

## Avoiding Harmonic Resonance with Low Pass Harmonic Filters

Industry experience has shown that certain types of harmonic filters can alter the natural resonant frequency of an electrical system and cause harmonic current or voltage to be amplified. Harmonic resonance can also occur when power factor capacitors are added to a system which has sources of harmonics. APQ Low Pass Harmonic Filters are specially designed to prevent problems associated with harmonic resonance.

### Harmonic Resonance

Harmonic resonance is caused when the electrical system reactances (capacitive and inductive) combine to form a tank circuit (LC network) with its natural resonant frequency near any frequency where electrical energy may be present. Harmonic resonance can appear in two different forms: parallel resonance and series resonance. Parallel resonance occurs when the parallel combination of system inductance and capacitance tune close to a harmonic frequency.

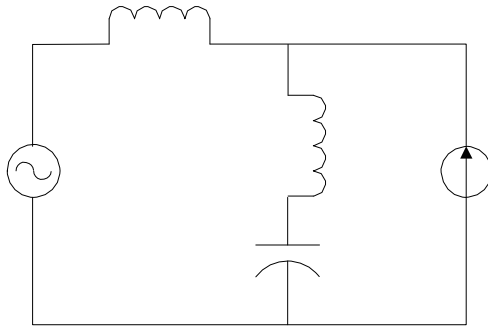


Fig. 1: Series Resonance Equivalent Circuit

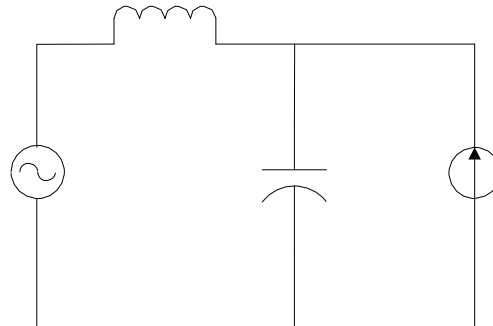


Fig. 2: Parallel Resonance Equivalent Circuit

At the resonant frequency of the parallel LC network  $X_L = X_C$ . This means that for parallel resonance, the combined impedance will be very high, so any harmonic current present may cause large harmonic voltages to be present. For series resonance, where the L and C components appear electrically in series with each other,  $X_L = X_C$  and therefore the combined impedance is very low. This means that if harmonic voltage is present at a frequency close to the resonant frequency, the harmonic current into the network can be equal to the harmonic voltage divided by the LC network impedance (near zero), causing excessive current at a specific harmonic frequency.

### Typical Harmonics

When six-pulse rectifiers are supplied from three phase power sources, they produce a very consistent spectrum of harmonics. The harmonic spectrum for three phase, full wave bridge rectifiers will result in a pattern of harmonic frequencies which follow the following formula:

$$h = k \cdot p (+/- 1),$$

where  $h$  equals the harmonic number (harmonic frequency divided by fundamental frequency),  $k$  is a constant (1,2,3,4...) and  $p$  = number of pulses in rectified DC voltage (typically number of diodes or Thyristors in the three phase rectifier). Using this formula, we can see that the normal harmonics associated with a six pulse rectifier are  $h = 5, 7, 11, 13, 17, 19$ , etc. If an electrical system has a natural resonant frequency near the 7th harmonic, then a six pulse rectifier (producing 7th harmonic current) could excite the network with at that frequency and amplify the 7th harmonic energy.

### Preventing Harmonic Resonance

The best way to avoid harmonic resonance is to assure that series and parallel combinations of system capacitance and inductance do not tune near a harmonic frequency. This requires special care in system analysis and design when either capacitors or harmonic filters are considered. One common method for power factor correction capacitors is to use a reactor to purposely detune the capacitor to a frequency where no harmonic energy is expected. For obvious reasons, the most popular detuning frequency is near the fourth harmonic. Since a three phase system will normally not produce the 4th harmonic, and the lowest harmonic associated with three phase equipment is the 5th harmonic, the (LC) network will normally not be excited at this frequency.

### APQ Low Pass Filters Avoid Harmonic Resonance

APQ low pass harmonic filters are specially designed to avoid harmonic resonance - at both the input and output of the filter. When viewed from the perspective of either the line or load side circuits, the combination of series reactor plus shunt elements, naturally tune the filter to a frequency near the fourth harmonic. Since there is normally no harmonic energy at this frequency, or even below the 5th harmonic, the filter can achieve its objective of removing harmonics, without concern for resonance conditions.

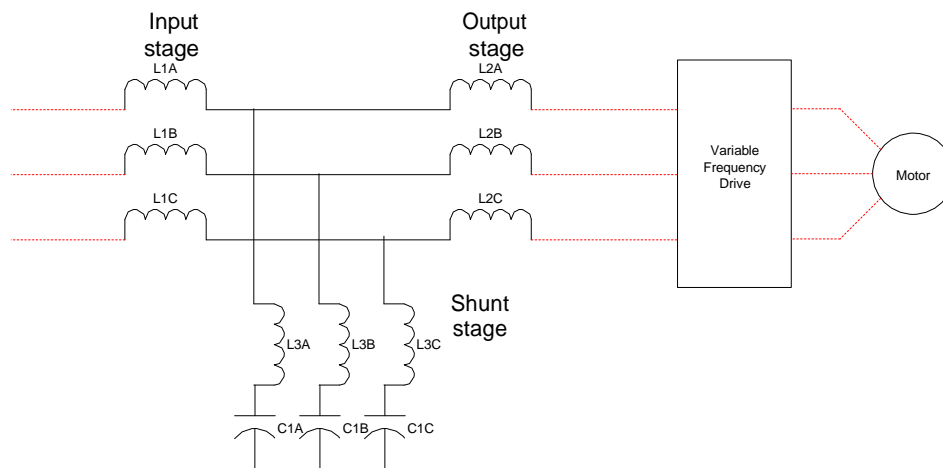


Fig. 3: Low Pass Harmonic Filter schematic

The shunt network portion of the low pass harmonic filter is typically tuned near the frequency of the fifth harmonic in order to achieve maximum attenuation of 5th harmonic current. The natural resonant frequency is determined by the formula:

$$f_r = \frac{1}{2\pi \cdot \sqrt{L \cdot C}}$$

When either the input or output stage reactors are considered in series with the shunt network, the natural resonant frequency is now forced to be near the 4th harmonic due to the larger total inductance (L). This means the APQ low pass harmonic filter will not cause harmonic resonance problems. The additional benefit of this design is that APQ's low pass harmonic filter does not attract harmonics from other non-linear loads that are supplied from the same power source as those loads connected to the filter. These two important features of the APQ low pass harmonic filter enable it to be used without the need for performing a harmonic study or system analysis.