Applying Low Voltage Harmonic Filters, Revisited

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Introduction

Many industrial facilities, big and small, are applying harmonic filters due to problems occurring within their facility or because the utility is requiring them to prevent other customer problems. Harmonic filters are not a piece of equipment that may be purchased "Off the Shelf", and the customer can become discouraged as conflicting recommendations are presented during the quotation process. When the decision to purchase and install filters has been made, the information presented here will help the manufacturer and the customer enjoy a pleasant relationship. It is critical to understand what you are purchasing and why one unit may be so much less expensive than another. There are several types of filters available for various goals, but the most common is the shunt connected series notch filter. This is the harmonic filter discussed in this paper.

What Information Needs to be Provided?

There is nothing mystical about harmonic filters. The concept is to create a lower impedance path, as compared to that of the source, for currents at frequencies other than 60 Hz. As a minimum, the filter manufacture requires the source impedance, utilization voltage, load power information, and harmonic summaries at each load condition.

Before we discuss each of these independently, the goals of the installation must be determined. These will typically fall into one or more of the following: 1) Power Factor Correction to avoid utility demand charges, 2) Release of Capacity to unload system transformers and cables, 3) IEEE-519 Compliance , 4) A Plant Operation Problem . Number four is included because quite often a plant manager will have a POP and order a harmonic filter to meet the 519 limits. After the filter is installed, the limits may be met, but the POP has not been resolved because it is caused by some other power quality problem such as neutral to ground voltages, transients, or notching. Knowing what the project goals are up front will help get the most cost effective and appropriate solution installed initially.

System impedance is important because it will determine how big, how many stages, and how aggressive the filter or filters must be tuned. If the source is stiff (a small impedance) than the filters need to be more aggressively tuned and may require to be tuned at multiple frequencies (stages) to meet the project goals. If the system is weak (a large impedance) than a less aggressive, single stage filter may be used. Information required to determine the system impedance are the three phase fault MVA of the utility distribution connection and the kVA and percent impedance of the step down transformers. A one-line diagram or sketch of the power system helps when multiple transformers are involved, see Figure 1.

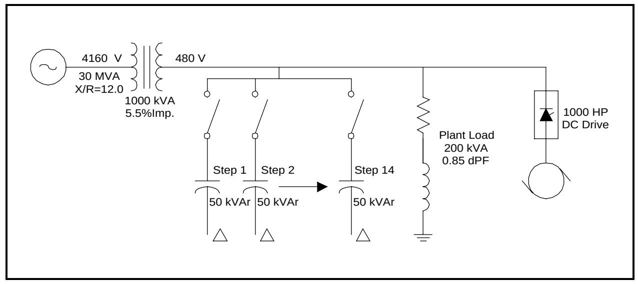

Figure 1 - One-Line Diagram

The utilization voltage is necessary to size the capacitors. Low voltage capacitors are commonly available in the U.S. with 240V, 480V, 600V, and 1000V ratings, off shore capacitors may be found at other ratings. Series notch harmonic filters consist of a reactor in series with a capacitor. The series reactor will create a slightly higher voltage on the capacitor than that of the line. If the harmonic current that the filter needs to absorb is large, this voltage could become excessive and require the use of a higher voltage capacitor.

Harmonic data is the most critical information to be provided. So much so that manufacturers may choose to visit the facility to take their own measurements once the project has been awarded. As a minimum, it is important to take snap-shots of the harmonic spectra in all of the plant operation configurations. Ideally, the harmonic spectra will be trended over several plant cycles (day, week, month, etc.) To assure that the largest load has been measured and to help with reactive power requirements, it is a good idea to include the past 12 months of utility bills. If possible, a snap-shot measurement with minimal plant load will help determine the amount of utility distortion that the filter may need to absorb.

At some point, it must be decided who will be collecting the information. If the facility only has one or two transformers and a few variable speed drives, plant personnel should be able to provide sufficient information. If the facility is more sophisticated than this, it is wise to work with someone who is knowledgeable in power quality. The utility company is a good place to start in the search for such a person. Keep in mind that some manufacturers will provide this service for a fee that all or part of may be applied to the purchase of their equipment. Often times this will lead to the smoothest solutions. Figure 2 offers one format for the data collection process.

Filter Application Guideline Sheet

Goal of Harmonic Filter Application: (Choose All That Apply)

Power Factor Correction ☐
Release of Capacity ☐
IEEE-519 Compliance ☐
Plant Operation Problem (Explain)

____

Other (Explain)

____

System Information:

Fault MVA at the Primary of the Transformer ________
Transformer kVA ________
Transformer % Impedance ________
Transformer Primary & Secondary Voltages ________
Transformer Connection (Include Grounding) ________
How Many Transformers Feed Plant Loads
Are the Transformers Connected to Plant or Utility Distribution ________
Are their Capacitors on the Line or Load Side of the Transformer ________

Load Information:

Horse Power or kVA of Harmonic Loads ________
Horse Power of Motor Loads ________
kVA of all Other Loads ________
Peak Load kVA and dPF ________
Average Load kVA and dPF ________
Minimum Load kVA and dPF ________

Harmonic Summary:

	Voltage (Volts or %Fund.)				Current (Amperes)			
Harmonic	Peak	Average	Minimum		Peak	Average	Minimum	Harmonic
1								1
2								2
3								3
4								4
5								5
7								7
9								9
11								11
13								13
17								17
19								19
%THD								%THD

Application Information:

Indoor / Outdoor Application ________
Enviromental and Electrical Classification Considerations ________
Circuit Length from Filter to System Connection ________
Dimensional Restrictions ________
Maximum / Minimum Ambient Temperatures ________
Required System Protection ________

Customer Information:

Company Name ________ Phone ________
Contact Person ________ Fax ________
Date Initiated ________ Date Required ________

Form Created 4/95

Figure 2 - Filter Application Guideline Sheet

Where should the Filters be Located?

There are three choices when deciding where to apply harmonic filters: At the Load, At the transformer, or on the Primary Distribution. From application to application the correct choice will differ. Below the pros and cons of each are discussed.

Lets start with the later. At first glance the distribution connection is an attractive location for filters. The filter cost per kVAr will be less, the voltage is higher so the currents will be smaller, and there may be multiple transformers feeding the facility that can be corrected from one location. The down side is that protective devices will be more expensive, the cost of automatic switching is very expensive, and if the distribution is owned and operated by the utility there is little control over neighbors harmonics overloading your filter. For facilities with relatively constant load and that maintain their own distribution, this may be a cost effective solution.

Motor switched capacitors are still quite common, a specific piece of equipment can run at unity displacement power factor and reduce feeder size and voltage drop concerns. Many people have shied away from this practice because it can be a maintenance nightmare and can set up multiple parallel resonance's throughout a facility amplifying harmonics. If these motor switched capacitors are configured as harmonic filters, an additional concern arises, OVERLOAD. Just like the distribution filter being applied to a utility feeder, the filter may be undersized to handle harmonic currents absorbed by neighboring loads. In this case a filter installed and sized for a specific harmonic load may need to absorb harmonics from other nonlinear loads that do not have filters on the same motor control center. This practice is highly discouraged for loads less than 100 kVA to keep the filter from becoming too low of an impedance and should only be installed with a line reactor (choke) as shown in Figure 3.

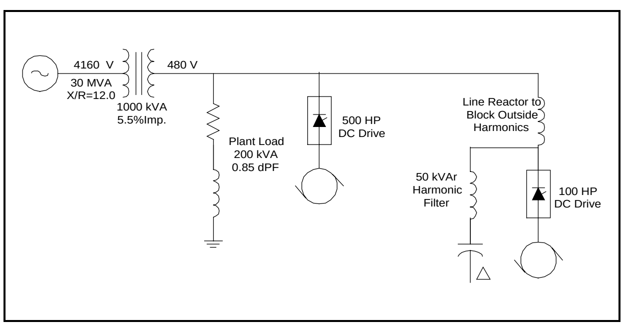

Figure 3 - Application of Filters at Individual Loads

Application of harmonic filters near the load side of the transformer, refer to Figure 1, will typically prove to provide the best performance to cost ratio. The largest impedance in the circuit is the transformer, so losses and system capacity are improved the greatest by shunting current away from it. This approach also rides the middle of the road for reliability and maintenance. There is a unit for each transformer so that the facility is not relying on one or two filters as with medium voltage applications. On the other hand, there are a reasonable number of systems to maintain unlike the many units with motor switched applications. The primary advantage of this is that automatic switched systems are economically feasible to maintain unity power factor at each transformer. This of course minimizes the kVA that the transformer must supply to the load.

Should they be Fixed or Automatic?

Like deciding where the filters should be located, whether or not they should be fixed or switched depends on the application. If an automatic switched system is going to be used, it most likely will be applied at the load side of the distribution transformer. The primary reasons to use an automatic system is to release the maximum capacity from the supply system and to avoid excessive capacitance on the line during lightly loaded conditions. The two main drawbacks are: if the installation and protection cost are not incorporated as part of other types of installations, then the per kVAr cost of a low voltage automatic system will be larger than any other installation and second there is a concern about over loading the filter system under lightly loaded conditions. The later will be discussed further in the component section, but can often be overcome by incorporating a fixed bank filter in conjunction with the automatic filter.

How Big do they need to be?

Sizing of harmonic filters can be accomplished by various methods: rules of thumb, hand calculations, computer simulations, etc. The bottom line is that one must determine how much harmonic current each filter section will absorb. Once this is done, harmonic filter components may be designed with appropriate margins for overload. As a rule of thumb, a 480V 100kVAr filter tuned to the 4.7^{th} harmonic should be applied for every 80Arms of 5^{th} harmonic produced by the load. For instance, if the load of a facility produced 400Arms of 5^{th} harmonic current it should be expected that a 500kVAr filter would be required. This should be used only as a starting point and it may be possible to design a smaller filter to handle the same current. This rule of thumb is only provided so that a conservative estimate can be made. It is recommended that a more comprehensive analysis be done for all applications. For a one or two transformer facility, hand calculations or a simple spreadsheet analysis should suffice. For a larger facility with multiple transformers, a program such as the Electrotek Concepts SuperHarm$_{tm}$ harmonic analysis software should be used.

Filter System and Component Selection

<u>Capacitors</u>

The capacitors should comply with the requirements of IEEE Std 18-1992 for allowable overload limits:

- 110% of rated rms voltage
- 120% of rated peak voltage
- 180% of rated rms current
- 135% of rated reactive power

Request from the filter manufacturer what the expected values for each of the criteria are for capacitors in your filter system. This information will be used later as a base for the verification process.

A controversial topic is whether to use dry or oil filled capacitors. For harmonic applications, **specify oil filled**. This is becoming difficult as more and more capacitors from Europe are being used in the United States and these are primarily of dry construction. Capacitors are constructed of a foil conductor laminated to either a polymer dielectric or kraft paper with a polymer dielectric between layers. These layers are then rolled to form a cylinder. Several of these cylinders are connected in parallel for each phase and then a three-phase configuration before being placed in a metal or polymer case. The polymer dielectric traps heat between the layers. With the increased losses induced by large harmonic currents, an effective means to release heat from inner layers must be used. In what is known as a soggy film (kraft paper) capacitor, the kraft paper will wick oil between layers helping to conduct heat from within the capacitor. This is not possible with a Metalized Polypropylene constructed capacitor because no material that will wick oil exists. In addition to this, the ends are often covered with metalized “End Spray” which creates a barrier between the ends of each layer prohibiting oil from passing. Even though oil can’t get between the layers, it is felt that it is still beneficial to have oil which surrounds each roll and is able to get heat to a preferably metal shell, or one that can conduct the heat to the ambient air. No official comparison test have been published, but several filter systems with degraded dry capacitors have been witnessed and no oil filled capacitors in comparable or worse harmonic applications have been found.

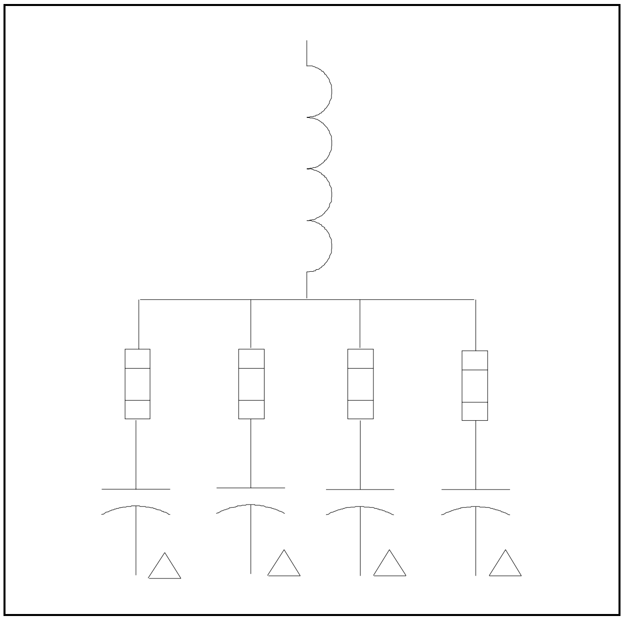

Figure 4 - Filter with Multiple Capacitors per Step

When large fixed banks are constructed it is necessary to gang capacitors together with a single reactor, see Figure 4. This practice should be avoided unless necessary. For low voltage systems, capacitor cells are available up to 200 kVAr, so only fixed filters larger than this would require multiple cells. Below this size should utilize one cell with one reactor. This way if a problem occurs with a cell (bad connection, failure, clearing of protective device, etc.) the filter will be out of service instead of detuning. The danger in detuning is that the filter tuning frequency will increase and go above the nominal frequency. As this occurs, the filters corresponding parallel resonance approaches the nominal tuning point, amplifying current at that frequency instead of absorbing it, see Figure 5.

Often times capacitors with a larger rms voltage rating than the line voltage are used. This is because a slight voltage rise occurs across the filter reactor creating a higher voltage at the capacitor than that of the power system. The price of doing this is that the available reactive power per cell is reduced by the square of the voltages. For instance, 600V capacitors applied to a 480V system will only yield 64% of the nameplate reactive power (kVAr). Typically if capacitors meeting the IEEE Std 18 are used, than 480V capacitors may be applied to a 480V system with moderate harmonic duty. It is important that the filter manufacturer knows what the peak system rms voltage recorded for the facility was and that they calculate the voltage rise of the system with capacitors on-line to assure that derated capacitors will not be required. As the tuned frequency

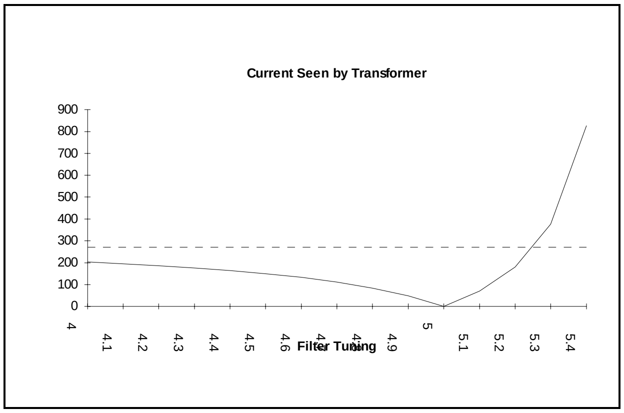

Figure 5 - Transformer Current vs. Filter Tuning

of a filter is decreased, voltage rise will increase at the fundamental frequency. So the voltage at a capacitor in a filter tuned to the 4.2nd harmonic will be higher than that of a filter tuned to the 4.7th harmonic. Therefore this is of greater concern with lower order filters.

Reactors

Up to 5kV applications, reactors typically are iron core dry type. This is due to control of the magnetic field and compactness as compared to an air core reactor. There is no standard that exist to address harmonic reactors, but most manufacturers use ANSI/IEEE C57.12.01 (General Requirements for Dry-type Distribution and Power Transformers) as a guideline.

For low voltage applications, reactors typically are not given a BIL test. The insulation should have as a minimum a low frequency voltage test, (Hi-Pot) on each phase to ground. This test is typically on the order of 10 times the rms voltage rating. ANSI/IEEE C57.12.01 suggest 4kV on 480V systems. If a similar field test is to be performed, consult with the filter manufacturer on the values to expect and the procedure to be used.

Single phase vs. three phase reactors is a decision not to be taken lightly. Fine-tuning of a harmonic reactor is done by adjusting the air gap. With a three-phase reactor the fringing characteristics are different for the center leg than they are for the outer legs, which will affect the flux density and inductance of that phase. This is a tough physical characteristic to overcome, being all three gaps are usually the same for a three-phase core. There are techniques that allow three-phase reactors to be tuned reasonably balanced, but it takes additional care to do and there are manufacturers that do not realize this. By using a distributed gap, instead of a single gap as with an E-I lamination, this effect can be minimized. On the other hand, with single-phase reactors each phase may be individually tuned and adjusted. Understand that with low voltage reactors, once the epoxy is applied and baked the only way to adjust inductance is to replace the reactor. To assure proper tuning, the manufacturer should do an inductance measurement at rated current near the tuned frequency for each phase of each reactor.

Switching Devices

When applying automatic systems below 1000V, it is typical that a mechanical switching device (contactor) will be used. These need to be rated for capacitor switching and have a voltage rating in excess of the line voltage. Figure 6 shows the voltage across the contacts of a contactor as it opens. The line reactor dampens the transient as it propagates to the power system, but the switching device contacts will see a substantial voltage. In theory, this voltage can approach two times the system peak voltage. Internal discharge resistors of low voltage capacitors along with proper switching delays, at least one minute, minimize the closing transient which in theory could approach three times peak. If switching transients are of great concern, than costly solid state switching devices with zero crossing detectors may be justified.

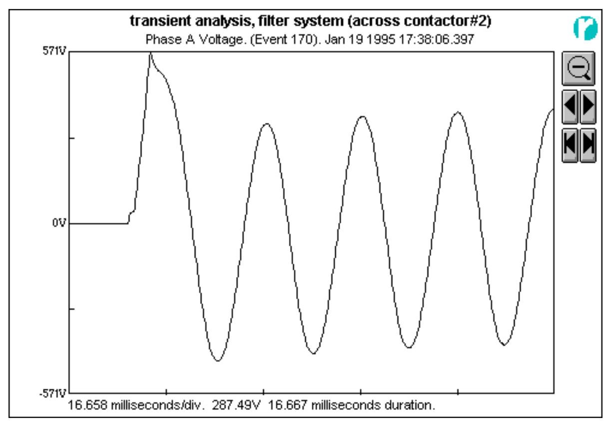

Figure 6 - Voltage Across Filter Switching Device

Protection

Capacitors that have a UL rating will have internal expansion links to avoid case rupture. As an additional precaution it is recommended that all three phases of capacitor cells be fused. Ideally, these fuses will be located in front of the switching device, reactors as well as the capacitor to provide short circuit protection of the entire filter section without effecting adjacent sections. The National Electric Code requires 135% over-current protection for capacitors, but this value will approach 180% for filters.

The primary cause of reactor failure is the over heating of the insulation system. Reactors of this type typically have a 200^{o}C insulation system, although it is possible that they have a 150, 185, 200 or 220^{o}C rating. If the hot spot of the winding is operated near these ratings, UL reports the life expectancy to be at 20,000 hours (2.3 years). Thermal aging data shows that for every $10^{o}C$ below the maximum rating that an insulating system is operated, the life expectancy doubles. For example, if a $200^{o}C$ insulation system is used in a harmonic reactor designed for $115^{o}C$ average temperature rise in a $40^{o}C$ ambient the life expectancy would be 160,000 hours, or just over 18 years. The hot spot will be approximately $15^{o}C$ higher than the average temperature. $[200^{o}C - (40^{o}C + 115^{o}C + 15^{o}C) = 30^{o}C$, $30^{o}C/10^{o}C=3$ so the life expectancy doubles three times. At least one phase of a filter cell should have temperature cutout protection imbedded near the hot spot that will take that section off line when the hot spot temperature approaches $180^{0}C$. Recognize that the hot spot temperature will be significantly higher than any spot on the surface of the reactor. When applying filters at voltages above 1000V, embedded temperature cutouts may not be possible due to the degradation of BIL rating.

Filter detuning protection is a great feature that is not very common due to the competitiveness of the filter business. As the end user of a harmonic filter, it is money well invested to specify detuning protection. If multiple capacitors are grouped with a single reactor, as discussed previously, it is essential to require detuning protection, to prevent parallel resonance amplification.

Component Tolerances

It is often assumed that a harmonic filter is precisely tuned to the specified frequency. Just like cutting a piece of wood, filters are usually tuned near the intended mark. What makes the difference between vendors that assemble reactors with capacitors from one who builds harmonic filters is tolerance management. If a capacitor is built to IEEE-18, 1992 then it will have -0 / +15% of the nameplate capacitance. From observation it is rare to find low voltage capacitors with less than +4% and more than +10% capacitance with the majority being near +8%. The key is that a filter vendor has very little control over the tolerance of capacitors because they are produced in mass production.

On the other hand, the tuning reactors can be adjusted in their pre-epoxy bake to control the tuning point. No standard presently exist for filter reactors, although ANSI C57.16 is often referenced. Between consultants and manufactures there is little common ground on what these tolerances ought to be. C57.16 suggest -3% to +7% and others say +/- 2.5%. When talking about low voltage filters there are two facts: typically there are not enough turns on the reactor to allow the use of multiple taps and while a manufacture can hold tolerances within a 5% span most will not guarantee shorter than 10%. This means that a tolerance needs to be selected that is going to optimize the tuning frequency and that there is little hope for field adjustment. Based on the capacitor tolerances, it is clear that reactor tolerances should be +0% to -10% realizing that the manufacture will target -5%.

The effect of tolerances will now be demonstrated:

$$f_{\text{tuned}} = f_{\text{nominal}} \bullet \frac{1}{\sqrt{(1+t_r)(1+t_c)}}$$

f_{tuned}	Actual Tuned Frequency
f_{nominal}	Specified Tuned Frequency
t_r	Reactor Tolerance (pu)
t_c	Capacitor Tolerance (pu)

Lets say that a filter is specified to be tuned to the 4.7th harmonic. Using the above equation tuning point ranges have been calculated. In both cases the capacitor tolerance are -0 / +15 with expected to be +8%. First we will look at the range with a + / - 2.5% tolerance with expected to be 0%. This results in a range from the 4.33rd to the 4.76th and an expected value of 4.52nd. Next we use the +0 / -10% with expected to be -5%. This results in a range from the 4.38th to the 4.95th and an expected value of 4.64th harmonic.

Another concern in low voltage applications is the feeder inductance from the filter unit to where it is connected to the power system. Reactors for these systems will be on the order of 100's of µH. It is not unusual for long cable inductance's to be a few µH which will significantly affect the filters tuning frequency as seen by the power system.

When determining what frequency your harmonic filters need to be, do not forget to figure out the tolerances including the feeder cable inductance. Being the manufacturer has more control over the reactor tolerance than that of the capacitors, it is recommended that a range of acceptable tuning points for the assembly be provided instead of tolerances for individual components. If tuning is critical, advise the filter vendor so that components with tighter constraints are utilized and prepare to pay a premium.

Selecting a Qualified Vender

The key here is to use common sense. Even though it is important to use vendors that are involved in national standards committees and other power quality working groups, over the telephone any company can seem to be an expert. Make sure they take the time to explain their approach to filter application, this business is as much about educating the customer as it is about building quality equipment. Request a customer list with references to contact. Specifically ask if there are projects that had difficulties and to speak to a contact at one of those facilities. If a vendor says that all of there jobs have gone off without a hitch, they are either lying or haven't been building filters for very long. It is more important to know how the vendor reacts when an occasional project goes sour than to hear about the long list of successful applications. Finally, ask about warranties on individual components, the complete system, and performance.

What to Expect when the Filters Arrive?

Low voltage filter systems cost between $50 and $75 per kVAr with special applications approaching $100 per kVAr. For example, a 600 kVAr fully automatic system will be on the order of $35,000. Don't be too disappointed when a gray box with some other gray boxes and copper coils wrapped around an iron core shows up at your facility. Think of it on the lines of a transformer at five times the cost: It is a lot of money for a gray box that sits there and hums, but the plant can operate a lot better with it. Also keep in mind that in many parts of the country the reduction of utility demand charges will provide a less than two-year payback.

Measurement of Filters for Verification

Once a harmonic filter is installed, it is important to verify its performance and the magnitude of critical parameters of the individual components. Verifying the performance of the filter assures that it is doing what the manufacturer said it would, along with providing valuable information to improve computer simulations. Measurement of critical parameters are important to assure that the filter rating is not exceeded. In addition, this gives a bench mark for evaluating the filters condition as it remains in service.

Figure 7 shows the meter setup for measuring the harmonic filters performance. The diagram shows the ideal situation where one current transformer (CT) is used to measure the load, one for the filter, and one CT for the transformer. Space restraints and load connection points may make this connection more difficult. It is important to use a meter that will sample all of the transducer channels simultaneously (or near simultaneously) and that all the probes be connected to a common phase so that a correlation between the three currents may be made. The values in Table 1 were taken when the Sample System, shown in Figure 7, had the drive operating at 500 kVA and 500 kVAr of harmonic filter was connected.

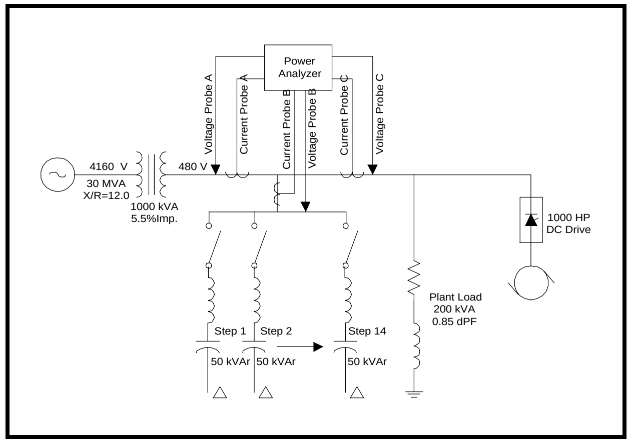

Figure 7 - Meter Setup for Filter Performance Measurement

Table 1 shows that of the 138 A of 5th harmonic current being injected into the system, the filter shunts away 130 A, leaving 8 A to the utility power system. For this simple example, the phase angles have been omitted. If utility voltage distortion were present, it is possible that the filter would shunt all of the drives 5th harmonic current and sink harmonic current from the utility system. This is why paying attention to phase angles and looking at the three points shown in Figure 1 is important.

Table 1 - Measured Currents

Harmonic	Transformer Probe A (Amps)	Filter Probe B (Amps)	Load Probe C (Amps)
5	8	130	138
7	22	43	65
11	12	16	28
13	9	12	21

Parameter	Rated	Measured
Wye Equiv. Cap. Range (uF)	575 - 633	610
Peak Voltage (Vpk)	800	692
Current (Arms)	108	64
Reactive Power (kVAr)	68	56
RMS Voltage (Vrms)	528	500
Inductance (uH)	498 - 553	524
5th Harmonic Current (Arms)	45	13
7th Harmonic Current (Arms)	10	5
11th Harmonic Current (Arms)	5	2
13th Harmonic Current (Arms)	5	2
Total Current (Arms)	80	64
Harmonic Filter Tuned Harmonic	4.48 - 4.95	4.69

Figure 8 - Sample Filter Verification Table

To create a benchmark for comparison of future test, critical parameters should be recorded. Figure 8 shows typical measurement results from such a test. The filter manufacture needs to provide the information shown in the rated column. The measured values are obtained using the following technique.

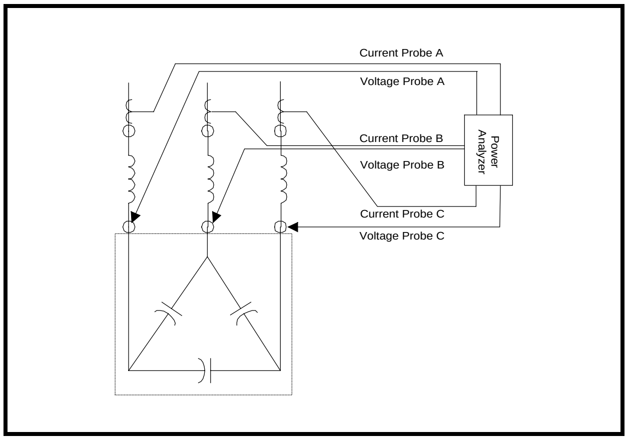

Figure 9 - Meter Setup for Capacitor Limit Measurement

To find the capacitor parameters, the meter setup is as in Figure 9. It is important that the voltage probes be connected at the terminals of the capacitor. The power analyzer will display the values of Peak Voltage, Current, Reactive Power, and RMS Voltage. These values are recorded and compared with the rated values provided by the manufacturer.

What to do when Things go Wrong?

Here is where talking to the manufacturers other customers ahead of time pays off. While most filter applications are done without any problems, there are a small number that do occur. Most common with low voltage applications are tuning out of tolerance and filter overload leading to premature failure.

Tuning out of tolerance may or may not be critical depending on the goals of the project. If the filter is out of tolerance and forces tuning above the harmonic frequency injecting current into the system, i.e. a 5th filter tuned to the 5.2nd, the system needs to be modified to avoid amplification due to parallel resonance. On the other hand, if tuning is lower than anticipated, performance compared to the project goals need to be assessed to determine the action taken.

More serious is a filter that is over loaded. It is more common then preferred to see a filter be applied based on measured utility distortion, say one or two percent, then six months later the reactors burn up or nuisance trip due to overheating protection. The utility distribution is active with system reconfiguration and new customers and loads being connected continuously. The IEEE-519 allows utilities to operate with 5% Vthd and 3% distortion at any one frequency. These values should be assumed regardless of what short term monitoring show. This also shows the importance of temperature protection. If the problem does arise, it is best to meet with the utility and manufacturer to discuss utility system changes that have occurred that may have caused the increase in distortion. It will require the cooperation of all three parties to determine the best solution to rectify the problem. This may incorporate utility system changes, modification of the filter system, and/or additional filtering at neighboring facilities.

Conclusions

Application of harmonic filters is a sizable investment for any facility. It is worth investigating harmonic filter vendors for their technical capability and rapport with past customers. The importance of talking with a customer that had a difficult installation can not be emphasized enough. If it is a small installation, make sure the chosen vendor takes time to educate you to a point where you feel comfortable. For larger installations an independent consultant may be preferred, utilities and filter manufacturers are a good source to refer someone. A systems approach should be taken as opposed to applying a filter for a single piece of equipment. After the filter is installed, take verification measurements to assure compliance with the specification and to have a base case measurement to compare to the filters performance in years to come.

References

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[4] IEEE Std 1036-1992, IEEE Guide for Application of Shunt Power Capacitors

[5] ANSI/IEEE Std 59-1992, IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems.

[6] ANSI/IEEE Std C57.12.01-1989, IEEE Standard General Requirements for Dry-Type Distribution and Power Transformers Including Those With Solid Cast and/or Resin-Encapsulated Windings.

Biography

Brian Prokuda, P.E. Presently performs power quality investigations, trouble shooting of power and control systems and failure analysis. He holds both Professional Engineering and Electrical Journeyman's licenses in the State of Michigan and a BSEE and MSEPE from Michigan Technological University and Rensselaer Polytechnic Institute respectively. Currently Brian is a member of the IEEE Capacitor Subcommittee and Harmonics Committee. As a member of the Harmonics Committee, Brian is co-writing several sections dealing with capacitor and filter installations for the IEEE-519A, Harmonic Controls Application Guide. Prior experience included two years of designing and constructing harmonic filters for Var Controls, Brian headed up the data collection for the EPRI Distribution Power Quality project that was performed by Electrotek Concepts, Inc. and designed process control and drive systems for the Dow Chemical Company.