Applying IEEE 519 – Part II
Controlling Harmonic Distortion Levels

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Last issue we discussed some of the concerns associated with applying IEEE 519 but I couldn't fit everything I wanted to say in one column so I had to defer to this issue for the conclusion. Basically, we covered the most important concerns associated with applying the limits but we didn't get to the topic of reducing harmonic levels if they turn out to be a problem. In this issue, we will focus on the different methods available for controlling harmonic levels. It is a timely topic because active filters are a finally becoming a viable alternative to passive filters for controlling harmonic levels and it is worthwhile to look at where it makes sense to consider this new technology.

Harmonic problems can be solved or prevented at a number of different levels of the system:

- You can purchase equipment that has reduced harmonic generation. This decision usually has to be made at the design stage for a facility since it is difficult to modify or replace the equipment once it is in service.
- You can apply technologies (e.g. magnetics) to achieve cancellation of harmonics from different loads. This can often be done with standard transformer connections.
- Many problems are the result of resonance conditions that magnify the harmonic levels. These problems can often be solved by changing the system configuration to avoid the problem resonances.
- When power factor correction is needed and harmonics are a concern, the best approach is usually to apply the power factor correction as passive harmonic filters. We will talk about some basic filter design guidelines.
- If power factor correction is not needed and harmonics are a concern, the best approach may be the application of active filters. This technology has come along way and appears to finally be a realistic economic alternative for controlling harmonic levels.

Each option is worth considering and could be the best approach depending on the specific circumstances. Basically, the choice will be determined by the economics of the different alternatives in the end. Let's look at each of these options in a little more detail to get a better idea of when each option might make sense.

Buying Equipment with Reduced Harmonic Generation

The most effective way to solve harmonic problems is often right at the source of the harmonics. The Europeans use this as the basic approach for controlling harmonic levels from single phase equipment that gets applied in offices and residential applications. Standard IEC 1000-3-2 (formerly 555-2) specifies allowable harmonic generation for single phase equipment up to 16 amps. Design of equipment with reduced harmonic generation involves additional costs and some manufacturers claim that this may not always be the most economical method of dealing with the harmonic issue.

One example of reducing harmonic generation at the equipment level is the application of inductive chokes for adjustable speed motor drives. Without the chokes, harmonic currents for adjustable speed drives can have distortion levels of 80% and higher. A simple 3% choke can reduce the harmonic currenet distortion to less than 40% which might be enough to prevent problems in many cases. Figure 1 illustrates the effect of a choke on the harmonic current distortion levels for a typical pulse width modulation (PWM) type adjustable speed drive. Note that the distortion levels without the choke are dependent on the size of the drive with respect to the supply transformer. If the drive is big enough, the supply transformer looks like the choke.

Many adjustable speed drive manufacturers now include a choke in the dc link of the drive that has the same effect – check on it before you buy your next drive.

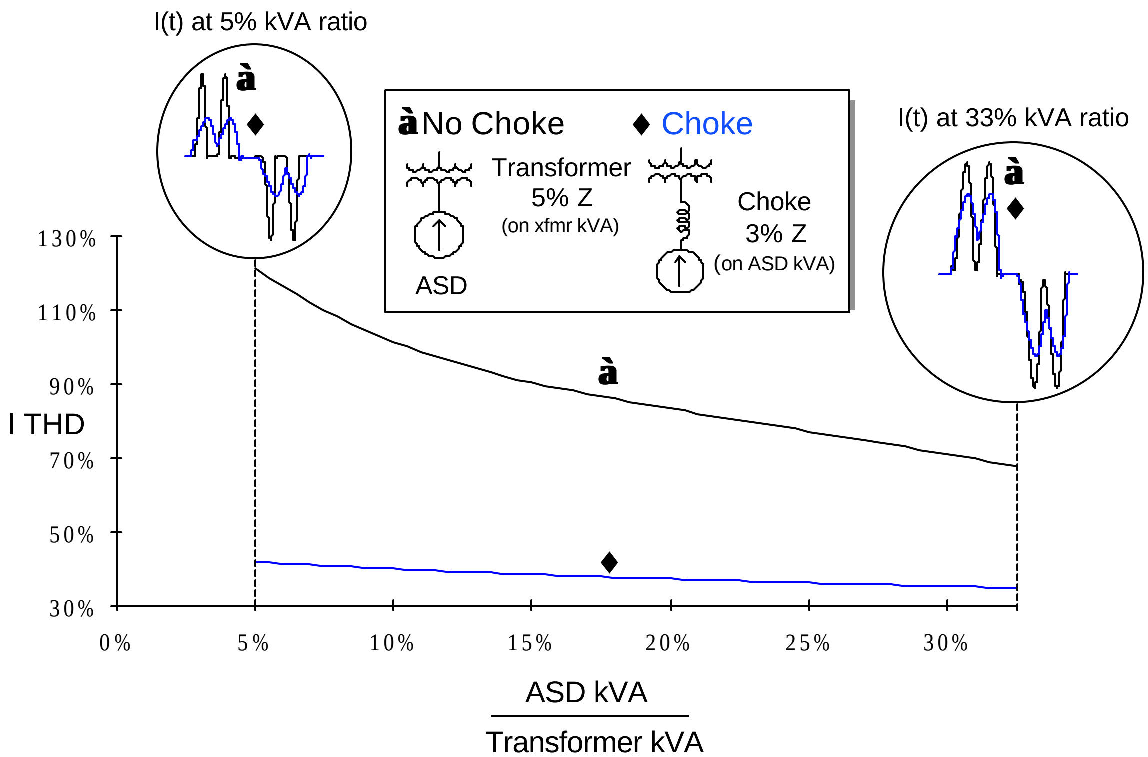

Figure 1. Effect of an ac line choke on the harmonic current distortion levels for a PWM-type ASD.

Harmonic Cancellation

Another method of controlling harmonic generation at the source is to buy adjustable speed drives or other rectifier equipment with higher pulse numbers. The pulse number refers to the number of commutations, or steps, in the ac waveform to a rectifier load. A six pulse device has six steps. The harmonics generated by these loads are related to the pulse number. A six pulse drive or rectifier has its first two characteristic harmonics at the fifth and seventh harmonics. A twelve pulse drive has the first two characteristic harmonics at the eleventh and thirteenth harmonics and the magnitudes are much lower.

You can make multiple drives look like higher pulse number loads when they are combined through judiciuous application of transformers with different connections. The basic principle is illustrated in Figure 2. One drive is connected through a transformer with a delta-delta connection and another drive is connected through a transformer with a delta-wye connection. The resulting phase shift changes the waveform at the primary of the transformer and results in cancellation of the fifth and seventh components. You can see that the combined waveform for the two drives is much cleaner. Note that you will probably not get perfect cancellation so you have to be careful in applying harmonic filters in a situation like this (more about this later).

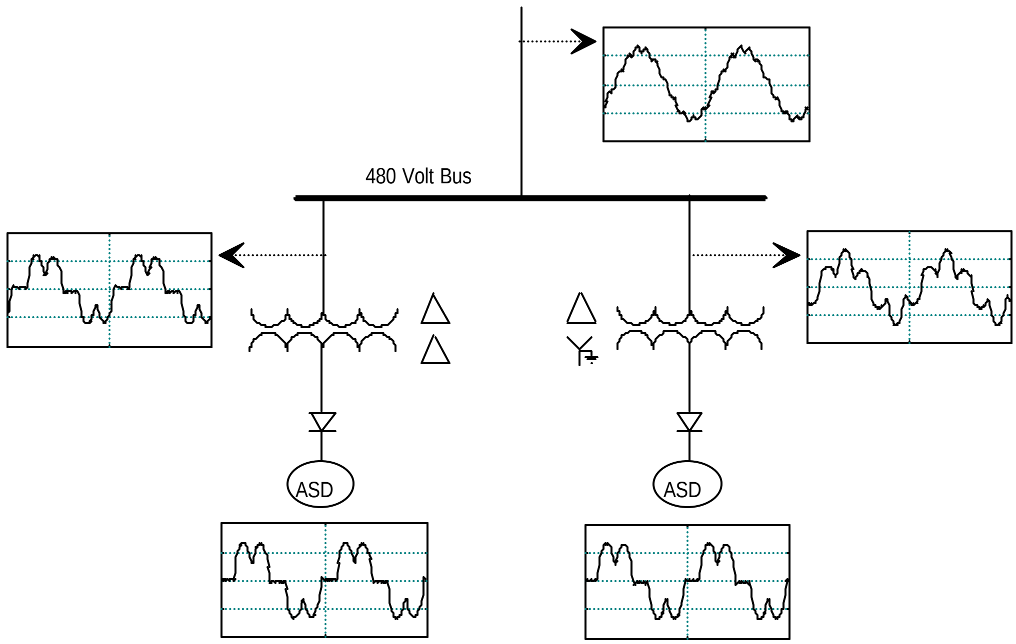

Figure 2. Using transformer connections to achieve harmonic cancellation for multiple adjustable speed drives.

Avoiding Resonance Problems

Be careful in applying power factor correction capacitors. Hopefully, you got that message from the column in the last issue. Capacitors combine with the system source inductance to cause a parallel resonance. The basic circuit is illustrated in Figure 3. A parallel resonance means a high impedance at the resonant frequency. Remember that nonlinear loads look like harmonic current sources (that is the basis of the IEEE 519 standard). When these harmonic currents see a high impedance near the resonant frequency for the circuit, they cause high voltage distortion and magnified harmonic currents in the capacitor bank and the source. Figure 4 illustrates the effect of different capacitor bank sizes on the magnification of the harmonic currents for a typical case (1500 kVA transformer supplying a facility).

How do we avoid this problem of magnified harmonic currents and high voltage distortion levels? Don't apply capacitor banks that result in a resonance near one of the characteristic harmonics for your nonlinear loads (usually the fifth or seventh). You can avoid problems of magnification in most cases by limiting the size of power factor correction capacitors to less than 20% of the transformer kVA rating. For example, if you are supplied with a 1500 kVA transformer, don't apply power factor correction of more than 300 kvar. In Figure 4, you can see that 300 kvar results in a resonance near the eighth harmonic. You don't want to get any closer to the seventh than that.

Many times you don't have a harmonic problem unless you create one with a resonance condition. Be careful.

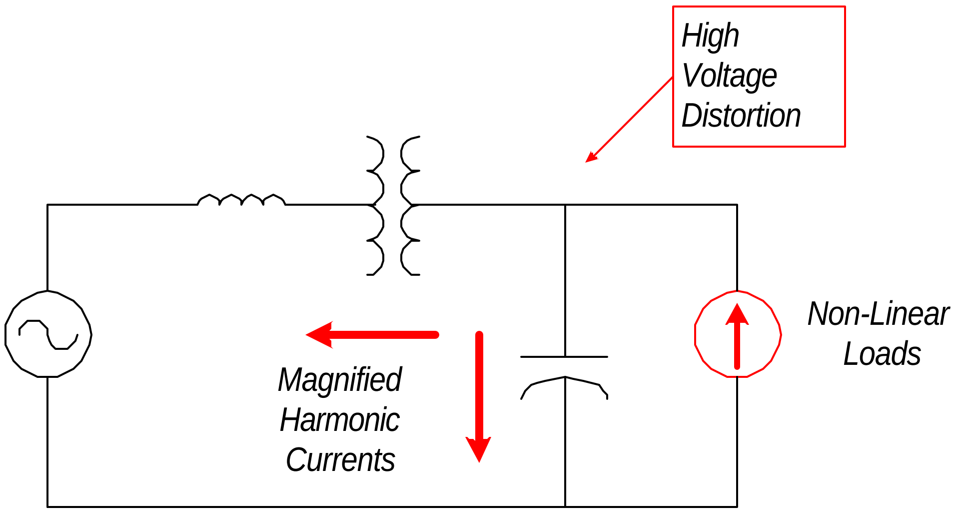

Figure 3. Basic circuit illustrating concern for parallel resonance.

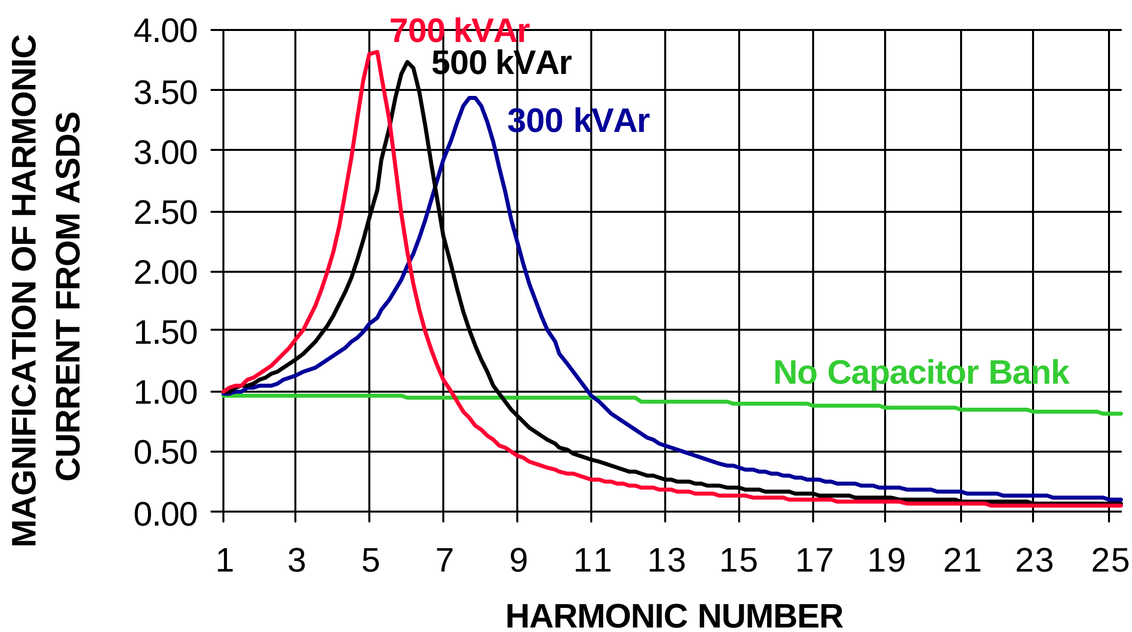

Figure 4. Magnification of harmonic currents caused by power factor correction capacitors (for the case of a facility supplied by a 1500 kVA stepp down transformer with 6% impedance).

Designing Passive Harmonic Filters

Passive shunt harmonic filters are the traditional method of controlling harmonic distortion levels. A single-tuned filter consists of tuning reactors in series with a capacitor bank. This series combination results in a low impedance at the resonant frequency. Therefore, we choose this resonant frequency to match up with one of the characteristic harmonics that we want to control. Then the filter will absorb the harmonic currents at this frequency and prevent them from flowing onto the supply system. The effect of the filter on the frequency response of the system is shown in Figure 5.

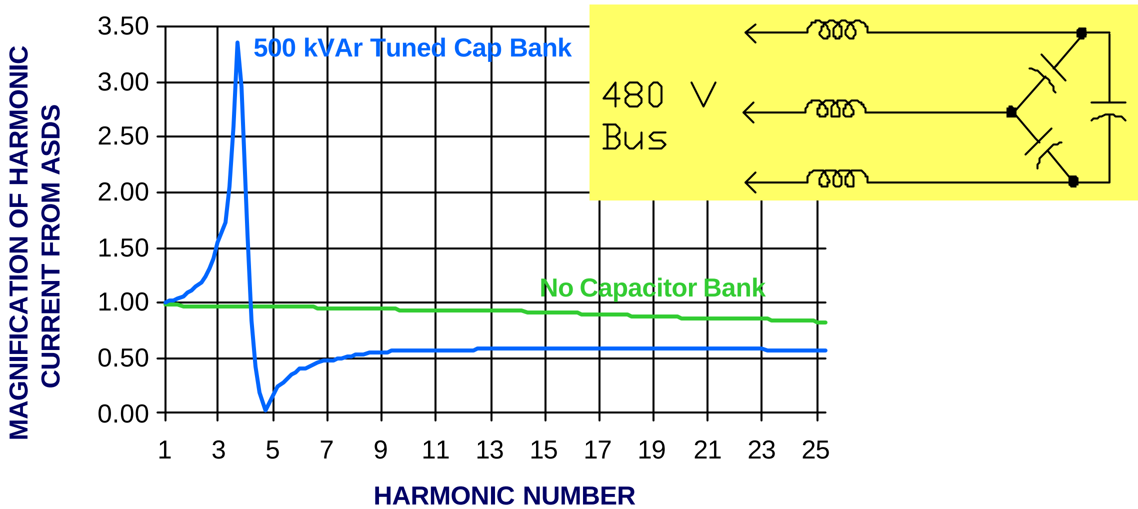

Figure 5. Effect of a tuned capacitor bank on the magnification of harmonic currents from nonlinear loads.

There are a few important principles to keep in mind when designing passive harmonic filters:

- Always design the harmonic filters for the lowest order harmonic component generated by the nonlinear loads. You can see in Figure 5 that the filters create a new parallel resonance at a frequency below the series resonance frequency. This was the concern I was talking about when discussing the application of filters for 12 pulse loads earlier. You might think that you could design an eleventh harmonic filter for these loads. However, you have to be careful to make sure you don't create a new resonance near the fifth or seventh harmonics because the 12 pulse configuration will not result in perfect cancellation of these components and you don't want to magnify them with your filter.
- Remember that a filter is a filter. It's a low impedance at the filter frequency regardless of where the harmonics are coming from. It can absorb harmonics from other nonlinear loads in your facility and it very likely will absorb harmonics from the power system. Unfortunately, it has to be designed to handle harmonics from all these sources. This makes it very difficult to apply generic filters for individual loads – they have to be derated too much for all the other harmonic sources that could affect them.
- You don't always have to tune the filter right on the harmonic component of interest. It is usually sufficient to tune the filter somewhere below the lowest characteristic harmonic (e.g. tuned to 4.7^{th} harmonic). This helps redue the impact of harmonics from the power system and from other loads. The most important thing is that applying the power factor correction as a tuned bank makes sure that you don't create a parallel resonance that makes thngs worse.
- Be careful in applying filters in combination with shunt capacitor banks. The capacitors create another resonance that can cause problems at other characteristic harmonics. If you are using a tuned capacitor bank to prevent resonance problems, apply all of your power factor correction as tuned capacitor banks.

If you keep these few cautions in mind, tuned capacitor banks will be an effective way to avoid harmonic problems. We have a spreadsheet that you can use to help choose the appropriate values and ratings for the components of a simple passive filter – drop me an email if you would like a copy of it.

Active Filters

Active filters are the answer to our prayers for a method to control harmonics without worrying about all the side effect problems associated with applying passive filters. The basic concept is illustrated in Figure 6. The active filter monitors the load current to be filtered, processes the current to determine the harmonic distortion components that need to be cancelled, and produces a current that will cancel the unwanted components in the load current.

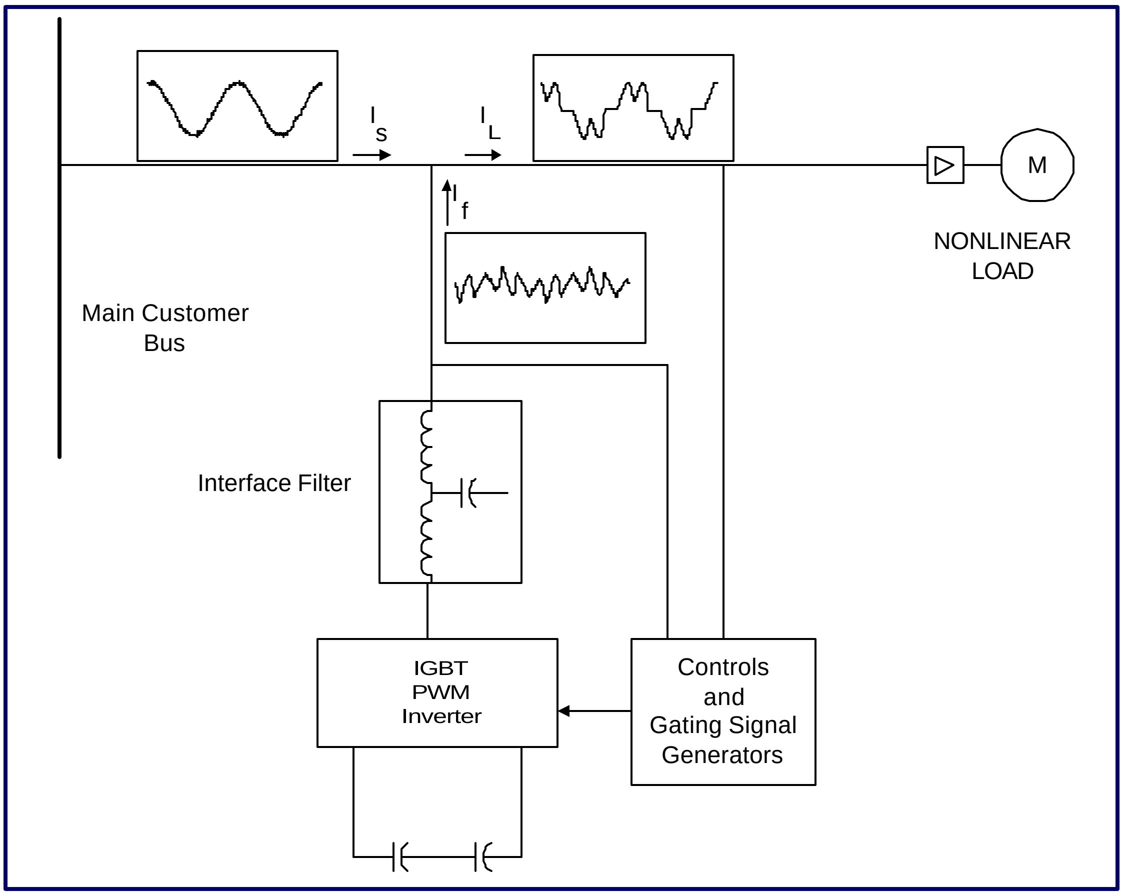

Figure 6. Basic configuration and operation of a parallel-connected active filter.

The active filter uses the same pulse-width modulation inverter technology that is used in adjustable speed drives. This has helped reduce the costs of the active filter technology substantially and also helps with the reliability of these devices – the components are essentially off the shelf.

Active filters have a number of important advantages over passive filters for many applications:

- Probably the most important advantage is that you can't overload them. They just produce as much current to cancel harmonics as they can produce. They are not affected by harmonic currents from other nonlinear loads in the facility or by harmonics from the power system. They can be rated just for the loads being compensated. This makes them ideal for OEM applications where they can be applied with individual pieces of equipment.
- They do not result in new resonances. In fact, they don't result in any resonances. You don't have to worry about canceling one harmonic and magnifying another harmonic. This makes active filters ideal for application with 12 pulse converter installations. It is difficult to apply passive filters in these cases

because they could magnify the fifth or seventh harmonics. The active filter will cancel the eleventh and thirteenth harmonics without mangifying any other harmonics.

- They can be designed with special control strategies to meet specific objectives. The control can be designed to control certain harmonics with higher priority than other harmonics. For instance, the control can be designed to control harmonics with weighting factors to match IEEE 519 limits.
- They don't have to compensate for all the harmonics. An active filter will absorb all the harmonics that it can. An active filter doesn't have to be rated for all the harmonics. It might be sufficient to cut the harmonic currents in half – in this case, you just have to rate the active filter for half the harmonic current from the load.
- Active filters don't have to provide power factor correction. The control can be designed to provide compensation of harmonic components without providing fundamental frequency power factor correction. Many applications with PWM type adjustable speed drives need harmonic control but the displacement power factor is very good. It is difficult to design passive tuned filters in this case because the filters must be sized for the harmonics and then they make the power factor leading.

Sound too good to be true. It's not. These active filters are for real. There still will be many applications for passive filters (basically, they will still be preferable when you need power factor correction anyway). But active filters are going to be an important part of the mix.