Harmonic Filter Bank Tuning
Tuned & De-tuned Banks

When designing or applying a harmonic filter, the question that comes to the mind of many engineers is; What harmonic or frequency should the harmonic filter bank be tuned too? i.e., 4.2 (de-tuned), 4.8 (partially de-tuned) or 5.0 (tuned). To answer this question, the engineer should know why the filters are being installed in the first place. Harmonic filters are generally installed to achieve one of the following objectives:

1. Capacitors are required to improve power factor, and possible system interaction may occur with the installation of a plain capacitor bank.

2. Permissible distortion limits of the local utility or IEEE-519 are exceeded, and filters are required to reduce them.

3. A combination of 1 and 2 above, whereby capacitors are required to improve power factor and with the addition of the capacitors, permissible distortion limits are exceeded.
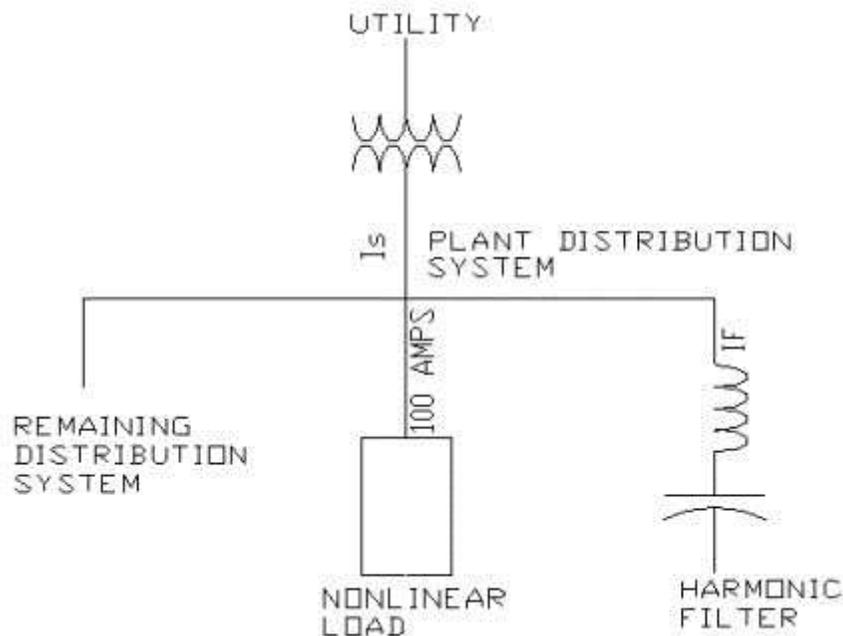
Figure 1 - Typical Industrial System

This technical article discusses the proper type of filter for each of the above applications and provides design and performance issues related to tuned, de-tuned and partially de-tuned harmonic filter banks. Consult NEPSI for other bulletins that may assist you in the selection and application of harmonic filter banks and capacitor banks.

Background – Tuning

Figure 2 shows a typical frequency scan for a 4.2th, 4.8th, and 5th harmonic filter when placed on a system as shown in Figure 1. The frequency scan shows the apparent impedance as a function of frequency as seen by an injected current at the location shown in Figure 1. This injected current is usually termed a harmonic current source and usually consist of non-linear loads, such as variable speed drives, switch mode power supplies, and welders. The scan shows how the tuning point affects the apparent impedance, mainly in the area of tuning, near the 5th harmonic. A blow up of this tuning area is shown in Figure 3
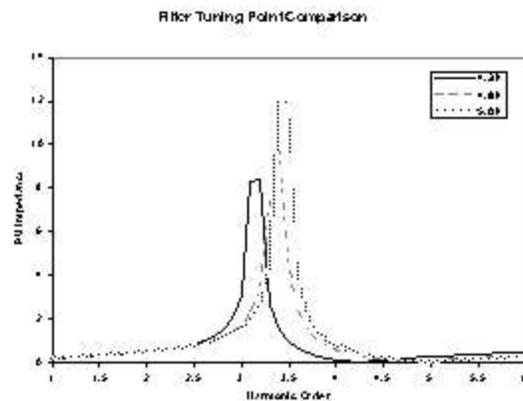
Figure 2 - Filter Tuning Point Comparison

The impedance scan is useful since it gives an indication of the filter characteristics and how it interacts with the system that it is being applied on. For example, the filter tuning point can be determined by looking at the minimum impedance, or "notch". In addition, the anti-resonant point, the peak just below the tuning point, can also be determined. The anti-resonant point always exists below the tuned frequency of a filter, and significant harmonics at this frequency should be avoided. When applying de-tuned filters below the 4.2th, careful consideration should be given to possible resonant concerns at the 3rd harmonic.

To put reality into the scans, one may say that one per unit of current injected into one per unit impedance produces one per unit voltage. In looking at Figure 3, one per unit current injected into the system at the fifth harmonic will produce those voltage levels shown on the ordinate of Figure 3. That is the 4.2th will produce a 5th harmonic voltage of 0.275 per unit. The 4.8th will produce a 5th harmonic voltage of 0.072 per unit and the 5th filter a voltage of 0.006 per unit. With respect to filtering, the 5th harmonic filters perform the best of the three filters, since the lowest harmonic voltage is produced for a one per unit injection.
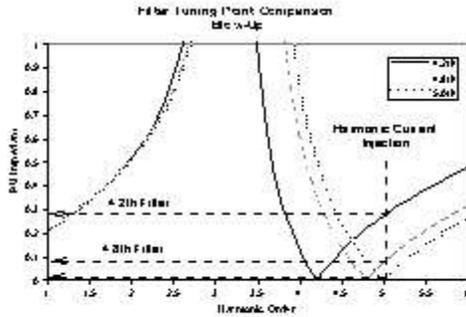
Figure 3 - Close up of tuning point

Filter Performance

From the above discussion, it is apparent that tuning has a definite effect on filter performance and system interaction. The question of whether to tune, de-tune or partially de-tune is a question of economics, objective of filtering, and negative system interaction. A tuned filter cost more than a partially de-tuned filter, and likewise a partially de-tuned filter cost more than a de-tuned filter. The reason the for the cost difference, is the duty requirements for both the capacitors and the reactors.

For example, the filter currents for various tuning points for the typical system in Figure 1 are illustrated in Table 1. The Table is based on 100 amps of 5th harmonic current injected from the nonlinear load. This current may flow back to the utility or into the harmonic filter, and is dependent upon the filter impedance and system impedance at the 5th harmonic. Table 1 shows that the 5th harmonic filter will absorb most of the harmonic current and that very little will be absorbed by the utility. As a result, the fifth harmonic filter would require a 5th harmonic current rating of 99 Amps. The 4.8th harmonic filter absorbs less, and would require a 5th harmonic current rating of 70 Amps. The 4.2th harmonic filter absorbs very little harmonic current (20 Amps), while the utility and the remaining system absorbs the remaining 80 Amps. The conclusion here is simple; tuning the filter closer to the fifth harmonics requires higher reactor current ratings, (and also capacitor voltage ratings) which result in higher filter bank cost.

Table 1 – Filter Performance		
Filter Type	Filter Current (amps)	Utility System (amps)
5th	99	1
4.8th	70	30
4.2nd	20	80

Conclusion

The choice of tuning frequency is based on the objective of the harmonic filter and economics. The following guidelines may assist the engineer in determining the proper type (tuning frequency) of filter.

De-tuned Filters (Tuning between 4.0 and 4.4)
If harmonic filters are being considered only for the purpose of power factor correction, then a de-tuned filter bank is the best choice. This filter will do little for removing any harmonic distortion present on the system but will allow the installation of a large capacitor bank without any adverse system interactions. De-tuned filter banks are less costly an are more reliable than partially de-tuned and tuned filter banks. The anti-resonant frequency should be considered to assure that it does not fall near the 3rd harmonic.

Partially Tuned Filter (Tuning between 4.4 and 4.8)
In some situations, a filter (or capacitor bank) is required to improve power factor, and at the same time distortion limits are exceeded. In this situation, a partially tuned filter bank is usually the best choice. A partially tuned bank offers less risk and is typically less costly than a tuned filter bank.

Tuned Filters (Tuning between 4.8 and 5.0)
If harmonic filters are being considered only for the purpose of reducing the harmonic distortion to acceptable limits, then a tuned filter bank should be considered. A tuned filter bank will require the least amount of kvar to bring the distortion down within limits, but will require the highest level of engineering design. It has the highest level of risk, since it will draw most of the harmonics present on the industrial system and local utility system. Harmonic load growth should be considered, along with ambient voltage distortion level. The application of this type of filter should include a detailed harmonic analysis by the manufacturer.

Other Filter Types
Fifth harmonic filters have been the main topic of discussion. Other types of filters are sometimes required, i.e., 5th, 7th, 11th filter banks. Or 5th, 7th, 11th and 13th high pass. These filters are designed with optimization and with specific current distortion limits in mind. They are more costly than simple tuned filter banks but are much more effective in reducing the system distortion. They are generally applied to systems with large amounts of non-linear load.