Power Quality

and Power Factor Correction

Introduction

Since most loads in modern electrical distribution systems are inductive, there is an ongoing interest in improving power factor. The low power factor of inductive loads robs a system of capacity and can adversely affect voltage level. For this reason, power factor correction, through the application of capacitors, is widely practiced at all system voltages.

A number of manufacturers have catalogues and design manuals to assist in the application of their products. These publications provide guidance in the selection and placement of capacitors and discuss general provisions that will affect the overall performance of the installation.

Although the methodology for applying capacitors is relatively straightforward, there are a number of influencing factors that must be considered. To ensure that the capacitor installation does not create more problems than it solves, consideration must be given to non-linear loads, utility interaction and system configuration.

This brochure was developed to provide commercial/industrial facility personnel with a straightforward guide for the specification, purchase, installation and operation of power factor correction equipment in the vicinity of harmonic-producing loads. When used properly, it can help you avoid the impacts of related power quality problems on plant equipment.

After reading this brochure, you should consult a qualified engineering firm and a licensed electrician who has the training, experience and knowledge of the Canadian Electrical Code as well as an understanding of the importance of following accepted proper wiring practices as they relate to electric power quality.

Furthermore, a close working relationship must be established with your utility, equipment manufacturers and, possibly, nearby facility managers to ensure that information is shared if problems are encountered.

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Harmonics and resonance

Harmonics

The objective of the electric utility is to deliver sinusoidal voltage at fairly constant magnitude throughout their system. This objective is complicated by the fact that there are loads on the system that produce harmonic currents. These currents result in distorted voltages and currents that can adversely impact the system performance in different ways.

As the number of harmonic-producing loads has increased, it has become increasingly necessary to address their influence when making any additions or changes to an installation.

To fully appreciate the impact of this phenomenon, there are two important concepts to bear in mind with regard to power system harmonics. The first is the nature of harmonic current-producing loads (non-linear loads) and the second is the way in which harmonic currents flow and how the resulting harmonic voltages develop.

Linear and non-linear loads

A linear element in a power system is a component in which the current is proportional to the voltage. In general, this means that the current wave shape will be the same as the voltage (see Figure 1). Typical examples of linear loads include motors, heaters and incandescent lamps.

On the other hand, the current wave shape on a nonlinear load is not the same as the voltage. Typical examples of non-linear loads include rectifiers (power supplies, UPS units, discharge lighting), adjustable speed motor drives, ferromagnetic devices, DC motor drives and arcing equipment.

The current drawn by non-linear loads is not sinusoidal but periodic, meaning that the current wave looks the same from cycle to cycle. Periodic waveforms can be described mathematically as a series of sinusoidal waveforms that have been summed together (see Figure 2).

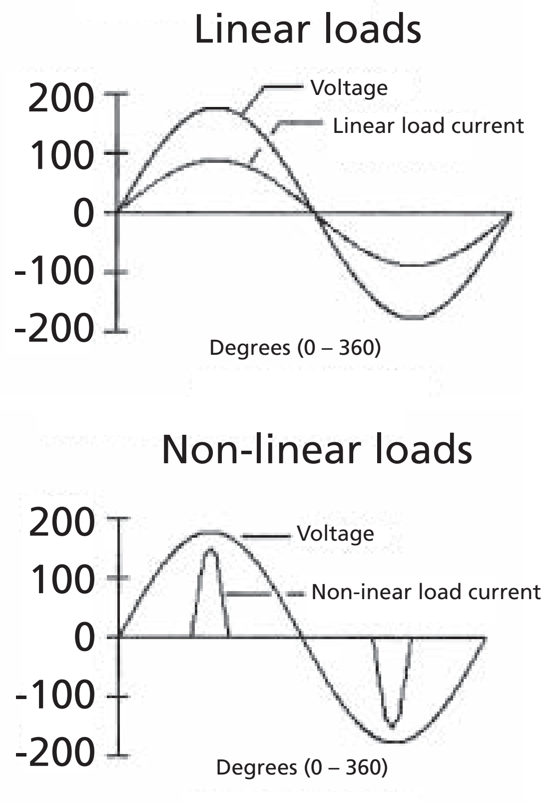

Figure 1. Voltage and current waveforms for linear and non-linear loads

The sinusoidal components are integer multiples of the fundamental where the fundamental, in Canada, is 60 Hz. The only way to measure a voltage or current that contains harmonics is to use a true-RMS reading meter. If an averaging meter is used, which is the most common type, the error can be significant.

Each term in the series is referred to as a harmonic of the fundamental. The third harmonic would have a frequency of three times 60 Hz or 180 Hz. Symmetrical waves contain only odd harmonics and unsymmetrical waves contain even and odd harmonics.

A symmetrical wave is one in which the positive portion of the wave is identical to the negative portion of the wave. An unsymmetrical wave contains a DC component (or offset) or the load is such that the positive portion of the wave is different from the negative portion. An example of unsymmetrical wave would be a half-wave rectifier.

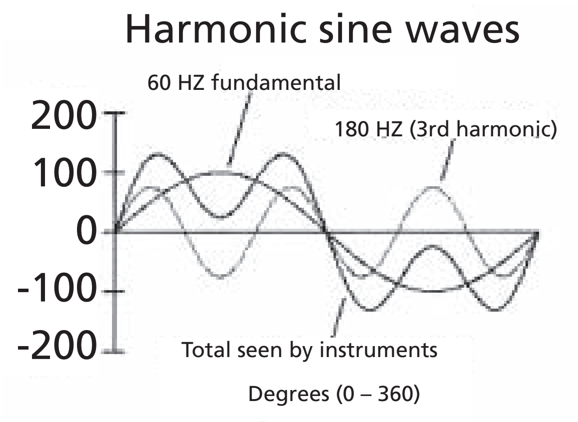

Figure 2. Waveform with symmetrical harmonic components

Most power system elements are symmetrical. They produce only odd harmonics and have no DC offset. There are exceptions, of course, and normally symmetrical devices may produce even harmonics due to component mismatches or failures. Arc furnaces are another common source of even harmonics, and they are notorious for producing both even and odd harmonics at different stages of the process.

Harmonic current flow

When a non-linear load draws current, that current passes through all of the impedance that is between the load and the system source (see Figure 3). As a result of the current flow, harmonic voltages are produced by impedance in the system for each harmonic.

These voltages sum and, when added to the nominal voltage, produce voltage distortion. The magnitude of the voltage distortion depends on the source impedance and the harmonic voltages produced.

If the source impedance is low, then the voltage distortion will be low. If a significant portion of the load becomes non-linear (harmonic currents increase) and/or when a resonant condition prevails (system impedance increases), the voltage can increase dramatically.

Power systems are able to absorb a considerable amount of current distortion without problems, and the distortion produced by a facility may be below levels recommended in IEEE 519 (see references on page 12). However, the collective effect of many industrial customers, taken together, may impact a distribution system. When problems arise, they are usually associated with resonant conditions.

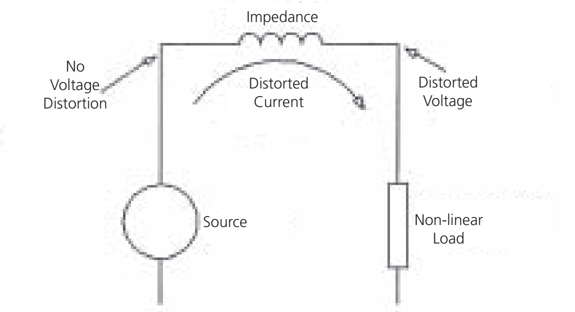

Figure 3. Distorted current-induced voltage distortion

Harmonic currents, regardless of the system resonance point, can produce a number of problems, namely:

- equipment heating
- equipment malfunction
- equipment failure
- communications interference
- fuse and breaker mis-operation
- process problems
- conductor heating

Power quality/power factor correction

Harmonic resonance

It is ironic to think that as steps are being taken to improve the operating efficiency at a facility, those very steps may be adversely affecting the facility in other ways. This is sometimes the case when power factor correction capacitors are installed at a facility. As an example, general application of capacitors on motors, when applied without regard to the connected system, can result in the inadvertent tuning of a system to a dominant harmonic.

Although "harmonic problems" are attributed to many power system problems, the term is sometimes overly used. There are other ramifications associated with the use of power factor correction capacitors, such as voltage rise and switching transients. Each of these power quality concepts will be discussed in turn.

A common problem that occurs when power factor correction capacitors are installed on a system is harmonic resonance. When this occurs, the power system at a facility is tuned to a specific frequency due to a combination of the system inductance and the added capacitance. The system "resonates" at this frequency if there are loads at or near the installation that produce that harmonic.

When this occurs, the normal flow of harmonic currents, from load to utility source, is altered. When the currents can flow normally, they combine with other load currents across the system. If the bulk of those other loads are linear, there will not be a significant percentage of distorted current. However, when the flow is altered by the installation of capacitors and the loads are non-linear, distortion levels may rise, causing problems within a plant, at nearby utility customers or at system substations. In addition, currents may flow where they are not desired, particularly in capacitor banks.

Capacitors can fail with as little as 10% of fifth harmonic content, and this can take place when there are no other noticeable effects on the system. As a result, it has been estimated that 30% to 40% of capacitor installations are not fully functional due to excessive harmonic currents.

A resonant condition can manifest itself in two ways, *parallel resonance* and *series resonance*.

Parallel resonance

When parallel resonant conditions exist, the shunt capacitor banks appear to the harmonic source as being in parallel with the system source reactance (or short-circuit reactance; see Figure 4). When harmonic currents, from the harmonic source, flow through this high-impedance circuit, high harmonic voltages develop. The high harmonic voltages can result in an overvoltage condition on the capacitors themselves and/or high-voltage distortion.

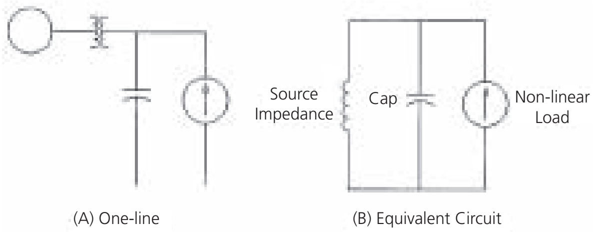

Figure 4. Parallel resonance

Overvoltage conditions can exceed the voltage rating of the capacitor and result in capacitor failure. High-voltage distortion can result in the mis-operation or failure of equipment.

Series resonance

When series resonant conditions occur, the capacitor appears to be in series with line impedance, as seen from the harmonic source (see Figure 5). This presents a low-impedance path to the flow of harmonic currents.

Currents, then, will flow on the system in ways that were unintended. This can result in interference on communications circuits that may be nearby, excessive voltage distortion at the capacitors or conductor heating.

If the capacitors are placed at the end of long feeders, harmonic voltage distortion can occur at the capacitor bank, since the bank acts as a "sink" for harmonic currents originating elsewhere on the system. If the capacitors are placed on the secondary of the service transformer, the capacitor/transformer combination can appear like a series tuned filter.

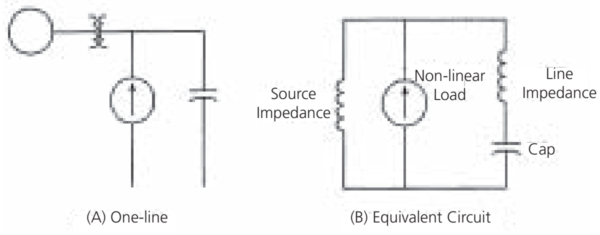

Figure 5. Series resonance

Since this combination behaves like a sharply tuned filter, its resonance at a significant harmonic would result in a very low-impedance path. This would result in a high-voltage distortion on the secondary, while the primary distortion would remain within limits of IEEE 519.

The resonant frequency of this combination can be calculated as follows:

$$h = \sqrt{\frac{kVA \times 100}{kVAR \times Z\%}} \qquad \textit{(Eq. 1)}$$

Where:

h - harmonic number referred to the fundamental
kVA - transformer kVA
Z% - transformer impedance
kVAR - rating of connected capacitors

For example: For a facility with a 1,500 kVA transformer with an impedance of 6.0% (both values are taken from the transformer nameplate or obtained from the utility if they own the transformer) and a 500 kVAR capacitor bank, the result would be:

$$\sqrt{\frac{1{,}500 \times 100}{500 \times 6.0\%}} = 7.1$$

This installation is likely to resonate around the seventh harmonic.

This calculation should be done whether there are harmonic sources at the facility or not. The resonant condition created by the transformer and capacitor may result in high-voltage distortion on the low-voltage side due to harmonic currents that might be present on the utility distribution system.

In a system that is parallel or series resonant at a frequency of concern, resistive load has a significant influence on the harmonic distortion. As the resistive load on the system increases, the overall damping factor of the circuit increases and the sharpness of the resonance decreases (see Figure 6).

When the resistive load decreases, the damping factor decreases and the sharpness of the resonance increases. The sharpness of the resonance determines the impedance that is seen by the harmonic currents. Therefore, harmonic voltage distortion will be worse on lightly loaded systems or systems where the load is mostly motors.

Resonant conditions and the influence of load become particularly important when a plant is operating from on-site generators. The steady-state positive sequence reactance of a generator is much higher than the utility source impedance mentioned above. As a result, harmonic currents produce higher harmonic voltages and overall voltage distortion.

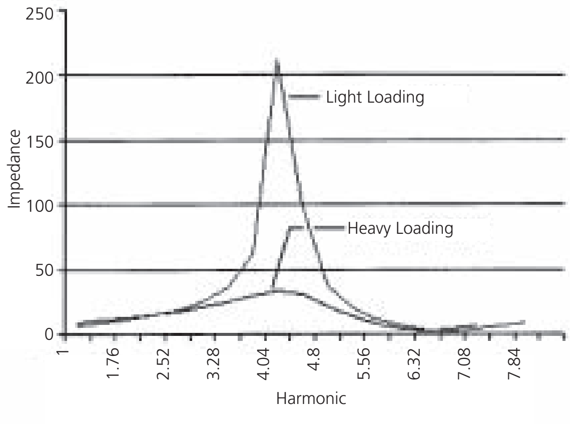

Figure 6. Resonance damping due to load

Additionally, generator regulators and control systems are sensitive to distortion on the voltage bus. If the non-linear load on a plant is a significant percentage of the overall generator load, the generator may not stay online. Furthermore, high harmonic currents cause heating in the alternator iron, which can lead to premature failure.

Switching transients

As mentioned earlier, capacitors are used at all voltage levels. Utilities install them at various locations on their transmission and distribution systems for voltage and VAR support.

When the utility energizes a discharged capacitor, the bus voltage will momentarily collapse. This occurs because the voltage across a capacitor cannot change instantaneously. This is followed by an oscillatory recovery that lasts about one-half of a cycle.

The overshoot associated with this oscillation can result in a peak voltage that has a theoretical peak value of two times the maximum value of the 60 Hz sine wave (crest voltage). The same effect can occur when a capacitor is switched off, if re-strike occurs during the switching operation (see Figure 7).

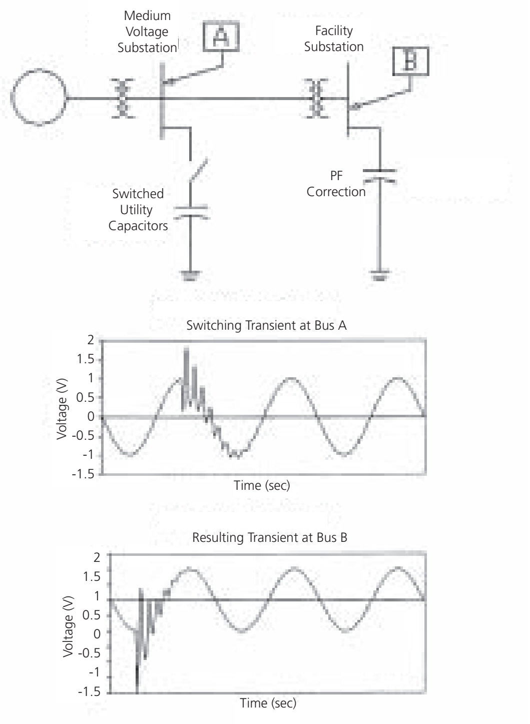

Figure 7. Switching transient

Transients of this magnitude and duration are usually not a problem on the utility system, but they can produce problems at a user facility. Severe overvoltages can appear on facility capacitors through a phenomenon known as voltage magnification.

The voltage at the end-user capacitor can be greater than the voltage at the utility capacitor. This translates to a peak voltage with a theoretical upper value of 400%, although this is rarely seen.

The highest transient voltages occur at the low-voltage capacitor bank when the characteristic frequency of the switching transient is nearly equal to the resonant frequency of the low-voltage system and when the switched capacitor is ten or more times the size of the low-voltage capacitor.

The IEEE Standard for Shunt Power Capacitors, ANSI/IEEE Std. 18-1992, specifies that capacitors "may reasonably be expected to withstand" transient overvoltages from 205% to 354% of rated peak voltage, depending on the number of times a year the overvoltage occurs.

Generally speaking, the voltage magnification will not result in capacitor damage. The problem that usually occurs is the failure or mis-operation of sensitive loads in the facility where the low-voltage capacitors are installed.

Voltage rise

At many facilities, fixed capacitors are used to reduce cost. Fixed capacitors are those that are permanently connected to the load bus and are not switched on and off as the load changes. When the load on the facility is low, the voltage may increase, due to the capacitor being sized for the higher load.

The limit on steady-state voltage is generally taken to be 110% of the rated voltage. If the voltage is allowed to rise above this point, transformers will saturate and overheat, mis-operation of equipment may occur and equipment life will be reduced.

If the prevailing bus voltage happens to be high, due to conditions on the distribution system feeding the facility, the voltage rise would be added to this already higher voltage. Therefore, system voltage should be checked when considering voltage rise.

A simplified calculation for voltage rise is shown below. For a simple installation where the capacitors will be installed at the service transformer, the voltage rise will be:

$$\text{VR\%} = \frac{\text{kVAR (Capacitor)} \times \text{Z\%}}{\text{kVA (Transformer)}} \qquad \textit{(Eq.2)}$$

Where:

VR% - voltage rise is percentage of nominal
kVAR - the kVAR rating of the cap bank
Z% - impedance of transformer
kVA - nominal rating of transformer

For example: From our previous example of a facility with a 1,500 kVA transformer and a 500 kVAR capacitor, the voltage rise that would result if the load were low would be:

$$\frac{500 \times 6.0\%}{1{,}500} = 2\%$$

For a system with a measured voltage of 488 volts, the unloaded voltage with capacitors would be 498 volts, or a 3.7% increase over nominal (480 volts). This value would be compared against equipment specifications and other criteria to determine if the rise would affect the system.

Facility Survey/New Capacitor Installations

Capacitor installations are usually straightforward. However, a number of steps can be taken to ensure that the maximum benefit is derived and there will be no problems when the capacitors are installed. For example, a comprehensive facility survey and cost analysis will indicate whether the benefit from the installation justifies the cost.

Cost analysis

Many times, when a decision has been made to install power factor correction capacitors, the cost analysis has been limited to an examination of the utility bills and an estimation of the likely savings. In most cases this is probably sufficient. However, when there are power quality issues to consider, this type of analysis may not reveal all of the costs.

The presence of non-linear loads, utility capacitors and mis-operating equipment might indicate that power quality problems exist and could be made worse by adding capacitors to a system. The true final cost may also include extended monitoring, an engineering study, relocation of existing capacitors, filter design and installation, switching equipment and/or follow-up measurements and re-work.

To determine what elements may be required, it is best to begin with a facility survey to identify non-linear loads, the size of the service entrance transformer, other plant data and utility information. This information, taken together, is usually sufficient.

In some cases, additional information is required, which may involve extended monitoring and/or verification of the system one-line diagram. The cost analysis would take into consideration the additional requirements and indicate what the true costs will be.

Identifying non-linear loads

Since the most common problems associated with capacitor installation are related to harmonic resonance, it is beneficial to identify all of the harmonic-current sources (non-linear loads) in a facility.

Begin by listing all of the adjustable speed drives in the facility and note their location in the distribution system. For each drive, list all of the information found on the drive nameplate. Include all of the electrical ratings, manufacturer, model/serial number and whether or not there is an isolation transformer or reactors installed on the line side of the drive.

The electrical ratings should include voltage and current ratings, kVA, horsepower and possibly the front-end configuration from the manufacturer’s specifications (e.g., 6-pulse, 12-pulse). If an isolation transformer is installed, the winding configuration should be noted (delta primary/wye secondary, delta primary/delta secondary, etc.). If reactors are installed, the rating of the reactor should be noted (3%, 5%, etc.).

When surveying the facility for adjustable speed drives, be sure to include the less-obvious ones, such as those used on elevators, air handling units or process equipment. Furthermore, if there is a possibility that additional drives may be installed in the near future, include this information also.

After all of the drives have been accounted for, survey the facility for other non-linear loads. These will include equipment such as UPS units, rectifiers on DC-operated equipment, DC drive motors, solid-state electronic equipment, battery chargers, arc furnaces, arc welders, UV disinfecting systems and discharge lighting. As with the adjustable speed drives, there will be markings on the equipment nameplates that will provide similar data.

Service entrance transformer/equipment

The size, impedance, winding configuration and primary voltage of the service transformer should be recorded. In many instances, the equipment necessary to supply a plant is owned by the servicing utility. If the data is not readily available, the utility can supply the information required. If more than one transformer serves the facility, this information should be obtained for each one.

Other plant data

Another important aspect of the facility that will be important is the number, size and location of capacitors currently installed at the plant. If capacitors are installed at the service entrance of the facility, the kVAR rating of the bank should be noted. The rating should be marked on the bank. If not, the manufacturer of the bank should be contacted.

In addition to the service entrance capacitors, those that are installed at individual pieces of equipment should be inventoried. All major pieces of equipment, including motor control centres, should be inspected if there is any question as to whether capacitors have been installed. When examining these capacitors, note whether they are switched with the loads they serve or if they are bulk connected and not switched.

In addition to noting the ratings of the various existing capacitors, it should be noted if there have been any recent problems with the banks, such as fuse failures, capacitor failures, capacitor bulging, capacitor heating, etc. If possible, existing capacitor current levels should be measured.

Information should be obtained from the utility with regard to the available short-circuit fault current on the primary side of the service transformer. This information should be obtained for each service entrance.

Finally, voltage measurements and currents should, if possible, be taken at all of the major buses. If there are non-linear loads at the plant, all measurements should be taken with a true RMS digital multi-meter. These meters will capture the influence of non-fundamental components. If suitable instruments are available, the harmonic spectrum at each bus should also be measured

When collecting system voltage and current data, make sure all electrical/mechanical connections are sound. Visually inspect all connection points for looseness, corrosion or conductive paths to ground. If there is any doubt about the quality of the connection, the connection can be checked by resistive measurement, voltage drop or temperature measurement.

If overheating is suspected, arrangements should be made for a thermal scan to determine the temperature and where the hot spots are. Likely locations of heating will include fuse holders, cable connections, transformers, capacitors and circuit breakers. Heat is an indication of a high-impedance connection or excessive currents.

Utility interaction

If the facility survey suggests a potential interaction is possible with utility equipment, contact BC Hydro to find out about existing and planned circuit parameters, such as fault level, capacitor bank locations and switching times.

Monitoring

Power quality monitoring is performed to characterize the power quality variations at specific locations over a period of time. The monitoring period depends on the nature of the power quality problem. Transients due to capacitor switching may be captured in just a few days of monitoring if they occur often. Problems associated with harmonic current sources should be characterized over a longer period to capture the variations that correspond to different plant loads and configurations.

An important monitoring location is the service entrance. Measurements taken at this location can provide insight into the impact of the problem on the entire plant and give some indication of the source of the problem. For a large facility, additional monitoring may be required on various feeders and loads.

Monitoring equipment must be configured before meaningful data can be collected. This is usually done with computer software via a connection between a computer and the monitoring equipment. Compatibility between the computer software and the instrument is not always assured and must be confirmed.

The quantities measured, trigger thresholds, and so on all contribute to the usefulness of the data collected, and each decision must be considered carefully.

Design considerations

After data has been collected on the facility, a quick assessment can be made to determine what level of effort may be required to complete an installation. For a simple installation, where there are no non-linear loads, the process may be as simple as sizing the capacitor and having it installed.

After checking for a resonant condition and completing the facility survey, consideration can be given to whether an engineering study is required. The following checklists will help identify situations where an engineering study is probably required.

The first checklist can be used if capacitors are being added for the first time. The second list can be used if capacitors are currently installed and additional capacitors are being added or capacitors are currently installed and problems are being encountered.

Computer modelling

As discussed in the previous section, a facility survey may indicate that a capacitor installation may affect power quality, and in that case an engineering analysis may be required. If the installation is complex, a computer model may be required to analyze the effectiveness of different solutions. The computer software required to model systems is usually quite expensive and will take some time to learn how to use. A computer model requires more information than is usually collected in a facility survey. Usually the entire electrical distribution system must be modelled. This includes conductor lengths, conductor sizes, load profiles for all of the buses and the harmonic spectrum produced by nonlinear loads.

Table 1

First-time capacitor installation

	An engineering study may be required if:
	Capacitors are being added to a system where 20% of the connected load are non-linear loads.
	The facility is located near other industrial facilities that may have a high concentration of harmonic sources.
	The utility has imposed harmonic limits on your facility.
	Plant loading is anticipated to require an increase in service transformer size.
	There are utility-owned capacitors at or near the service transformer.
	A plant expansion is currently being planned that might include harmonic sources.
	There is on-site generation that will provide power to a significant number of harmonic sources.

Table 2

System with capacitors already installed

	An engineering study may be required if:
	Capacitors are being added to a system where 20% of the connected load is harmonic sources.
	There have been unexplained operations of fuses or other protective devices.
	Measured capacitor currents are 135% (or greater) of rated current.
	There have been failures of capacitors currently installed at the facility.
	A plant expansion is currently being planned that might include additional harmonic sources.
	There have been instances of swelling or unusual noises on capacitors currently installed at the facility.
	The utility has imposed harmonic limits on your facility.
	There is on-site generation that will provide power to a significant number of harmonic sources.

Although complex, the model allows the engineer to test various configurations, filters, switching arrangements and load levels. The model will also indicate where currents are flowing and what the voltage distortion will be at all buses.

If the installation is such that long-term monitoring is required, the monitored data can be compared with the computer monitor to ensure that theoretical values match the measured ones. A mismatch would indicate an error in the model or a problem with the monitoring equipment. If the model requires correction, adjustments can be made and the simulation is run again.

Mitigation

Detuning

Detuning a system refers to techniques that are used to change the resonance point of a system and move it away from significant harmonics. As mentioned earlier, when shunt power factor correction capacitors are added to a system, the parallel combination of these capacitors and the system source impedance can tune the system to resonate at a particular harmonic frequency. This high-impedance path is the source of harmonic voltages when harmonic load current flows through the system.

One technique used to detune a system is to add a reactor to the system. Harmful resonance conditions are generally between the shunt capacitors and the source impedance. The reactor is added between the source and the capacitor bank. An effective way to do this is to add the reactor in series with the capacitor bank to move the system resonance point without tuning the capacitor to create a filter (see Figure 8).

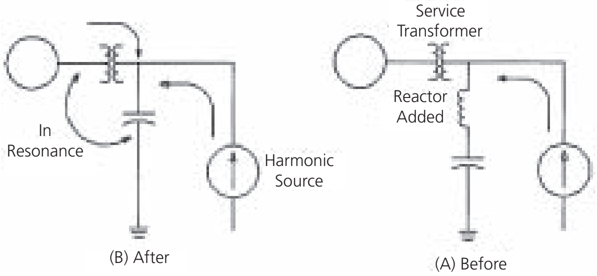

Figure 8. Detuning a resonant circuit

Another method that can be used is to change the size of the capacitor bank being considered. This is often one of the least expensive options. If the capacitor can be sized to move the resonance point without impacting other operational aspects (over/under correction, voltage rise, etc.), there will be no requirements for other mitigation.

Detuning can also be accomplished by moving capacitors to a point in the system with a different short-circuit impedance. This can also be considered if the installation of a capacitor causes telephone interference problems. In many cases, the capacitor cannot be moved far enough, within a plant, to make a difference; however, the technique should not be dismissed outright.

If capacitors are currently installed and problems related to harmonic current sources have been encountered, it may be cost-effective to remove the capacitors. In this case, a comprehensive cost-benefit analysis must be performed.

Filtering

In some situations it may be necessary to install filters to minimize the harmonic currents that are flowing on a system. Generally, filters provide a low-impedance path to shunt the harmonic currents, rather than having them flowing back through the distribution system (see Figure 9). Filters also change the system frequency response, most often, but not always, for the better.

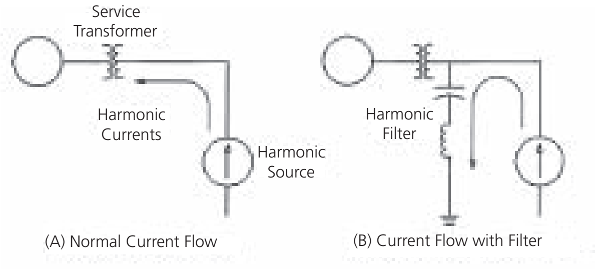

Figure 9. Filter installation

Adding a filter creates a sharp parallel resonance point at a frequency below the filter's tuned frequency. Filters are tuned slightly below the harmonic in case there is a change to the system or there is a component failure, either of which might move the resonance point into the filter.

Filters typically cost about three times what a simple capacitor installation might cost.

Filters are usually applied close to the component in a system where there is significant generation of harmonic currents. These filters are typically tuned to the fifth harmonic for three-phase loads, and the third harmonic for single-phase loads. These frequencies represent the lowest harmonic usually encountered on these systems, and the first filter in a system should be tuned to the lowest frequency.

Filter application is not as simple as mere capacitor application. Analysis that may range in scope from a survey to long-term monitoring and computer modelling may be required.

Filter capacitors are usually wired in a delta configuration on three-phase systems. As a result, they are largely ineffective when it becomes necessary to control third-harmonic currents. If triplen harmonics are determined to be a problem, other configurations can be used.

Filters should be placed on a bus where the available fault current is expected to remain constant. Although the notch frequency of the filter will not change, the system resonance point might move.

Finally, filters must be designed with the capacity of the bus in mind. The sizing of the filter cannot be based solely on the load that is producing the harmonic.

Grouping of loads

In installations where there are several harmonic current sources, it may be possible to electrically group the loads. As an example, this technique is used when the sources are six-pulse adjustable speed motor drives. Groups of six-pulse drives can be fed from transformers with different winding configurations. If the loads are balanced, the fifth and seventh harmonics tend to cancel, with the net profile being closer to that of a 12-pulse drive.

In a configuration such as this, the lowest harmonic would be the eleventh or thirteenth. This not only moves the predominant harmonic away from typical resonance points, but it also results in higher-frequency harmonics.

Higher-frequency components are generally lower in magnitude, and the energy contained in them will be less. Although less damaging, they may impact the system in other ways.

In addition to grouping loads for transformer feeds, the grouping also allows some cancellation that naturally occurs from the statistically random nature of loads and the corresponding harmonic spectrums. Although this cancellation is not of the magnitude discussed above, it is noteworthy.

Equipment changes

If it is determined that power factor correction capacitors may affect power quality at a facility, one solution may be to make some equipment changes. This may mean replacing some equipment with newer-technology equipment or adding enhancements to that equipment.

If adjustable speed drives were installed without isolation transformers or line-side reactors, consideration can be given to adding the appropriate equipment to the installation. Transformers and line reactors can provide solutions to a number of problems.

Line reactors are a cost-effective way to eliminate nuisance tripping of drives due to the transient overvoltages that result from utility capacitor switching. In addition, line reactors prolong the current pulse that is typical of the rectifiers on the input of these drives.

This results in a different, and much improved, harmonic current spectrum. Determining the correct reactor size, for transient voltage isolation, requires a detailed transient simulation that takes into account utility capacitor size and transformer rating.

Standard isolation transformers can provide the same sort of transient isolation, but size and cost considerations may preclude this option. Specialized transformers that provide harmonic mitigation may also be used. Any equipment added should be installed close to the drive and electrical connections kept as short as possible. If grouping of six-pulse adjustable speed drives is not practicable, consideration may be given to replacing an older-technology drive with a newer one or with a 12-pulse unit.

Glossary

6/12-pulse drives – three-phase adjustable speed drives convert AC to DC using two semiconductor switching devices per phase. For standard drives, this results in six pulses in the DC waveform. Some drives synthesize three additional phases, resulting in a 12-pulse waveform.

displacement/true power factor – true power factor is the ratio of real power to total apparent power. Displacement power factor is the power factor of the fundamental (60 Hz in Canada).

line reactors – air or iron core inductors used to insert additional impedance into a line.

RMS (Root means square) – a term used to refer to the most common mathematical method of defining the effective voltage or current of an AC wave.

total demand distortion – the ratio of the RMS value of the harmonic current to the RMS value of the rated or maximum demand fundamental current, expressed as a percentage.

total harmonic distortion (THD) – the ratio of the RMS harmonic content to the RMS value of the fundamental, expressed as a percentage of the fundamental.

transients – a variation in voltage between two steady-state values over a very short period of time (milliseconds or microseconds). The transient can be an impulse or a damped oscillation.

triplen harmonics – a term used to refer to the odd multiples of the third harmonic, which tend to be zero sequence.

Annotated reference list

1. Roger C. Dugan, et al, *Electrical Power Systems Quality*

   This is an excellent text on power quality. Terminology is clearly defined and explained and various influencing factors are discussed in detail. There is also a section on wiring/grounding and monitoring.

2. Michael Z. Lowenstein, "Improving Power Factor in the Presence of Harmonics Using Low-Voltage Tuned Filters", *IEEE Trans. Industry Applications*, vol. 29, no. 3, pp. 528-535, May/Jun. 1983.

   Good article and great case studies.

3. R.C. Dugan, D.T. Rizy, *Harmonic Considerations for Electrical Distribution Feeders*

   This is a comprehensive booklet that provides an excellent overview of all aspects of harmonics as they relate to power distribution systems. It is available from the National Technical Information Service, Report No. ORNUSub/81-95011/4 or Cooper Power Systems as Bulletin 87011.

4. P519A Task Force, Harmonics Working Group (IEEE PES T&D Committee) and SCC22 – Power Quality, *Guide for Applying Harmonic Limits on Power Systems*

   This is an unproved draft of a proposed IEEE Standard, subject to change. This document provides example applications of the procedures and limits found in *IEEE Standard 519-1992, IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems*.

Acknowledgement

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For more information contact:

Your Key Account Manager
Phone: Lower Mainland – 604 453-6400, other areas – 1 866 453-6400
Fax: 604 453-6280

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