duty

Filter design example

- Check capacitor rating limits
  - Table 7.3 in FPQ or 6.4 in PSQ is based on IEEE standards (RMS current limit is 135%) PSQ lists 180%.
- Check parallel resonance below notch frequency
  - 3.95th harmonic – nearly the 4th, which is acceptable because 4th harmonic distortion is normally low
- Check effect of component variations. Parameters of real-world components vary.

  (not required on midterm problem)

Next time

- Conclude Harmonics
  - Neutral loading
  - Interharmonics
  - Standards