DISTRIBUTE HARMONIC MITIGATION SOLUTIONS FOR BEST RESULTS

by

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Abstract: Harmonic mitigation equipment is often considered only after a facility has experienced financial loss or exposure to symptoms associated with poor power quality. All too often, a macro view of the situation results in a large piece of expensive equipment being applied to the bulk power distribution system. Although this solution may be the easiest to apply, and involve the least analysis, it may not be the best economical solution for the facility. In many cases, careful analysis of the root cause would suggest a smaller, localized and more economical set of solutions. Harmonics-related problems are best solved as close as possible to the source of the harmonics to minimize the impact on other pieces of equipment. The application of localized solutions can reduce the complexity and cost of the overall harmonic mitigation project, increase the availability of the equipment and improve the general level of power quality within the facility.

Whether discussing a utility power distribution system or facility power system, the greatest benefits in power quality and energy efficiency are realized when harmonics are mitigated as close as possible to their source. In addition, the solution is often simpler and more economical when applied at the source of harmonics.

Facility Voltage Distortion

When non-linear loads demand harmonic currents, those harmonic currents will flow from the power source through transformers, switchgears, distribution panels and conductors all the way to the load itself. As the harmonic currents flow through system impedances, they cause voltage drops at each of the harmonic frequencies. Ohm's Law defines the voltage at each frequency as:

$$V_h = Ih \times X_{Lh} \qquad \text{Eq. 1}$$

The rms value of these individual harmonic voltages appears as voltage distortion on the facility (or distribution) power system. The magnitude of voltage distortion is calculated as

$$\% \text{ THD-V} = V_h / V_f \times 100 \qquad \text{Eq. 2}$$

The greater the impedance through which the harmonic current flows, the higher is the harmonic voltage drop and the greater is the harmonic voltage distortion. Fig. 1 illustrates a simple power distribution. If the load demands harmonic current, then the distortion current flows from the power source through the source impedance (Xs) and through the transformer impedance (Xt) to the load. The purest voltage is measured and available right at the utility generating plant because it is purely sinusoidal at this point.

However, as the harmonic current flows through distribution system impedance and facility impedances, the harmonic voltage drops become more pronounced and thus the voltage becomes more distorted. Therefore, higher harmonic voltage distortion will be present at the primary of the transformer due to Vh = Ih x Xs, and a higher voltage distortion will be present at the secondary of the transformer due to Vh = Ih x (Xs + Xt).

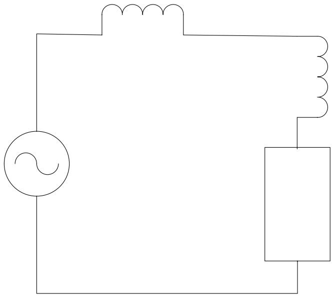

Fig. 1 simple power distribution circuit

Mitigation Equipment Location Alternatives

Generally, harmonic mitigation equipment can be applied either at an individual load (or group of loads) or at a central location such as a panelboard, MCC or transformer. With typical harmonic filters, that are shunt-connected or have a shunt element, the benefit in reduced harmonic current distortion is realized only upstream from the point where the filter is connected. Harmonic currents continue to flow between the mitigation equipment and harmonic-producing loads and will continue to contribute to network voltage distortion. This implies that whether for a power distribution system or for a facility, it is usually best to connect the filter as close to the harmonic producing loads as possible so that it may have the maximum benefit for the entire system.

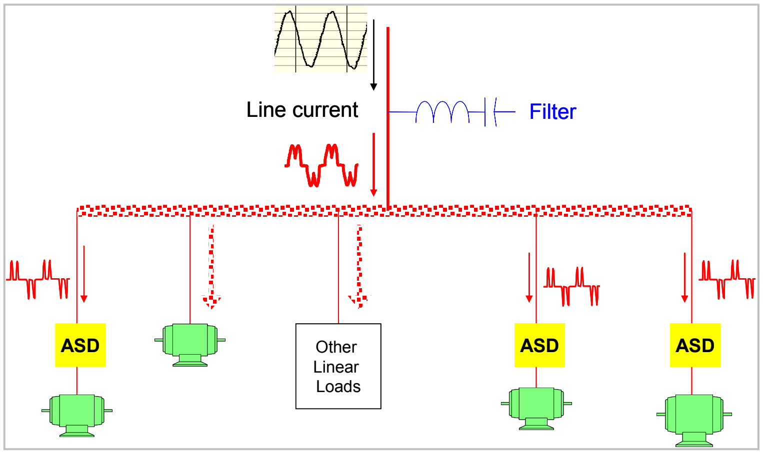

Fig. 2 Harmonic filter connected at central location – distorted bus voltage

Fig. 2 demonstrates the flow of harmonic currents when a filter is applied at a central location which is upstream from the loads and when a common power source supplies both linear and non-linear loads. The flow of harmonic currents between filter and non-linear loads, causes distorted bus voltage which in turn contributes to the flow of distortion current in the linear loads.

Fig. 3 demonstrates the current flows for the same loads, but using harmonic mitigation equipment that is connected as electrically close as possible to the non-linear loads as possible. In this case, the flow of harmonic current is primarily restricted to those conductors between the non-linear load and the filter. The voltage bus, which is common to the entire set of loads, is now clean, and if viewed with an oscilloscope, would be nearly a pure sine wave. The linear loads now draw sinusoidal current, as they would be expected to if they were supplied from a sinusoidal voltage source.

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Loads that are supplied from a distorted voltage source will draw harmonic currents which can increase equipment operating temperatures, reduce life expectancy and increase power losses. Some sensitive electronic loads, especially those that demand a sine wave reference, or involving timing circuits may cause errors or malfunction when supplied from a distorted voltage bus.

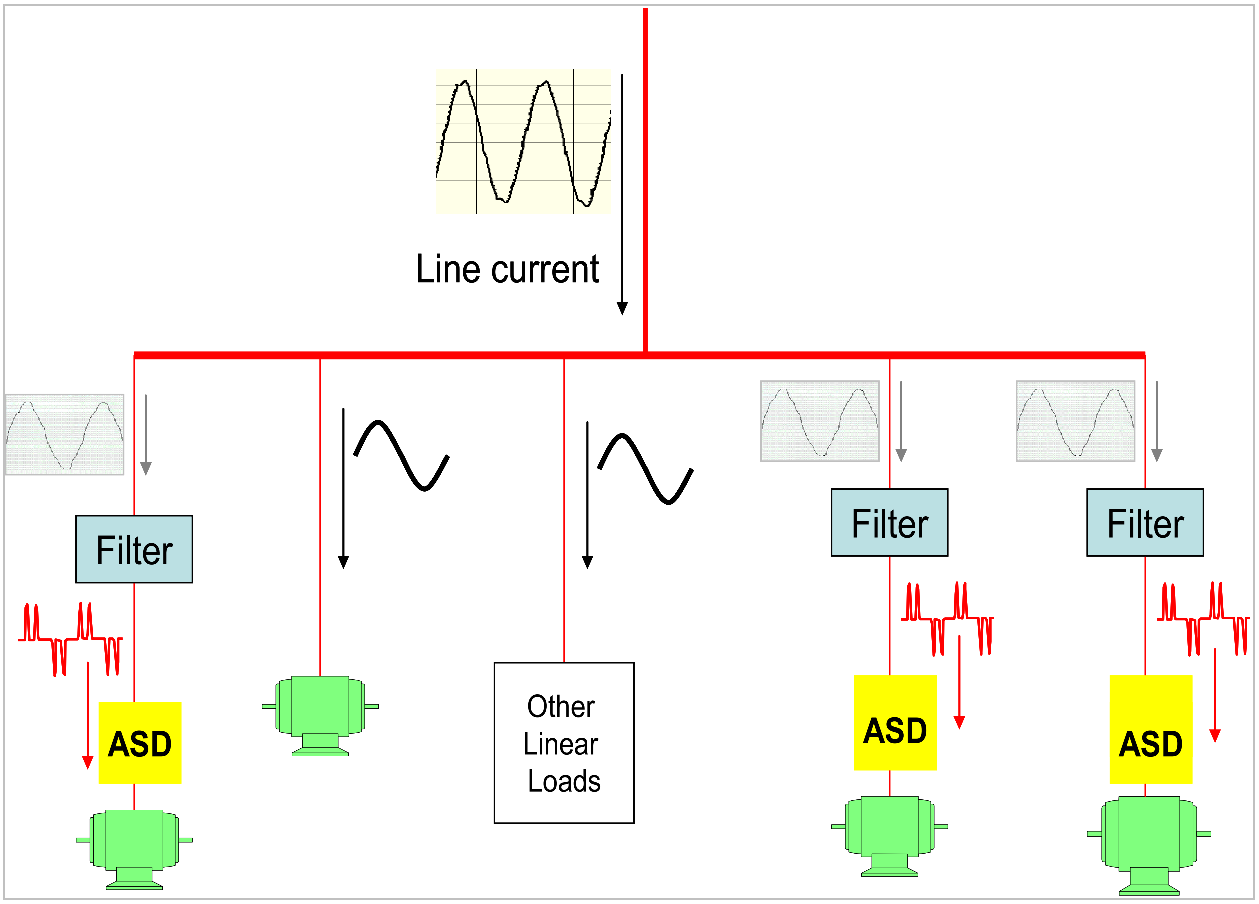

Fig. 3 Harmonic filters connected at loads – near sinusoidal bus voltage

The filters in Fig. 3 are applied electrically close to the non-linear loads that produce harmonic distortion. This approach results in a relatively non-distorted voltage source for all loads, linear as well as non-linear. Not only are power quality objectives, such as those outlined in IEEE-std-519, met at the point of common connection (i.e.: utility metering point) but the highest level of power quality is also achieved on the facility electrical power system. This technique can provide a direct benefit to the facility itself, as well as meeting harmonic distortion levels for the utility.

Economics of distributing mitigation equipment at the load

Initially, it may seem less expensive to apply a single harmonic filter at a central location (Fig. 2) that is upstream of all non-linear loads (i.e.: transformer, panelboard, switchgears). In some cases this may be true. However, when multiple loads are involved or when load conditions vary due to equipment speed or load changes, the bulk filter needs to be adjusted to match the load. This requires a controller, automatic switching capability and multiple steps of harmonic filtering.

For comparison, a simple system containing three non-linear loads (50HP, 100HP and 250HP) was considered. Individual filters can be applied at each of these three loads for less than $20,000., based on the average of list prices from three major equipment suppliers. The multi-step (4 or 6), automatic filter (150kVA) for bulk connection at a central upstream point in the system has an average cost of over $25,000.

In this simple, but realistic case, the bulk solution can exceed the cost of distributed mitigation by more than 25% and only benefit the utility in terms of power quality improvement. The facility owner paid for the equipment, but only the utility received the benefit. The harmonic current continued to flow on the facility electrical power system and contributes to voltage distortion on their system.

The distributed mitigation solution not only was accomplished at the lower cost, but also achieved superior power quality in the facility. Some of the internal benefits include improved voltage quality, reduced current distortion, reduced trms current, reduced kVA demanded from facility transformers, reduced transformer losses, reduced transformer heating, longer equipment life.

The application of harmonic filters at individual loads (Fig. 3) enables each filter to be sized and applied for its respective harmonic producing load. This method applies the proper filter capacity with the actual load, without requiring a special controller and switching contactors. If the filter includes a series input line reactor, the filter is detuned relative to the power system and the possibility of resonance or attraction of harmonics from other loads is virtually eliminated. When the load is not operating, the local filter will typically supply reactive power, but if this is not beneficial, a contactor may be added to disconnect the filter.

Utility Power Distribution Systems

Utilities deal with the problem of combined effects of harmonics contributed by multiple customers. Although the utility furnishes sinusoidal voltage, typical power electronic loads draw current in gulps, rather than sinusoidally. This causes distortion all the way back to the power source and can affect other loads that share the power source and distribution system.

The task of reducing distribution system distortion is more difficult to solve. The alternatives include adding filters: upstream at the substation, on distribution poles, at the primary side of customer transformer, or on the customer side of the transformer. Similar to facility power systems, the greatest benefit is realized when harmonics are suppressed as close to the load as possible.

The problem of applying filters at the substation transformer primary is that the benefit is realized upstream – on the transmission system, not the distribution system. If applying on the substation transformer secondary, then again the benefit is realized in the transformer and transmission system. Additionally, it is difficult to size a filter for the distribution system because it will be capable of attracting harmonics from throughout the distribution system. Careful

analysis is required to determine the impedance at the tuned harmonic frequency relative to multiple customers on the system.
A worthwhile consideration for adding either capacitors or filters to a medium voltage distribution system would be to use detuned capacitors or filters. If a power factor capacitor is desired, then by detuning it (adding a capacitor protection reactor), the capacitor represents higher impedance at the harmonics frequencies. This can prevent a resonance condition and also restrict the magnitude of harmonics current flowing in the capacitor. If a filter is desired, then a detuned capacitor achieves a limited amount of harmonic filtering with less chance for resonance problems and with restricted harmonic current flow in the capacitor. However, it is important to realize that even with shunt-connected harmonic filters on the distribution system, harmonics may continue to flow between the customers with non-linear loads and the filters.

Since non-linear loads cause harmonics, harmonic mitigation should rightfully be the responsibility of the customer, not he utility. Customer harmonics increase distribution system losses and distribution transformer losses, and may cause premature failure of distribution system capacitors. Utilities would therefore be justified in assigning responsibility for harmonic filtering at the customer facility. Not only would this solve the harmonics problem closer to the non-linear loads, resulting in maximum benefit everywhere upstream, the impedance of the customer transformer could help to detune the filters relative to the distribution system as well.

Conclusion

Whether for electrical power distribution or facility power systems, in most cases, harmonic mitigation can be applied close to the non-linear loads to achieve best overall performance. The complete set of benefits including reduced current and voltage distortion, reduced kVA demand, and reduced transformer (I^2R and eddy current) and system losses (I^2R) are realized within the facility as well as by the utility. Depending on the distance and circuit topology, it may be possible to realize system energy savings from 2% to 4% on the KWH consumption. In many cases, it is not only simpler to apply filters at individual loads, but it may also be more cost-effective.

References:

IEEE-std 519

AUTHOR BIOGRAPHIES

Cesar Chavez is Manager of Electrical Engineering (Low Voltage products) at ARTECHE / Inelap, a leading North American manufacturer of electrical power quality systems. He earned his Master’s degree I Electrical Engineering from the Instituto Politecnico Nacional of Mexico. Chavez’s career has involved managerial responsibilities in MCC production, field engineering and design engineering. He has held positions responsible for the production, design, and commissioning of electrical power quality equipment. .Chavez has extensive experience in the design, application and commissioning of reactive compensation and harmonic mitigation equipment. His expertise encompasses both passive and active solutions.

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