

## Principles for Controlling Harmonics

Harmonic distortion is present to some degree on all power systems. Fundamentally, one needs to control harmonics only when they become a problem.

There are three common causes of harmonic problems:

- The source of harmonic currents is too great.
- The path in which the currents flow is too long (electrically), resulting in either high voltage distortion or telephone interference.
- The response of the system magnifies one or more harmonics to a greater degree than can be tolerated.

When a problem occurs, the basic options for controlling harmonics are:

- Reduce the harmonic currents produced by the load.
- Add filters to either siphon the harmonic currents off the system, block the currents from entering the system, or supply the harmonic currents locally.
- Modify the frequency response of the system by filters, inductors, or capacitors.
- These options are described in Secs. 6.2.1 through 6.2.3.

### **Reducing harmonic currents in loads**

There is often little that can be done with existing load equipment to significantly reduce the amount of harmonic current it is producing unless it is being misoperated. While an overexcited transformer can be brought back into normal operation by lowering the applied voltage to the correct range, arcing devices and most electronic power converters are locked into their designed characteristics. PWM drives that charge the dc bus capacitor directly from the line without any intentional impedance are one exception to this. Adding a line reactor or transformer in series (as shown in Sec. 5.7.1) will significantly reduce harmonics, as well as provide transient protection benefits.

Transformer connections can be employed to reduce harmonic currents in three-phase systems. Phase-shifting half of the 6-pulse power converters in a plant load by  $30^\circ$  can approximate the benefits of 12-pulse loads by dramatically reducing the fifth and seventh harmonics. Delta-connected transformers can block the flow of zero-sequence harmonics (typically triplens) from the line. Zigzag and grounding transformers can shunt the triplens off the line. Purchasing specifications can go a long way toward preventing harmonic problems by penalizing bids from vendors with high harmonic content. This is particularly important for such loads as high-efficiency lighting.

### Passive Harmonic Filters

Passive harmonic filters consisting of capacitors, inductors, and/or resistors can be classified into tuned filters and high-pass filters. They are connected in parallel with nonlinear loads such as diode/thyristor rectifiers, ac electric arc furnaces, and so on.

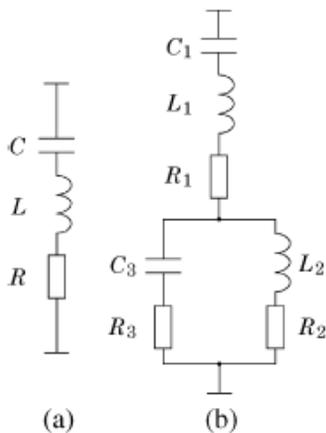


Fig. 1. Passive tuned filters. (a) Single tuned.

(b) Double tuned

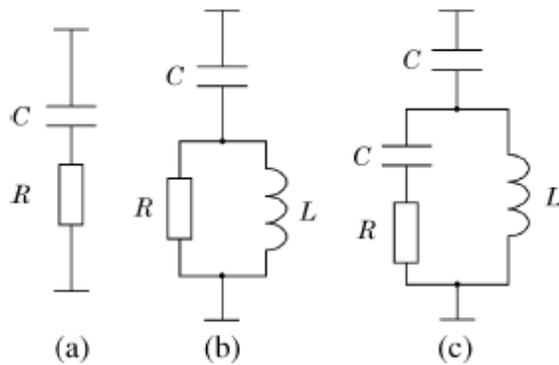


Fig. 2. Passive high-pass filters. (a) First order.

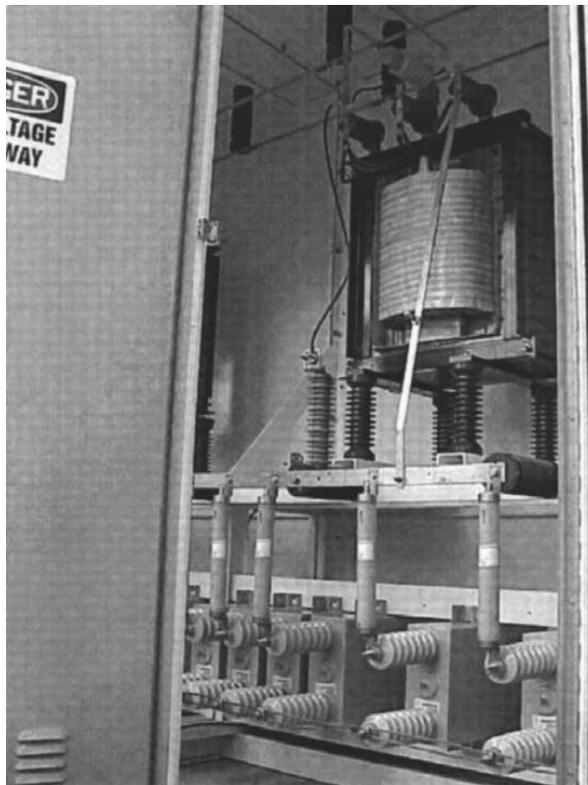
(b) Second order. (c) Third order.

Figs. 1 and 2 show circuit configurations of the passive filters on a per-phase base. Among them, the combination of four single-tuned filters to the fifth, seventh,  $11^{\text{th}}$ , and  $13^{\text{th}}$  harmonic frequencies and a second-order high-pass filter tuned around the  $17^{\text{th}}$  harmonic frequency has been used in a high-power three-phase thyristor rectifier.

Installation of such a passive filter in the vicinity of a nonlinear load is to provide low-impedance paths for specific harmonic frequencies, thus resulting in absorbing the dominant harmonic currents flowing out of the load. The actual value of the low-impedance path for each single-tuned filter is affected by the quality factor of the filter inductor, which determines the sharpness of tuning. Usually, a value of ranges between 20 and 100. Although a second-order high-pass filter provides good filtering performance in a wide frequency range, it produces higher fundamental-frequency loss than its corresponding single-tuned filter.

Notch filters can provide power factor correction in addition to harmonic suppression. In fact, power factor correction capacitors may be used to make notch filters.

Figure 6.13 shows one example of such a filter designed for medium voltage applications. The dry-type iron-core reactor is positioned atop the capacitors, which are connected in a wye, or star, configuration with the other phases (not shown). Each capacitor can be fused with a current limiting fuse to minimize damage in case of a can failure. In outdoor installations it is often more economical to use air-core reactors. Iron-core reactors may also be oil-insulated.



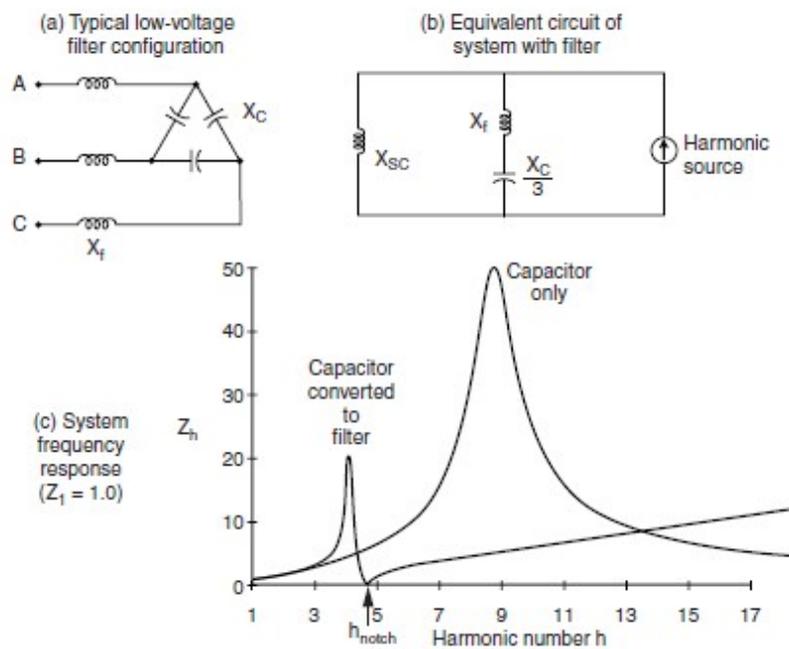
**Figure 6.13 One phase of a three-phase metal-enclosed filter.**

Figure 6.14 shows another design for industrial site applications. Here the reactors are placed on top of the cabinet housing the capacitors and switchgear.



**Figure 6.14 Filter for industrial power system applications.**

An example of a common 480-V filter arrangement is illustrated in Fig. 6.15. The figure shows a delta-connected low-voltage capacitor bank converted into a filter by adding an inductance in series with the phases. In this case, the notch harmonic  $h_{\text{notch}}$  is related to the fundamental frequency reactances by



**Figure 6.15** Creating a fifth-harmonic notch filter and its effect on system response

One important side effect of this type of filter is that it creates a sharp parallel resonance point at a frequency below the notch frequency (Fig. 6.15*c*). This resonant frequency must be safely away from any significant harmonic or other frequency component that may be produced by the load. Filters are commonly tuned slightly lower than the harmonic to be filtered to provide a margin of safety in case there is some change in system parameters that would raise the notch frequency. If they were tuned exactly to the harmonic, changes in either capacitance or inductance with temperature or failure might shift the parallel resonance higher into the harmonic being filtered. This could present a situation worse than one without a filter because the resonance is generally very sharp.

To avoid problems with this resonance, filters are added to the system starting with the lowest significant harmonic found in the system. For example, installing a seventh-harmonic filter usually requires that a fifth-harmonic filter also be installed. The new parallel resonance with a seventh-harmonic filter alone is often very near the fifth, which is generally disastrous.

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