harmonic voltage disturbance in the network causing an increased voltage distortion.

This results in a higher voltage across the capacitor and excessive current through all capacitor components. Resonance can occur on any frequency, but in general, the resonance we are concerned with is on, or close to, the 5th, 7th, 11th and 13th harmonics for 6 pulse systems. See Fig. 8.

Avoiding Resonance

There are a number of ways to avoid resonance when installing capacitors. In larger systems it may be possible to install them in a part of the system that will not result in a parallel resonance with the supply. Varying the kvar output rating of the capacitor bank will alter the resonant frequency. With capacitor switching there will be a different resonant frequency for each step. Changing the number of switching steps may avoid resonance at each step of switching. See Fig. 9.

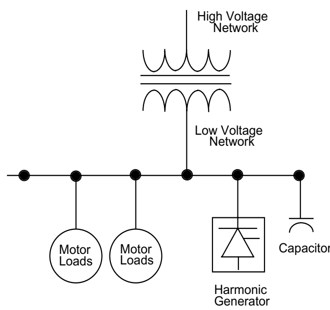
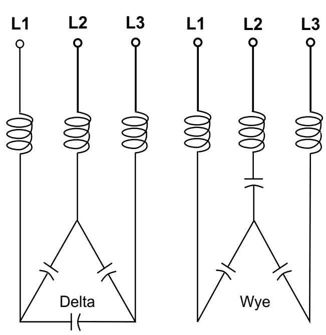


Fig. 9

Overcoming Resonance

If resonance cannot be avoided, an alternative solution is required. A reactor must be connected in series with each capacitor such that the capacitor/reactor combination is inductive at the critical frequencies but capacitive at the fundamental frequency. To achieve this, the capacitor and series connected reactor must have a tuning frequency below the lowest critical order of harmonic, which is usually the 5th. This means the tuning frequency is in the range of 175 Hz to 270 Hz, although the actual frequency will depend upon the magnitude and order of the harmonic currents present.



Detuned Capacitor/Reactor Systems

Fig. 10

The addition of a reactor in the capacitor circuit increases the fundamental voltage across the capacitor. Therefore, care should be taken when adding reactors to existing capacitors. See Fig. 10.

Reduction of Harmonic Distortion

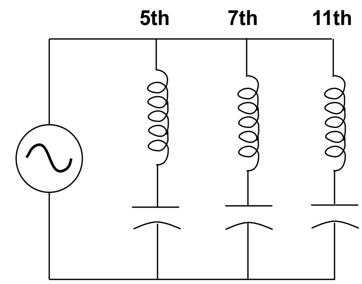
Harmonic currents can be significantly reduced in an electrical system by using a harmonic filter.

In its basic form, a filter consists of a capacitor connected in series with a reactor tuned to a specific harmonic frequency. In theory, the impedance of the filter is zero at the tuning frequency; therefore, the harmonic current is absorbed by the filter. This, together with the natural resistance of the circuit, means that only a small level of harmonic current will flow in the network.

Types of Filters

The effectiveness of any filter design depends on the reactive output of the filter, tuning accuracy and the impedance of the network at the point of connection.

Harmonics below the filter tuning frequency will be amplified. The filter design is important to ensure that distortion is not amplified to unacceptable levels. Where there are several harmonics present, a filter may reduce some harmonics while increasing others. A filter for the 7th harmonic creates a parallel resonance in the vicinity of the 5th harmonic with magnifi-cation of the existing 5th harmonic; therefore, a 7th harmonic filter requires a 5th harmonic filter. See Fig. 11. Consequently, it is often necessary to use a multiple filter design where each filter is tuned to a different frequency. Experience is extremely important in the design of such filters to ensure:



Shunt Filters

Fig. 11

(a) the most efficient and cost effective solution is selected;

(b) no adverse interaction between the system and the filter.

Load Alteration

Whenever load expansion is considered, the network is likely to change and existing filter equipment should be evaluated in conjunction with the new load condition. It is not recommended to have two or more filters tuned to the same frequency connected on the same distribution system. Slight tuning differences may cause one filter to take a much larger share of the harmonic distortion. Or, it may cause amplification of the harmonic order which the equipment has been designed to reduce. When there is a need to vary the power factor correction component of a harmonic filter, careful consideration of all load parameters is necessary.

Harmonic Analysis

The first step in solving harmonic related problems is to perform an analysis to determine the specific needs of your electrical distribution system. To determine capacitor and filter requirements, it is necessary to establish the impedance of the supply network and the value of each harmonic current. Capacitor, reactor and filter bank equipment are then specified under very detailed and stringent computer analysis to meet your needs.

Your ABB Solution to Harmonics

ABB is the world's largest manufacturer of dry type low voltage capacitors! ABB Control Inc. utilizes this experience in recommending three options to solve the problems associated with applying capacitors to systems having harmonic distortion:

1. Apply the correct amount of capacitance (kvar) to the network to avoid resonance with the source. This may be difficult, especially in automatic systems as the capacitance is always changing. This solution usually means connecting less capacitance to the system than is actually needed for optimum power factor correction.

2. Install reactors in series with capacitors to lower the resonance below critical order harmonics; i.e., 5th, 7th, 11th & 13th. This design tunes the resonant frequency of the system well below the critical harmonic and is called an anti-resonance bank. This solution allows the capacitors to operate in a harmonic environment.