IEEE Std. 1531 – 2003 Overview

Guide for Application and Specification of Harmonic Filters.

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Objectives

- Review and understand IEEE Standard 1531 – 2003.
- Determine proper sizing of harmonic filter elements according to the Standard recommendations.
- Establish a procedure for harmonic filter components specification.

Webinar scope

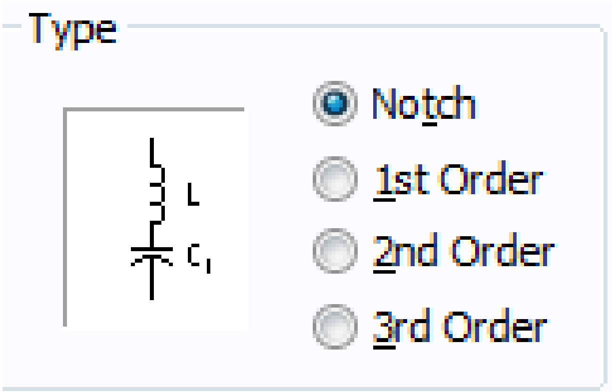
- The IEEE Std. 1531 – 2003 are general guidelines for any (passive) filter design. This webinar will only reference notch – type filters.
  - These are the simplest filters in design.
  - Other filters have design criteria beyond the scope of this webinar.
- This Standard is good for 50/60 Hz design and its harmonic multiples up to 1 kHz. Higher frequency filters have other design considerations.
- This webinar will review only low voltage filters.
- Electrical design (tuning) of the filter is not explored in detail in this webinar.

Suggested Webinar.

- Electrical design (tuning) of the filter is not explored in detail in this webinar, but there is a fantastic webinar by Chris Duffey on this subject. You may watch it here: http://easypower.com/videos/harmonic-notch-filters-video.php
- Or here:

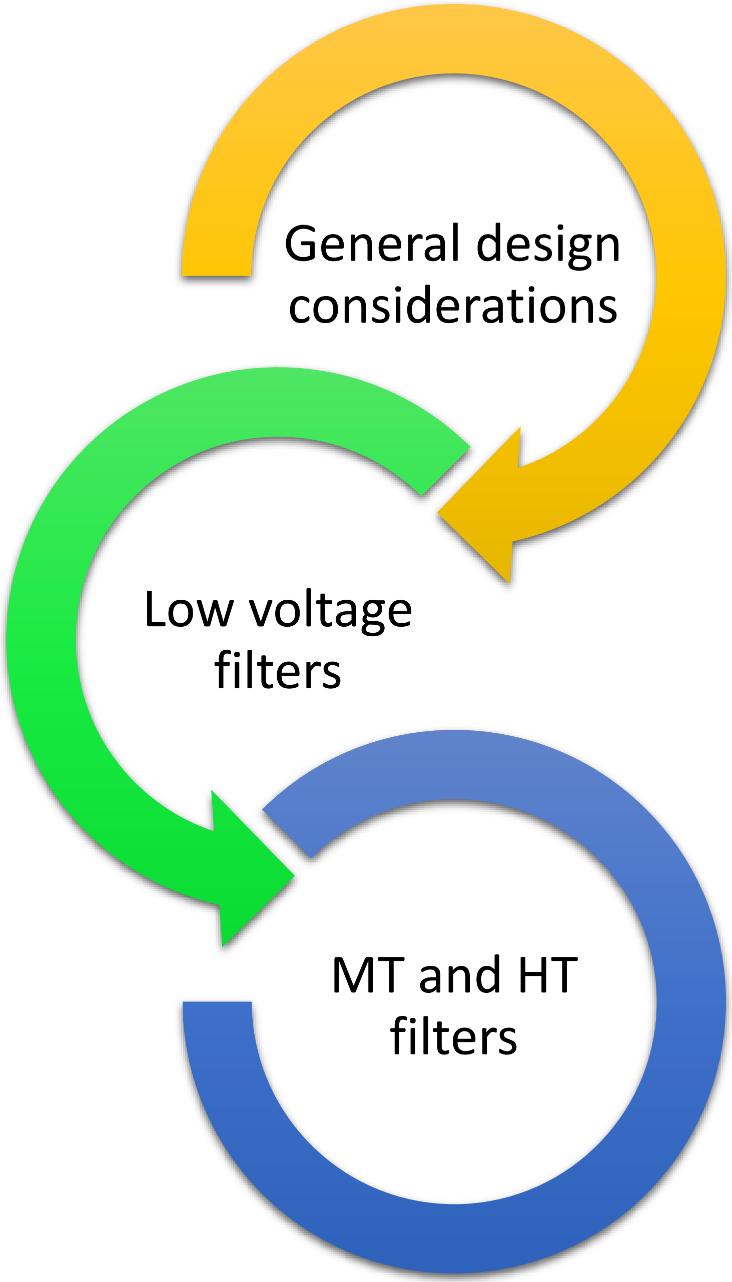
Background.

- What is a harmonic filter?
  - A combination of capacitors, inductors, and (sometimes) resistors tuned to a certain frequency, preventing harmonic currents of flowing into the system.
- What type of filters can we construct?
  - Many. Including but not limited to: notch, 1st order, 2nd order, c-type.
  - Different types of filters have different behaviors and have different applications.



Complimentary material

1. IEEE Std 1036-1992, IEEE Guide for Application of Shunt Power Capacitors.
2. IEEE Std C37.99-2000, IEEE Guide for the Protection of Shunt Capacitor Banks.
3. IEEE Std 18-2002, IEEE Standard for Shunt Power Capacitors.
4. IEEE Std 519-1992, IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems.



- Filter sizing & configuration.
- Filter tuning.
- Harmonic content.
- System conditions.

- Capacitors.
- Reactors.
- Contactors.
- Fuses.
- Breakers.
- Connections.

- Capacitor assemblies.
- Reactors assemblies.
- Switchgear.
- Connections.
- Relays and protection.

General considerations

Checklist.

- ✓Reactive power considerations.
  - Usually from power flow studies and (of course) EasyPower.
  - Keep voltage rise under 2 – 3 %.
- ✓Harmonic limitations.
  - Systems limits as defined per IEEE Std 519-1992.
    - Under 5% for PCC.
    - Under 8% for LV buses.
  - Equipment withstand capabilities.
    - Keep fully loaded transformers under 5% I THD (Not really recommended).
      - IEEE Std C57.12.00-2000
      - IEEE Std C57.12.01-1998
    - Capacitor heating capabilities.

Filter configurations.

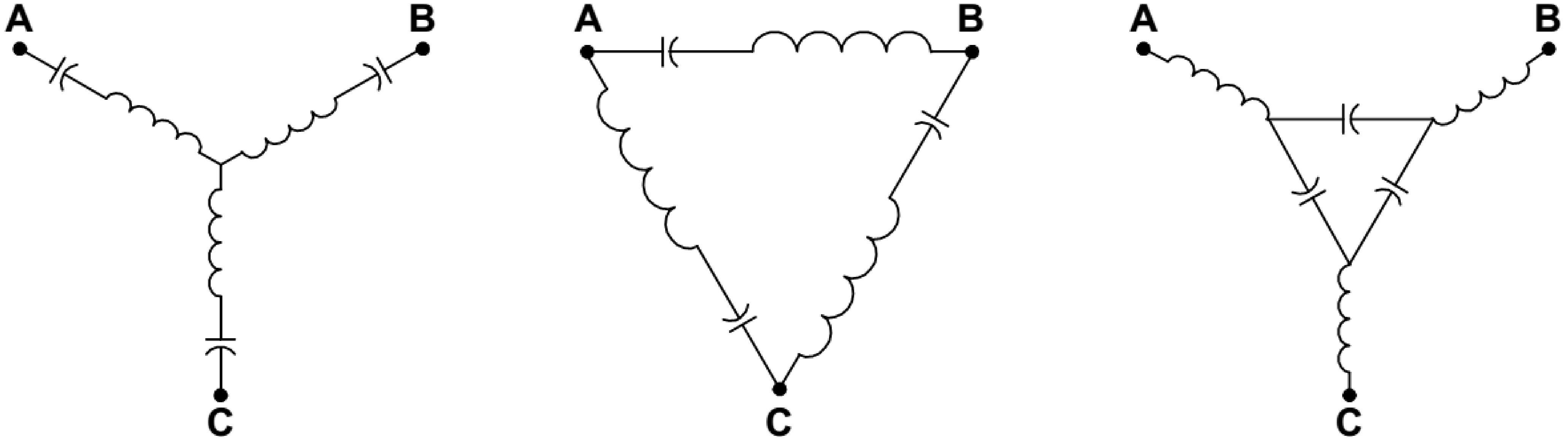


Figure 3—Different configurations that give identical filtering performance

Capacitor heating limits.

- IEEE Std 18-2002.
- a) 110% of rated rms [root-mean-square] voltage
- b) 120% of rated peak voltage, i.e., peak voltage not exceeding 1.2 x (square root of two) x rated rms
  voltage, including harmonics, but excluding transients
- c) 135% of nominal rms current based on rated kvar and rated voltage
- d) 135% of rated kvar.

*Capacitors rated for banks are normally not well suited for harmonic filters.

Capacitor heating limits.

$$\left|2000\ \pi f C \sum_{h} \left(h V(h)^{2}\right)\right| \leq\ 1.35\left|Q_{\text{rated}}\right|$$

$$\left|\sum_{h} \left(V(h) I(h)\right)\right| \leq 1.35\left|Q_{\text{rated}}\right|$$

- Considering:
  - No significant DC voltage.
  - Harmonic voltages are smaller than fundamentals.
  - Frequencies no larger than 1kHz.

Checklist

✓Normal system conditions.

- Characteristic and un characteristic harmonics.
- Background and future loads.
- System voltage variation. +5% normal. +10% unloaded.
- System frequency. ±0.1 Hz.
- System configurations.
    - Changes in transformers and main feeders.
    - Changes in system source.
- Loading conditions.
- System unbalance.

Checklist

- ✓Contingency conditions.
  - Switching.
    - Avoid simultaneous energization.
    - Transformer energization overvoltages.
    - When switching off/on, give the capacitors time to discharge. 5 min for MV, 1 min for LV.
  - Multiples filters on a bus.
    - Current sharing due to impedance differences.
  - Unknown harmonic sources.
  - System configuration changes.
- ✓Contingency harmonic filter conditions.
  - Keep an eye on not overrating filters when one or more go out.

Low voltage filters


DANGER
415 VOLTS
DANGER
415 VOLTS

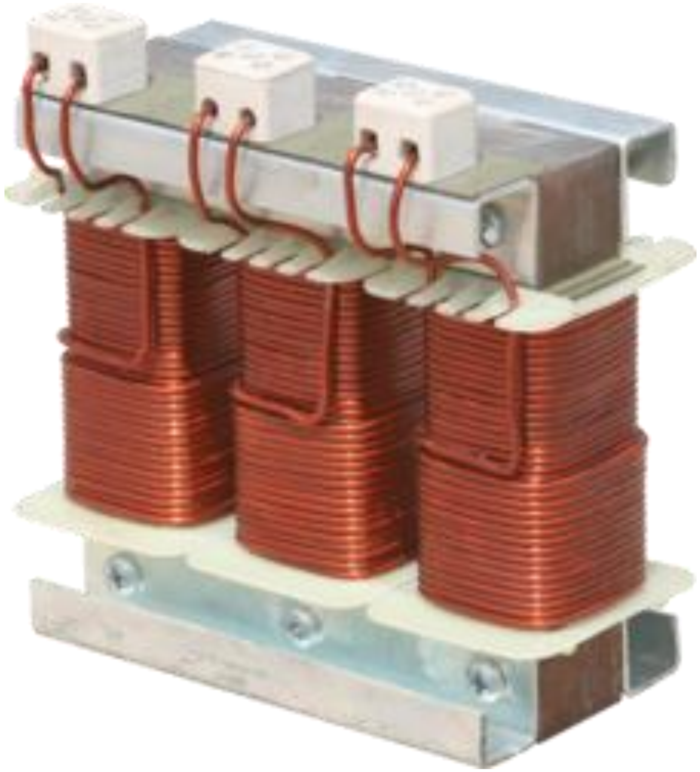
Capacitors

- Larger than bus rated voltage.

60 Hz			
480 V		525 V	
Q_n (kvar)	I_n (A)	Q_n (kvar)	I_n (A)
5,0	6,0	6	6,6
7,5	9,0	9	9,9
10,0	12,1	12	13,2
12,5	15,1	15	16,5
15,0	18,1	18	19,8
20,1	24,1	24	26,4
25,1	30,1	30	33

- Must have discharge means as to reduce the capacitor voltage to less than 50 V within a minute of de-energization.
  - IEEE Std 18-2002.
  - Article 460-6 of NFPA 70-2002

Reactors



- Dry-type iron core.
- Detuned reactors.
- Core.
- Windings.
- Clamping.
    - Noisy reactor/filter? Check for clamping.
- Author’s experience:
    - Detuning factor for LV filters is typically 7%

$$h = \sqrt{\frac{1}{DT}} \approx 3.78$$

Reactor specification

- Largely manufacturer responsibility.
- You should provide current harmonic spectrum (EasyPower!).
  - Coil loss.
  - Core loss.
  - Gap loss.

$$P_c = \sum [I(h)^2 R_{\text{ac}}(h) + P_{\text{eddy}}(h) + P_{\text{stray}}(h)]$$

Reactor protection.

- The main failure for reactors is overheating.
- Installing a thermistor or thermal cutout near the reactor’s hot spot is recommended.
- Thermal imaging needed.

Tolerance

- Per IEEE Std 18-2002 capacitors should have a -0% to +10% tolerance.
- Care should be excercised because capacitor & reactor tolerance.
- An improperly tuned filter WILL bring more problems tan it is intended to solve.

$$f_{\mathrm{tuned}} = f_{\mathrm{nominal}}\left(\frac{1}{\sqrt{(1+t_{\mathrm{r}})(1+t_{\mathrm{c}})}}\right)$$

F nom	4.7

F tuned		Tr																				
		-10%	-9%	-8%	-7%	-6%	-5%	-4%	-3%	-2%	-1%	0%	1%	2%	3%	4%	5%	6%	7%	8%	9%	10%
Tc	0%	4.95	4.93	4.90	4.87	4.85	4.82	4.80	4.77	4.75	4.72	4.70	4.68	4.65	4.63	4.61	4.59	4.57	4.54	4.52	4.50	4.48
	1%	4.93	4.90	4.88	4.85	4.82	4.80	4.77	4.75	4.72	4.70	4.68	4.65	4.63	4.61	4.59	4.56	4.54	4.52	4.50	4.48	4.46
	2%	4.91	4.88	4.85	4.83	4.80	4.77	4.75	4.73	4.70	4.68	4.65	4.63	4.61	4.59	4.56	4.54	4.52	4.50	4.48	4.46	4.44
	3%	4.88	4.85	4.83	4.80	4.78	4.75	4.73	4.70	4.68	4.65	4.63	4.61	4.59	4.56	4.54	4.52	4.50	4.48	4.46	4.44	4.42
	4%	4.86	4.83	4.80	4.78	4.75	4.73	4.70	4.68	4.66	4.63	4.61	4.59	4.56	4.54	4.52	4.50	4.48	4.46	4.43	4.41	4.39
	5%	4.83	4.81	4.78	4.76	4.73	4.71	4.68	4.66	4.63	4.61	4.59	4.56	4.54	4.52	4.50	4.48	4.46	4.43	4.41	4.39	4.37
	6%	4.81	4.79	4.76	4.73	4.71	4.68	4.66	4.64	4.61	4.59	4.57	4.54	4.52	4.50	4.48	4.46	4.43	4.41	4.39	4.37	4.35
	7%	4.79	4.76	4.74	4.71	4.69	4.66	4.64	4.61	4.59	4.57	4.54	4.52	4.50	4.48	4.46	4.43	4.41	4.39	4.37	4.35	4.33
	8%	4.77	4.74	4.72	4.69	4.66	4.64	4.62	4.59	4.57	4.55	4.52	4.50	4.48	4.46	4.43	4.41	4.39	4.37	4.35	4.33	4.31
	9%	4.75	4.72	4.69	4.67	4.64	4.62	4.59	4.57	4.55	4.52	4.50	4.48	4.46	4.44	4.41	4.39	4.37	4.35	4.33	4.31	4.29
	10%	4.72	4.70	4.67	4.65	4.62	4.60	4.57	4.55	4.53	4.50	4.48	4.46	4.44	4.42	4.39	4.37	4.35	4.33	4.31	4.29	4.27
	11%	4.70	4.68	4.65	4.63	4.60	4.58	4.55	4.53	4.51	4.48	4.46	4.44	4.42	4.40	4.37	4.35	4.33	4.31	4.29	4.27	4.25
	12%	4.68	4.66	4.63	4.61	4.58	4.56	4.53	4.51	4.49	4.46	4.44	4.42	4.40	4.38	4.35	4.33	4.31	4.29	4.27	4.25	4.23
	13%	4.66	4.63	4.61	4.58	4.56	4.54	4.51	4.49	4.47	4.44	4.42	4.40	4.38	4.36	4.34	4.31	4.29	4.27	4.25	4.23	4.22
	14%	4.64	4.61	4.59	4.56	4.54	4.52	4.49	4.47	4.45	4.42	4.40	4.38	4.36	4.34	4.32	4.30	4.28	4.26	4.24	4.22	4.20
	15%	4.62	4.59	4.57	4.54	4.52	4.50	4.47	4.45	4.43	4.40	4.38	4.36	4.34	4.32	4.30	4.28	4.26	4.24	4.22	4.20	4.18

Low-voltage (any) harmonic filters are often tuned below the nominal frequency; e.g., a 5th harmonic filter may be
tuned to the 4.7th harmonic. The reasons for this practice include the following:

a) Capacitors with metalized film construction lose capacitance as they age, resulting in a gradual increase in tuning frequency when used in harmonic filters. Using capacitor manufacturersí aging tables, a harmonic filter tuned at 6% below its rated frequency will still exhibit acceptable tuning at the end of its 20 yr life. (Nonmetalized electrode capacitors have fairly stable capacitance. Refer to the manufacturersí aging tables.)

b) Tuning a harmonic filter more sharply than required to attain the desired performance unnecessarily stresses the components and generally makes the harmonic filter more prone to overload from other harmonic sources.

c) The manufacturing tolerance of the harmonic filter reactor may result in a tuning frequency higher than nominal.

d) Operation of capacitor fuses on failed capacitor units or elements will result in an increase in tuning frequency.

How much detuning?

- Filters are tuned a little farther (to the left!) from their intended harmonic for many reasons.
- Medium voltage filters can be tuned around 92 – 94% of their nominal harmonic.
  - Fifth harmonic: 4.7, 4.6
- Low voltage filters should be detuned further from their intended harmonic so they don’t absorb as much current.
  - Fifth harmonic: 3.78

Contactors

- IEC or NEMA rated. UL-Listed, CSA-certified.
- Rating:
  - Maximum system voltage. (harmonic overtvoltage)
  - Maximum continuous current (fundamental and harmonic).
  - Number of switching operations.
    - Contactors FOR FILTERS can be sized with the manufacturers inductive ratings.
  - Capacitor switching duty.

Fuses

- UL-Listed Class J or T.
- CSA rated HRC-1.
- Rated currents must be at least X2 the capacitor rated current.
- Voltage rating should be at least equal to the system bus voltage.
- Internal capacitor fuses should not be used as a means of primary protection.
- In filters with more than one capacitor per reactor, each capacitor should be individually fused.

Fuses

- Must be located before the main disconnecting device and before the contactors.
- Phase load or thermal overload devices shall not replace fuses.

Circuit breakers

- Maximum system voltage.
- Harmonic spectrum.
- Interrupting rating.
- Fault limiting.
- Frequency of operations.

Connections and building.

Point of connection.

- Individual load.
  - A)The need to oversize distribution equipment is eliminated.
  - b) System losses are minimized.
  - c) Voltage distortion at the point of utilization is minimized.
  - d) The harmonic filter can be sized specifically for the load.
  - e) The harmonic filter can be switched on and off with the load.
- Distribution bus.
  - Recommended where power factor is the main concern.
  - PCC It can draw large amount of harmonic current from the source.
  - Watch for overvoltage!
  -

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- Thank you very much.