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Combining Capacitors with Active Harmonic Filters

Optimizes Power Factor Correction for Petrochemical Plant

by Frank J. Angelini, P.E. & Dan Carnovale, P.E.

Today's modern industrial plants are not immune to the problems associated with a low power factor including overloaded cables and transformers, reduced voltage levels, poor motor performance, and utility penalties. However, with proper analysis and implementation of creative, energy-optimizing measures, power factor problems can be greatly reduced – or eliminated – efficiently and cost-effectively.

Approximately two years ago, a privately owned, medium-sized petrochemical company realized they were quickly heading toward a serious problem. Their plant electrical system needed a number of improvements, and the local utility company was about to impose a hefty penalty due to a low power factor rating. The newly-hired electrical engineer recommended a plant-wide power system study. Eaton's Cutler-Hammer business was awarded the bid, and over the next several months engineers assisted in data gathering, including long-term monitoring of several circuits. The resulting study recommended implementing a combination of modern *active harmonic filters*, and traditional fixed and switched *power capacitors* to improve power system performance.

Cutler-Hammer Low Voltage Fixed Capacitors

A new twist to the traditional approach

Traditionally, power system engineers have solved most power factor problems by the application of *power capacitors*. Properly applied, power capacitors provide an efficient, reliable and cost-effective means for power

In This Issue

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Cutler-Hammer Low Voltage Switched Capacitors

factor improvement. In the presence of harmonics, where harmonic resonance is of concern, engineers have successfully applied single and multiple series-tuned capacitor/filter banks with good results. However, where systems employ a number of operating configurations, and where future harmonic-producing loads are anticipated, this traditional approach often fails.

Active harmonic filters utilize analog and digital logic to sense and inject equal and opposite current, canceling harmonics and allowing reactive control of the plant's power systems. Used in combination with standard capacitors, they can create a plant-wide power factor correction system that optimizes equipment investment and safeguards against power factor penalties.

Detailed analysis and modeling led to cost-effective recommendation

A complete power system analysis was performed, including a short-circuit analysis, protective device coordination, load-flow analysis and harmonic analysis. The analysis showed a need to correct the power factor, which would require investment in correction equipment.

Some power factor correction capacitors were previously installed on the power system but the study indicated that additional capacitance was required to avoid the potential for a utility imposed penalty. The study concluded that simply adding more capacitors to achieve an acceptable power factor level would likely result in harmonic resonance and would require a substantial investment to avoid damage to the existing and/or new capacitors or other power system components. A typical, but substantially expensive, solution in this instance would be to remove all of the existing capacitors and replace them with tuned harmonic filters. Though active harmonics filters are generally more expensive than standard filters, by modeling the system's power problem areas and judiciously combining the lesser-cost capacitors with active filters, the overall equipment investment was less than removing all existing capacitors and replacing with standard filters.

The engineers, therefore, looked at areas in which capacitors could be combined with active filters, generating a harmonic system model that could be tweaked to optimize the number, size and position of the equipment on the system. Where the system model showed unacceptably high levels of harmonic resonance at each of four low voltage substations and each of two 200 HP DC drives, active filters were employed. Therefore, other areas on the system could get by with just the capacitors.

The power system study also resulted in substantial recommendations concerning power system grounding. In the past, this facility had been plagued with unexplained equipment failures and damage – likely the result of arcing ground faults on the power system. The recommendation was made to install several high resistance grounding units. These units eliminate the potential for arcing ground faults that can cause motor failures and insulation breakdown, thus protecting equipment and maintaining process continuity.

Conclusions

After the system corrections had been in effect for approximately a year, two independent sets of detailed measurements on the power system have shown the plant's power factor was corrected to greater than 95%, alleviating the utility penalty.

Furthermore, the implementation of a power factor correction system utilizing conventional, fixed, and switched capacitor banks and active harmonic filters virtually eliminated the interaction of harmonic currents with the power factor capacitors. This approach

Cutler-Hammer Active Harmonic Filter

For a complete description of the study and recommendations outlined in this article, please contact Frank J. Angelini, P.E., at FrankJAngelini@Eaton.com, 610-364-2603 and request a copy of the White Paper entitled *Petrochemical Plant Power Factor Correction Utilizing Active Harmonic Controllers and Conventional Fixed and Switched Power Factor Capacitor Banks.*

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avoided the power factor penalty, regulated the system voltage for loads, and released capacity in transformer/cables by eliminating a significant amount of the reactive current flow. Moreover, reserve capacity in several of the active harmonic controllers allow for reactive power control for future anticipated load growth.

	BEFORE	AFTER
Power Factor	0.8	0.97
kVA Loading (Total)	5436	4484
kVAR Loading (Total)	3258	1030
kW	4350	4330
THD (Voltage) @ PCC	1.03%	0.08%
THD (Current) @ PCC	6.38%	1.35%

Understanding the Random Nature of PQ Events – Power Quality Troubleshooting

by Dan Carnovale, P.E.

Knowing what to look for, maintaining a consistent approach to problem solving, and working with an expert will help you avoid common or reoccurring problems and sustain a healthy and productive power system.

Every power quality engineer has stories about problems that appeared to be unsolvable. Some eventually get solved, others never do and still others come and go seemingly with the wind. False conclusions are often reached as a result of many factors including the experience level of the troubleshooter, the type of problem and the equipment available for analysis.

If power quality events were purely a function of electrical system components, the analysis required to solve these problems would be greatly simplified. Unfortunately, they are not. Humidity, dust, suicidal squirrels or a leaky roof can all lead to power quality mishaps.

Know What to Look for and Keep an Open Mind

Experienced power quality engineers look for patterns in data and consistency in details from site personnel. However, relying only on the memory of site personnel to determine the source of the problem can be misleading and lead to false conclusions. For example, if site personnel have knowledge of only one aspect of power quality, harmonics for instance, they would likely equate a transformer-heating problem to harmonics. If you walk into the site with a preconceived notion of the problem without keeping an open mind, you will very often allow yourself to reach the wrong conclusion. Using good judgment and monitoring equipment will ensure an accurate analysis of the situation.

TYPICAL HARMONIC SYMPTOMS
• Overheated transformers/motors
• Overheated neutral conductors
• Electrical fires
• High motor loss and vibration
• Transformer or motor audible noise
• Capacitor failures
• Nuisance trips of protective devices
• Timing circuit/digital clock errors

Power Quality Pitfalls

So you think you've got it all figured out. You put A and B together and you reach a conclusion only to find out that one of your assumptions was wrong. It happens to all of us. Here are some pitfalls to watch for:

1. After solving a complex power quality problem, similar patterns can be seen in a new issue. Many power system problems are complex, but by jumping to the conclusion that situations are identical, simple solutions can be overlooked. Before assuming a problem requires a complex solution, be sure to rule out simple issues including steady-state overvoltage, overloaded circuits or incorrect circuit breaker settings. And when working with a power quality expert, make sure they know which issues have been ruled out so that they do not under- or over-simplify their interpretation of the problem.

2. Don't automatically assume newly added equipment is the source of the problem. While this is a good starting point, don't jump to this conclusion without proof.

3. Lots of data is not always a good thing. In many cases, ten pages of good power quality monitoring data is much better than having 400 pages of non-specific power quality data. It is often a worse situation trying to sort through 400 pages of general data. Be selective on how and when data is acquired.

4. Don't assume that just because there is new or different data, there is a problem. Very often, when a new portable meter or a panel mounted meter is installed, unusual looking data raises a flag. It often appears unusual since this type of data has not been viewed in the past. It is important to understand how the new data is to be interpreted, before assuming there is a problem.

TYPICAL VOLTAGE SAG SYMPTOMS
• Lights flickering
• HID lights dropping out
• Intermittent UPS alarms
• Computer lockups
• Contactors or drives drop-out
• PLC lockups
• Erratic load operation

5. Keep in mind that just because you have accumulated megabytes of PQ monitoring data doesn't mean that you've captured the problematic event. For example, high frequency transients often "sneak" by unnoticed with conventional power quality monitors. Often, simple voltage sags or insignificant harmonics may be blamed for causing the problem because they occurred at a roughly the same time as a noted event. Taking several approaches to analyzing the problem will help rule out culprits. Often knowing what *isn't* causing the problem is nearly as important as knowing what is.

6. Is it a three-phase or single-phase problem? Control power for three-phase motor contactors, starters, drives and other power electronics is usually single-phase-fed from a control power transformer. If a single-phase voltage sag occurs on the phase with control power connected, the unit may drop out. However, if it occurs on another phase, the unit may keep operating. This is often very confusing for troubleshooters. Consistent wiring practices will make this problem easy to identify and solve. Also keep in mind that drives have a substantial ride-through capability for single-phase events versus three-phase events (energy storage is rapidly depleted for a three-phase event).

7. "Harmonics are not a problem unless they are a problem." Very often, harmonic issues are raised because the levels exceed IEEE 519-1992 recommended limits somewhere in a power system. Most equipment can withstand harmonic distortion levels well above these conservative recommended limits. Harmonics can be problematic, but they are often blamed for problems with no real proof. Taking the time to learn about harmonics and how power systems and equipment are affected saves time and money.

8. "If you can't figure it out, you can always blame grounding!" Be careful not to fall into this trap. While grounding issues account for a majority of power quality problems, grounding is also the least understood aspect of power quality. Therefore, recommendations for remedial action often do not correct the problem. For example, isolation transformers often treat problems that may or may not be related to grounding.

Troubleshooting Tips

Here are some examples of things to watch out for when troubleshooting PQ problems:

1. Transients may occur all day long but may only affect equipment at night. Watch for background steady-state voltage levels. The rms voltage level can significantly vary over a 24-hour period (typically could be as much as +/- 10%) and as transients are superimposed on a high average rms voltage, problems may occur.

2. Voltage sags are generally the most problematic and costly source of power quality problems because they affect an entire facility. Voltage sags are typically the result of faults on the utility grid and are caused by uncontrollable problems including animal faults, tree contact, lightning, dig-ins on underground cables, etc.

3. Soil resistivity is highly dependent on the water content in the soil. As the summer heat dries out the soil, ground resistance increases and may cause significant problems. It may appear that problems are the result of other issues when, in fact, they are simply related to high soil resistivity.

4. Relative humidity should be a consideration. In an extremely dry air environment, static discharge can cause significant damage or disruption to electronic components. Often the air must be humidified in the winter months when heating units dry the air.

5. UPSs may switch off line and call upon battery power during "normal conditions" if the conditions are outside a standard setting for the UPS. If the rms voltage is too high or low, if harmonic distortion is significant, or if the frequency is not consistent in the case of operation on a stand-by generator, the UPS batteries may fully discharge. Under these circumstances, the UPS batteries will not be available for correcting problems when they are actually needed.

6. Conductive dust and chemical contaminates can cause intermittent faults and nuisance trips that are difficult to locate. For example, if the sys-

tem requires positive pressure to reduce the buildup of dust particles, voltage sags may trip the drive system on the blowers or fans and dust may build up causing insulation breakdown. The first impression may be that lightning has caused the failure when, in fact, it was only indirectly related by causing the voltage sag.

7. Loose connections and bad splices cause intermittent problems that are very difficult to locate.

8. Harmonic resonant conditions occur with very specific power system configurations. Slight variations in source impedance, capacitor switching steps, and harmonic sources make it difficult to determine or reproduce the exact conditions that cause a problem.

9. Water often causes random faults (especially when combined with conductive dust) during times when other events are occurring. For example, if faults always occur during thunderstorms, lightning transients may be blamed, when in fact, the roof over the mezzanine unit substation leaks!

10. Electric and/or magnetic field problems can be conducted or radiated (through the air) and are difficult to determine and mitigate. In addition, the EMI/RFI may cause monitoring equipment to malfunction or record suspect data. Appropriate diagnostics by an experienced professional will help pinpoint problems.

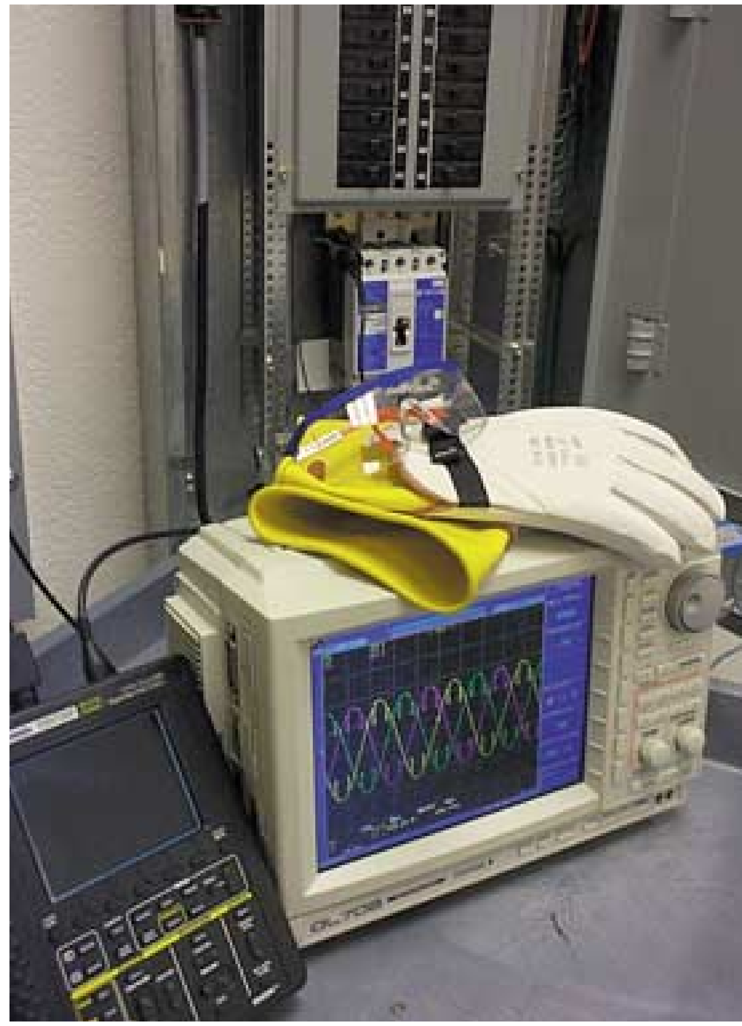
Nothing Takes the Place of Knowledgeable Experience

There is no "Magic Box" or special software that solves every power quality problem. Many companies sell products that claim to fix all power quality problems. There is no device available on the market.

Artificial intelligent software is also available as a resource for solving power quality issues. Don't rely only on this information. It can be used as a resource but independent conclusions should be made based on the data. Nothing takes the place of experience, thoroughness, and expert knowledge to ensure the appropriate, and most economical, solution.

Maintain a consistent approach to power quality problem solving in order to avoid reaching the wrong conclusion. Begin with simple monitoring and data gathering and proceed to complex and detailed analysis.

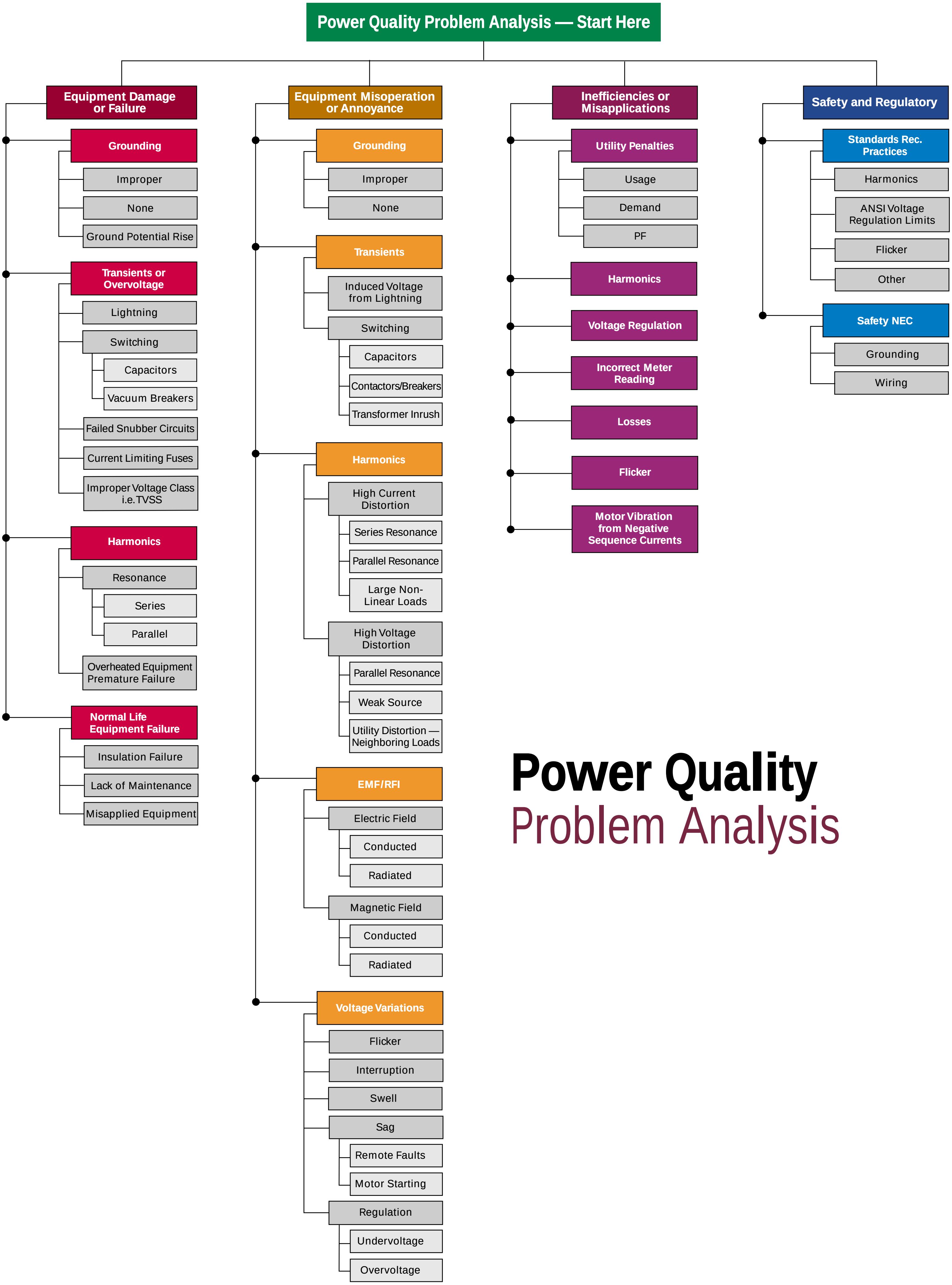
TYPICAL SURGE SYMPTOMS
• Drives trip/damaged by overvoltage
• Daily UPS alarms
• Failure of electronic equipment
• Damaged/burnt printed circuit boards
• Transformer/motor insulation breakdown
• Telephone and data equipment damage
• Erratic process control



A sample method for analyzing power quality problems is shown on the next page. Use this as a guide for determining potential issues, but use your common sense to arrive at your final conclusion.

We Are Here to Help
Cutler-Hammer Engineering Services and Systems (CHESS) has performed thousands of power system and power quality studies. Draw from our wealth of knowledge to help resolve confusing PQ problems.

Call the PQ Hotline for all your Power Quality, Reliability, and Energy Management questions. 1.800.809.2772 (Option 1, SubOption 2).



Power Quality
Problem Analysis

Questions and Answers

Q: It's been an unusually hot summer, and I noticed that the fluorescent lights in my kitchen and garage sometimes flicker for a long time when I turn them on. In fact, on a couple of hot evenings, some of the lights never completely turned on. Any ideas, and should I be concerned?

A: Fluorescent light ballasts are sensitive to low voltage, and may not successfully start if the voltage is below 110V. Since the problem occurs at times when the local electrical load is the highest, it is possible that you are experiencing lower-than-normal voltage. Sustained low voltage can damage other devices in your house; therefore, you should contact your local utility to investigate and correct this condition. (Editor's note – subsequent measurements confirmed that the voltage at the utility meter occasionally dropped as low as 108V. Five houses are served by a single 30 kVA transformer, and most of the houses have added air conditioning in the last five years. The local utility is now planning to install a larger transformer.)

Q: I had heard that stray voltages on dairy farms can severely effect dairy cows – are they also dangerous to humans?

A: Stray voltage in a dairy farm is caused by the same conditions that could cause stray voltage in other locations: improper wiring, poor grounding, unbalanced voltage, fault equipment, or poor or corroded connections. A dairy barn is usually a wet, humid, and corrosive environment – ideal conditions for developing stray voltage, resulting in very serious problems on dairy farms. In short, stray voltage can be present on equipment that is grounded to the electrical system or connected to the grounded neutral conductor. The voltage is usually less than 10V and can be measured between ground and any metal equipment in the barn such as pipe lines and livestock drinking fountains. Since the voltage is generally less than 10V, it is below the perception level for humans and is not dangerous. However, dairy cows are very sensitive to stray voltage to the point that if they are shocked while taking water from the livestock drinking fountain, they may reduce their water intake. A reduction in a cow's consumption of water leads to reduced milk production and eventually sickness.

Q: What are the IEEE standards for momentary overvoltage for capacitors?

A: IEEE Std 18-1992* notes: A capacitor may reasonably be expected to withstand, during normal service life, a combined total of 300 applications of power frequency terminal-to-terminal overvoltages without superimposed transients or harmonics content, of the magnitudes and durations in the following table:

	MAXIMUM PERMISSIBLE VOLTAGE**	
DURATION	PER UNIT	FOR EXAMPLE: OVERVOLTAGE FOR 2770V CAPACITOR
30 minutes	1.25	3462.5
1 minute	1.30	3601
15 seconds	1.40	3878
1 second	1.70	4709
0.25 sec (15 cycles)	2.00	5540
0.1 sec (6 cycles)	2.20	6094
0.0167 sec (1 cycle)	2.70 (*per IEEE Std 19-1980)	7479
0.0083 sec (_ cycle)	3.00 (*per IEEE Std 19-1980)	8310

* Permissible Capacitor Power Frequency Overvoltage Per IEEE Std 18-1992
** RMS Equivalent

Q: I thought my power had gone out several times in my shop one afternoon. My radio went off several times but the fan motor kept running. What happened?

A: Often, what are thought to be power outages are actually voltage sags, a temporary reduction in voltage but not a complete interruption. Electrical devices such as radios, VCRs, computers, small motors, etc., all have different tolerance levels to voltage variations. In this case, the radio was not as tolerant to voltage sags as the fan motor. In addition, rotating loads (i.e. motors) have some inherent "ride through." Voltage sags can be caused by short circuits in the utility lines, large motors starting up, or any increase of resistance in the circuit. (Editors note: In this case, the voltage sags occurred on a particularly windy day. The utility was contacted and they investigated the incoming service to the individual's shop. The connection of the overhead line to the pole transformer was loose and the wind-swinging line intermittently increased the resistance of the connection, which created a voltage drop large enough and long enough to cause the radio to turn off, but not the fan.)

We encourage you to submit your questions and/or case studies.

If your submission is published, you will receive a Home Surge Protection Package.

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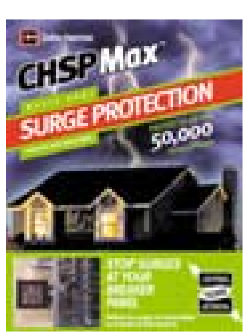

Having trouble understanding a problem related to Power Quality, Reliability, or Energy Management? Confused about what technology to apply to improve facility uptime or cut energy costs?

Call our Power Quality Hotline, 1-800-809-2772 (Option 1, SubOption 2), to talk to our Power Quality Experts, or e-mail us at pqhotline@eaton.com.

IQ 7000 Advanced Power Quality Meter

The Cutler-Hammer IQ 7000 assists energy users in making quick and confident power quality and power management decisions. This sophisticated meter provides highly accurate revenue metering, power quality analysis, communications and control.

The IQ 7000 records and analyzes transient events, surges, sags and harmonics with high-speed sampling and has an abundance of on-board memory to store important information. Features include four standard Modbus communication ports, with options for direct Ethernet or modem interface. The IQ 7000 provides built-in functionality for PLC-like logic control, choice of LED display or touch-screen graphics display, and several software options.

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Future Issues

We will continue to include "Ask the Expert" in upcoming issues and we encourage you to submit power quality questions or comments. Please fax your questions to 403-717-0579 or e-mail pqconnection@eaton.com, attention "Questions for the Power Quality Expert."

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