Monitor induction motors to drive power quality

By Jon Bickel, Staff Product Specialist, Square D/Schneider Electric -- Plant Engineering, 6/1/2006

First of two parts

Motors are essential pieces of electrical equipment. The most common of motors in use today is the poly-phase induction motor, with more than 90% of these being squirrel cage induction motors. The poly-phase induction motor is preferred for several reasons:

- It is relatively inexpensive
- It has a rudimentary design
- It is easily replaced
- It operates reliably
- It has a range of mounting styles and environmental enclosures.

Due to the significant capital and operational investments made by companies in induction motors — investments that impact the bottom line — knowing the condition of these motors is vital. Induction motors are generally robust, but they can fail prematurely. Causes of motor failures include poor maintenance practices, improper lubrication, harsh operating environment, inadequate source voltage or misapplication of the motor. All of these issues have one thing in common: excessive temperature rise.

Excessive heat is the nemesis of motors (Fig. 1). Temperature rise can originate in the bearings (lubrication, alignment, etc.) or the windings (design, voltage, etc.) or be imposed by external conditions (ambient temperature, atmosphere, etc.).

A permanent power monitoring device can provide a great deal of information about induction motors. By monitoring the voltage, current and temperature, today's monitoring devices can provide data on many aspects of an induction motor, including:

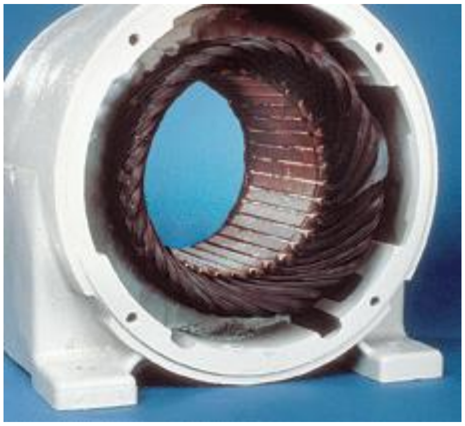
- Quality of the motor's terminal voltage
- Energy usage
- Loading concerns
- Excessive cycling
- Starting characteristics
- Environmental considerations.

Although each aspect is important, this article will focus on detecting problems with the terminal voltage to increase the life of an induction motor.

Quality of the motor's terminal voltage

Induction motors have nameplate ratings to help ensure that the motor is used properly. The nameplate data should be observed as closely as possible, but there are times when external factors cause variations beyond the approved constraints of the motor. The quality of the terminal voltage depends on each phase's magnitude, angle, frequency and duration of any deviation from the rated voltage. Deviations in one or more of these factors can reduce the operating life of induction motors. Combinations of these factors are grouped into eight categories of terminal voltage problems that can affect poly-phase induction motors:

- Undervoltage
- Overvoltage
- Unbalance
- Harmonics
- Transients
- Sags
- Swells
- Frequency deviation.



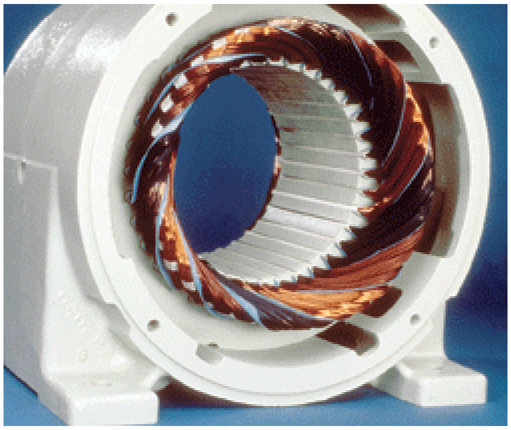
Courtesy of Electrical Apparatus Service Association

Overvoltage and undervoltage

Induction motors are designed to operate within a limited range around their rated voltage (NEMA MG1 specifies ±10%). At full load current, a 10% overvoltage at the motor's terminals can substantially increase the core losses of the motor resulting in overheating. An elevated ambient temperature exacerbates the problem. The overvoltage will always be less at the motor's terminals than is measured by the monitoring device due to the voltage drop of the circuit.

Low voltage at the terminals of a fully loaded motor also results in additional heating, due to increased current flow. Adequately installed protective devices such as overload relays should limit this problem during operation, but starting during low voltage conditions is particularly taxing on the motor. When starting during severe undervoltage conditions, the developed torque may not be sufficient to allow the motor to come up to speed.

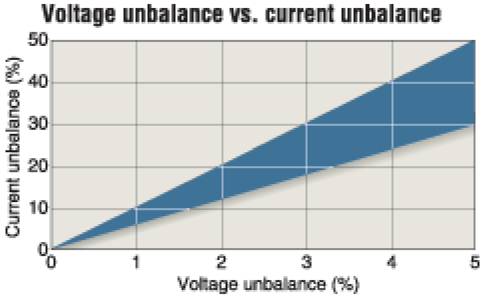
If the monitoring devices are located remotely from the motor, the voltage drop between the two should be accounted for when setting the alarm thresholds.



Courtesy of Electrical Apparatus Service Association

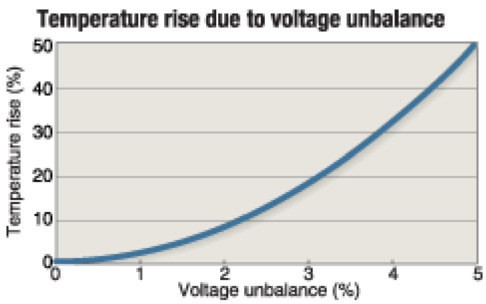
Unbalance

Voltage unbalance (including single phasing) is a major cause of motor failures (Fig. 2). Voltage unbalance in fully loaded poly-phase induction motors produces a disproportionately higher current unbalance (Fig. 3). The current unbalance causes additional losses in the motor resulting in a temperature rise (Fig. 4). Ultimately, increased heating can stress the motor's insulation, shortening the life of the motor.



To minimize these insulation stresses, the motor loads should be reduced proportionate to the degree of voltage unbalance. Derating should be considered for voltage unbalances greater than 1%. Removing the motor from service should be considered when voltage unbalances exceed 5%.

Many monitoring systems provide the ability to measure voltage unbalance using either the IEC method (based on symmetrical components) or the NEMA method (based on the maximum deviation from the average). Both methods are acceptable as long as the chosen method is used consistently. Measuring the voltage unbalance on an unloaded system is a more valid approach than measuring voltage unbalance on a system with loaded three-phase motors. Loaded three-phase motors have a tendency to “rebalance” an unbalanced system (to a degree), potentially masking the true severity of the problem.



Harmonics

Distorted voltage harmonics are additional frequencies that are integer multiples of the fundamental frequency. Voltage harmonic frequencies produce additional heat in the motor. Heating resulting from the I2R losses increases due to the additional harmonic currents. Eddy current and hysteresis losses are affected by the frequencies at the motor terminals. The higher frequency components associated with harmonics increase these losses.

Voltage harmonics include positive, negative and zero-sequence components depending on which harmonic frequencies are present (Table 1). Positive-sequence components develop torque in the same direction the motor is turning. Negative-sequence components develop torque in the opposite direction than the motor is turning. The zero-sequence components have no effect on the motor’s torque, but generate ancillary losses. The torque developed by the positive and negative sequential components opposes each other, resulting in higher currents and additional heating within the motor.

IEEE Standard 519-1995 provides a good guideline for the acceptable levels of voltage distortion to loads (including motors). A broad recommendation is to establish the voltage distortion monitoring limits at 5% total harmonic distortion (THD) and at 3% for any particular harmonic frequency. The types of connected loads and system impedances are major factors in the level of exposure a motor has to voltage distortion.

Transients

Transients are very fast (sub-cycle) discontinuities in the ac waveform on the plant’s electrical system. They are often caused by switching events or even by lightning. Voltage transients stress the insulation on the motor’s winding causing it to degrade over time or sometimes catastrophically fail. Factors that contribute to the effects of voltage transient include its magnitude, duration, rise-time, associated energy or even system impedances.

Damage due to voltage transients is generally either turn-to-turn or turn-to-ground depending on whether the electrical system is grounded or ungrounded. Due to their inductive nature, motors appear to be open circuits at high frequencies, often resulting in damage to the first turn or two of the windings. This condition is a classic indicator of damage due to voltage transients.

The ability to detect and alarm on high-speed voltage transient events is vital to ensuring longevity in the motor. Detecting transients requires that monitoring devices have a fast sample rate and a high dynamic range. Thresholds should be configured to detect at least two times the motor’s rated voltage. In order to minimize the filtering effects of the conductors, the voltage should be monitored in close proximity to the motor’s terminals.

Voltage sags and swells

Voltage sags and swells are momentary decreases and increases in the steady-state system voltage, respectively, as opposed to the long-term variations of undervoltage and overvoltage. Voltage sags can impact motors and their driven loads; voltage swells less so. Voltage sags reduce the available torque, stressing the motor and heating the windings.

The primary concern regarding voltage sags is their effect on a motor’s controls. During certain voltage sag conditions, the contactor’s coil loses its ability to effectively hold the contacts together causing the motor circuit to open. This problem becomes more complicated when the voltage sags to the threshold of the contactor’s ability to hold the contacts together. The contacts may then begin to bounce resulting in arcing, heat and damage. The variables that affect a motor’s susceptibility to particular voltage sags include the pre-event parameters, phase angle of occurrence, transitional phase shift and the contactor’s characteristics.

The coil should be expected to operate over a range of 85–110% of the rated voltage. The irony of motors is that their controls are sensitive to voltage sags, and yet the inrush currents associated with motor starts produce voltage sags.

The recommended power monitor settings for voltage sags and swells are 90% and 110% of nominal, respectively. This range ensures that all pertinent data is captured and available for analysis if a motor fails or operates erratically.

Frequency deviation

In most developed countries, governing bodies impose tight frequency constraints on utilities, so frequency deviations on the utility grid are rare. However, it is possible to experience significant frequency deviations when operating independent from the grid as is the case if you generate some or all of your own electricity. Three-phase induction motors are designed to operate most efficiently at their rated frequency. Significant frequency drift results in additional heating of the windings.

The recommended guideline for monitoring motors that may be vulnerable to frequency shifts is ±5% of the rated frequency. This range is further restricted as the terminal voltage deviates from the rated voltage of the motor.

Table 1 Harmonic component sequences

Harmonic component	**Component sequence**
1st	Positive
2nd	Negative
3rd	Zero
4th	Positive
5th	Negative
6th	Zero
7th	Positive
8th	Negative
9th	Zero
10th	Positive
11th	Negative
12th	Zero

Author Information

Jon Bickel of SquareD/Schneider Electric is responsible for developing and sustaining a variety of energy and power quality metering instruments. He has spent 15 years working with power quality and power generation. In the second part of this series in the July issue of PLANT ENGINEERING, he will discuss how monitoring systems collect data that can help improve the motor's efficiency and increase the operating life of the motor.

The Bottom Line...

- Poly-phase induction motors are critical components in most industrial processes, and their reliability is essential to the bottom line.
- There are many potential hazards both internal and external to the motor that can reduce its operating life.
- Continuously and effectively monitoring the motor's terminal voltages is a valuable way to maximize its performance, increase its longevity, and reduce its total operating costs.

Zero tolerance for counterfeiters

Just three weeks after it filed suit to block a rival company from selling counterfeit circuit breakers, Square D has won a consent order to block the practice.

On April 28, Scott Electric signed the Consent Order in U.S. District Court in Pennsylvania to prevent the sale of counterfeit QO circuit breakers bearing the Square D trademarks and copying Square D designs. The suit claimed Scott Electric sold the counterfeit products. Scott Electric has agreed to end the practice, inform Square D of any further products in its possession and intends to recall any counterfeit Square D products.

"The swift handling of this lawsuit demonstrates how determined and serious Square D is about putting an end to the counterfeiting of its products," said Bill Snyder, vice-president of channel development for the Schneider Electric North American Operating Division. "There will be many more battles as part of the larger war Square D intends to wage on counterfeiters."

On April 7, Square D filed suit against Scott Electric Company of Greensburg, PA, and a local retailer in the United States District Court located in Pittsburgh, PA. The lawsuit alleged that Scott Electric participated in false advertising, product disparagement and trademark infringement in violation of federal and state law and seeks monetary and injunctive relief to prevent Scott Electric from its false advertising and to stop both Scott Electric and the local retailer from selling or marketing counterfeit products.

"Square D is committed to enforcing its trademark and property rights and to prevent the sale and importation of counterfeit products bearing its trademarks or designs. Square D will also take appropriate action to prevent product disparagement and false advertising," Snyder said.

NEMA to conduct USTDA standards programs in China

NEMA will organize a series of U.S.-led training and cooperation seminars for Chinese industry and government officials. It will set up the workshops and provide on-site organization for the three-year, multi-sector series of programs.

U.S. Trade and Development Agency is sponsoring this initiative, known as the U.S.-China Standards and Conformity Assessment Cooperation Program, which will provide matching funds for approximately 25 events over the next three years. The award will be administered as a grant to the American Chamber of Commerce in China, which is retaining NEMA as a contractor and providing in-country oversight.

"NEMA is honored to have been chosen for this project," said NEMA President and Chief Executive Officer Evan Gaddis. "USTDA and AmCham have recognized our ability to organize this kind of seminar on behalf of our own members, and we appreciate their trust in our ability to coordinate first-rate programs on behalf of the entire range of U.S. industrial sectors."

NEMA opened its Beijing office in 2004 as a fully registered Chinese representative office. Since then, the association has sponsored a number of electrical equipment industry events in China on such issues as energy efficiency, protection of intellectual property rights, hazardous substance regulation and technical product standards.

Control panel compliance Webcast

Plant Engineering magazine will present a free Webcast titled "Control Panel Compliance" on Wednesday, June 21, at 10 a.m. CDT. Learn from our panel of experts how UL 508A and NEC Article 409 interact, what your responsibilities are when upgrading and specifying equipment for your plant, how to comply with current regulations and how to minimize the potential for equipment damage or injury to personnel. Visit **www.plantengineering.com** for more information or to register.

Monitor induction motors to ensure energy efficiency

By Jon Bickel, Staff Product Specialist, Square D/Schneider Electric -- Plant Engineering, 7/1/2006

Second of two parts

As energy costs rise around the world, the incentive for facilities to operate their equipment more efficiently will multiply. There are mandatory means (regulations) that authorities use to enforce conservation, and compensatory means (special rate tariffs) that reward users for using less energy. In either case, decreasing energy consumption decreases the bottom line costs to the user.

The first step industrial facilities should take toward effectively reducing energy costs is to evaluate their motors — the number one energy consuming culprit. Motors in industrial facilities consume by far the largest percentage of energy of any electrical device used in the US infrastructure. Tens of billions of kWh are consumed by motors each year, accounting for more than 25% of all electricity sales in the US.

Polyphase induction motors, more than 90% of which are squirrel cage, are the most commonly used. Because of their prevalence throughout the industrial and commercial sectors, polyphase induction motors offer a great potential savings opportunity in both energy and operational costs during the motor's useful life.

Sections:

Sidebars:

An adequate assessment of the impact that induction motors can have on an energy bill requires a detailed knowledge of the motor's many operational and electrical parameters. Permanently installed monitoring devices are the most effective tool in the arsenal to reduce energy consumption, especially in motors. Knowing which parameters to monitor and evaluate helps you save energy.

Monitoring your motors

Each motor within a facility operates with some level of distinctiveness from other motors. This distinctiveness may be due to a combination of factors, which include:

- Nameplate ratings
- Voltages
- Load/Application
- Duty cycle
- Environment
- Adjacent loads
- Impedances
- Age.

The more knowledge that can be accumulated about a motor and how it operates, the easier it is to reduce energy costs associated with that motor. Permanently installed monitoring systems are particularly useful because they are able to capture a great deal of information over the motor's life — both real-time and historical.

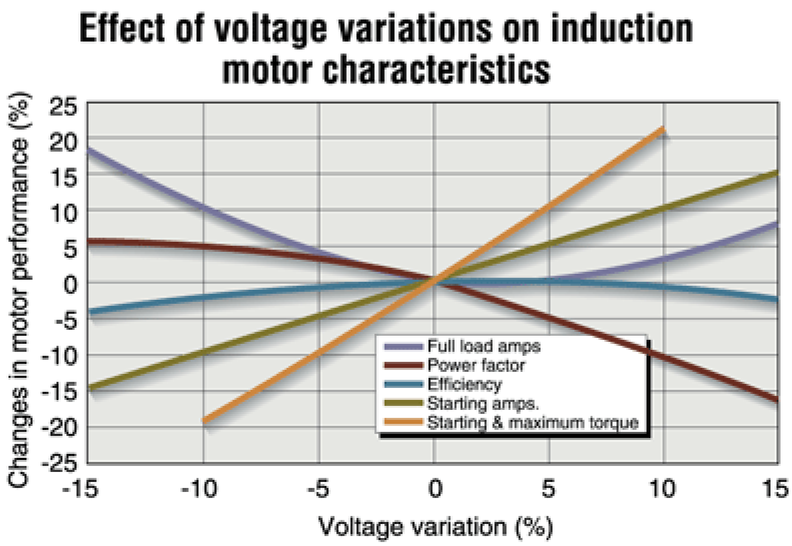


Fig.1

A fundamental issue that can affect a motor's energy usage is its suitability for the intended application. Motors are designed to operate most efficiently at their nameplate rating. Selecting the wrong motor for a particular application or operating the motor outside its recommended parameters decreases its performance by introducing additional energy losses into the electrical system. Monitoring systems identify many symptoms that result in reduced motor performance including deviations from various nameplate parameters (Fig. 1).

Where to look for savings

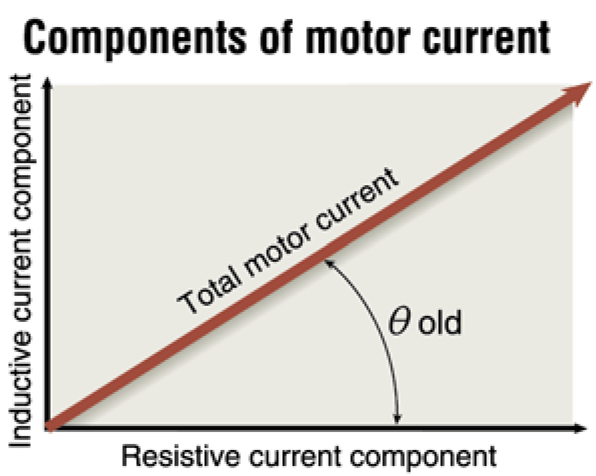


Fig.2

There is a wealth of information about a motor's well-being buried in the characteristics of the electrical signals at the motor's terminals. With the motor's nameplate data and these electrical characteristics, it is possible to quantify many energy savings opportunities for a given motor. The fundamental electrical characteristics include the voltage, current and frequency data for each phase. By collecting data on these fundamental characteristics, monitoring devices can provide additional information needed to maximize energy savings. This information includes:

- Power factor
- Voltage variations
- Voltage unbalance
- Motor load (based on current)
- Harmonic distortion
- Frequency deviations.

Monitoring systems also have the ability to measure and record temperatures, number of starts, running time and even vibration through the use of I/O modules.

Power factor improvement

The first and most obvious opportunity for motor energy savings is power factor correction. Most monitoring systems provide a wide range of data directly or indirectly associated with power factor including:

- Displacement power factor (total, and per phase)
- True power factor (total, and per phase)
- Distortion power factor (total, and per phase)
- Min/max power factor
- Reactive power and energy
- Real power and energy
- Apparent power and energy.

How does power factor relate to energy savings? Polyphase induction motors use current composed of both resistive and inductive components (Fig. 2). The resistive component includes the load current and the loss current; the inductive component includes the magnetizing current and the leakage reactance. It is possible to cancel out the inductive current component by using capacitance. A capacitor does not affect the magnetizing current or the leakage reactance of the motor. However, it offsets the inductive component at the point in the circuit where the capacitor is installed. As more capacitance is added, the power factor angle, è, becomes smaller until a unity power factor is achieved (è = 0). At a unity power factor, the electrical system is at its optimum performance for maximum power transfer (see “Example 1”). Placing excessive capacitance in the circuit causes a leading power factor condition (è is negative in this case), which can lead to serious complications.

Voltage unbalance

Voltage unbalance is both a leading cause of motor failures and a major contributor to energy losses in motors. The subsequent current unbalance produces additional losses in the motor. Monitoring systems are typically used to quantify voltage unbalance for power quality purposes, but may also be used to provide information on the losses due to voltage unbalance at the terminals of three-phase induction motors (see “Example 2”). The cost of energy losses is substantial in this case and will be further multiplied by additional motors exposed to the voltage unbalance within the facility.

Other voltage quality issues adversely affect the efficiency of induction motors. Operating a motor at 90% of its rated nominal voltage results in roughly a 2.5% decrease in efficiency (Fig. 1). Harmonic distortion at the motor’s terminals produces additional currents including counter-rotational (negative sequence) currents that reduce a motor’s efficiency. Even variations in the system frequency result in energy losses for motors. Each of these dynamics contributes to energy losses and present untapped methods of reducing operational expenditures.

Historical and real-time data provided by monitoring systems is not only the key to locating motors that are operating uneconomically, but these systems can allow the user to more easily determine the root cause of the problem(s). Remedies that are employed can also be assessed on an “as needed basis” by the monitoring system, and modified to insure they are effective. Concurrently, the return-on-investment for a given solution can be easily established.

The Bottom Line...

- Permanently installed monitoring systems collect vast amounts of data that can be scrutinized for motor savings.
- Actions taken to improve the motor’s efficiency will also increase the operating life of the motor.
- The payback period for improvements to the electrical system can be relatively short.
- Operating motors as closely as possible to their optimal parameters decreases capital expenses, lowers process downtime, lowers stress on the supporting infrastructure and reduces operating expenses — including energy bills.

Author Information

Jon Bickel joined Square D’s PowerLogic group in 2001 as a Hardware Product Manager. He is responsible for developing and sustaining various sophisticated energy and power quality metering instruments. He spent approximately 15 years employed at a large utility working in the areas of power quality, power generation, distribution, customer service, marketing and sales. Jon is a graduate of Kansas State University with B.S. and M.S. degrees in Electrical Engineering, and is a registered professional engineer in the state of Texas.

Example 1

A three-phase induction motor uses 200 A at a power factor of 0.78 (èold = 38.73 degrees).

$$\text{Real (resistive) current} = 200 \times \cos(\Theta_{old}) = 200 \times 0.78 = \underline{156 \angle 0^\circ \text{ Amps}}$$

$$\text{Reactive (inductive) current} = 200 \times \sin(\Theta_{old}) = 200 \times 0.63 = \underline{125.15 \angle 90^\circ \text{ Amps}}$$

$$\text{Total current} = 156 \angle 0^\circ + 125.15 \angle 90^\circ = \underline{200 \angle 38.73^\circ \text{ Amps}}$$

$$\text{New reactive current} = 156 \angle 0^\circ \times \tan(18.19) = \underline{51.26 \angle 90^\circ \text{ Amps}}$$

$$\text{Reactive current from capacitance} = 125.15 \angle 90^\circ - 51.26 \angle 90^\circ = \underline{73.89 \angle 90^\circ \text{ Amps}}$$

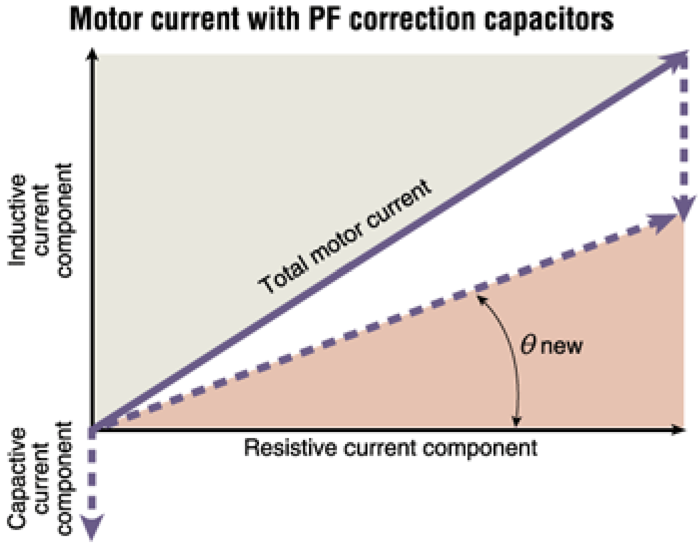
$$\text{New total current}_{new} = 156 \angle 0^\circ + 51.26 \angle 90^\circ = \underline{164.21 \angle 18.19^\circ \text{ Amps}}$$

To ensure these values are correct,

The reactive (inductive) component can be reduced by adding a capacitive load (generally a capacitor bank) near the motor. The capacitive load is also expressed as reactive in nature, but it uses the current 180 degrees out of phase from the inductive load; thus, a canceling effect occurs (Fig. A). To bring the power factor from 0.78 (èold = 38.73 degrees) to 0.95 (ènew = 18.19 degrees), a capacitor bank would have to be sized so that its corresponding current is:

A reduction in current (and energy) of approximately 18% is obtained by adding capacitance to the system based solely on the power factor improvement*. Each kVArh of reactive energy passing through an electrical system produces superfluous line losses and higher energy bills. Permanently installed monitoring devices can quantify these losses and offer additional savings opportunities within the facility.

***Note**: A word of caution: Most industrial systems use motors with adjacent loads that are complex (e.g, non-linear loads such as adjustable speed drives). These complex load-types may react negatively to the addition of standard power factor correction capacitors due to the capacitors' interaction with other frequencies produced by the complex loads. More information is available on the internet regarding the interaction between complex-load types and power factor correction capacitors (also see displacement power factor versus true power factor).



Example 2

A 200-hp three-phase induction motor operates 4,500 hours each year at an average load of 80%. The motor's efficiency (ç) is 93% at 80% load, assuming a negligible voltage unbalance. However, it is discovered after reviewing the monitoring system's data that the average voltage unbalance to the motor over the course of a year has been 3%. The facility's average energy cost is $0.13/kWh and the average demand charge is $16/kW.

The reduction in efficiency (based on Fig. B) is roughly 3.5% giving the new efficiency (çnew) as 89.5% (93% minus 3.5%). The losses due to the voltage imbalance are determined as follows:

$$\text{Loss in efficiency (kW)} = \text{HP} \times 0.746\ \text{kW/HP} \times \%\ \text{Load}\left[\left(\frac{100}{\eta_{new}}\right) - \left(\frac{100}{\eta_{old}}\right)\right]$$

$$\text{Loss in efficiency (kW)} = 200\text{HP} \times 0.746\ \text{kW/HP} \times 80\%\left[\left(\frac{100}{89.5}\right) - \left(\frac{100}{93}\right)\right] \approx \underline{5.02\text{kW}}$$

$$\text{Loss in energy (kWh/year)} = \text{Loss in efficiency (kW)} \times \text{Operational time (Hours/Year)}$$

$$\text{Loss in energy (kWh/year)} = 5.02\text{kW} \times 4{,}500\ \text{Hours/Year} = \underline{22{,}590\ \text{kWh/Year}}$$

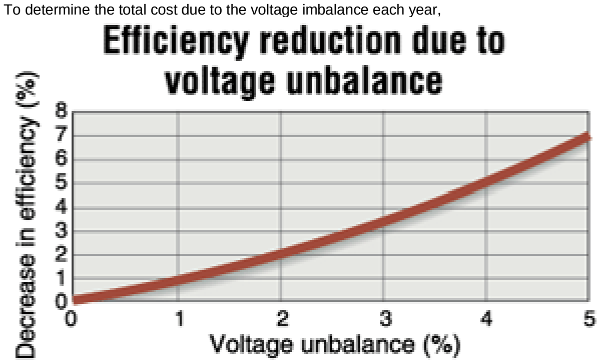
$$\text{Energy losses (\$/Year)} = \text{Loss in energy (kWh/Year)} \times \text{Energy cost (\$/kWh)}$$

$$\text{Energy losses (\$/Year)} = 22{,}590\ \text{kWh/Year} \times \$0.13/\text{kWh} = \underline{\$2{,}936.70/\text{Year}}$$

$$\text{Demand charges (\$/Year)} = \text{Loss in efficiency (kW)} \times \text{Demand charge (\$/kW)} \times 12\ \text{Months/Year}$$

$$\text{Demand charges (\$/Year)} = 5.02\ \text{kW} \times \$16/\text{kW} \times 12\ \text{Months/Year} = \underline{\$963.84/\text{Year}}$$

To determine the total cost due to the voltage imbalance each year,



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Motor Circuit Analysis for Energy, Reliability and Production Cost Improvements, Howard W. Penrose, Ph.D., BJM Corporation, Old Saybrook, CT, 2001.

Rockwell Automation to sell mechanical and motor business

In an ongoing effort to enhance shareowner value, Rockwell Automation announced its plan to sell its Dodge mechanical, Reliance Electric motors and motor repair services business. These are the principal businesses of the Rockwell's Power Systems reporting segment, and leading producers of mechanical power transmission products and industrial motors. Rockwell Automation will retain the Reliance Electric and Reliance branded drives and related parts and services as an integral part of its global drives and customer service businesses.

The Dodge and Reliance Electric businesses, headquartered in Greenville, South Carolina, contribute substantially all of the revenue generated by Power Systems. For fiscal year 2006, this segment is forecasted to generate about $1 billion in revenue and segment operating margins of around 15%.

Rockwell Automation has retained Sagent Advisors, Inc. for consultation throughout the sale process.

DOE funds LED development

Color Kinetics Inc. has received $1.7 million from the U.S. Department of Energy to develop solid-state lamps to replace traditional 60-W incandescent light bulbs. Solid-state lighting has the potential to more than double the efficiency of general lighting systems, reducing overall U.S. energy consumption.

The company designs illumination effects that rely on light-emitting diodes. It is putting up $550,000 of its own funds for the project.

TVA awards transformer contract

ABB has signed a five-year accord worth more than $100 million to provide the Tennessee Valley Authority with transformers and services. ABB will supply the TVA, which is the largest power utility in the U.S. by revenue, with transformers rated 230 kV and above.

The agreement includes outfitting new and existing TVA transformers with an electronic control monitoring system to support asset management and life extension efforts. The TVA also has an option to renew the contract for an additional five years.

Littelfuse completes Concord acquisition

Littelfuse, Inc. has completed the acquisition of Concord Semiconductor and its major subsidiaries for $25 million in cash and the assumption of $1.4 million in net debt. The acquisition is expected to be slightly accretive to earnings. Concord Semiconductor, which operates facilities in Taiwan and China, is a former Littelfuse supplier. The company has annual sales of approximately $15 million, excluding sales to Littelfuse.

“The acquisition adds silicon wafer manufacturing to our capabilities in Asia and expands our presence in the TVS diode market,” said Gordon Hunter, chief executive officer of Littelfuse.

Concord Semiconductor designs and manufactures TVS diodes and other overvoltage circuit protection products for the automotive, consumer electronics, computer, industrial and telecom markets.

Schneider Electric to acquire IBS

Schneider Electric announced that it will acquire Invensys Building Systems operations in North America and Asia, subject to regulatory approvals.

This follows the acquisition of Invensys Advanced Building Systems in 2005, and will be complementary with Schneider Electric’s building automation platform. IBS, a provider of building automation products and services, generated revenues of $142 million for the fiscal year that ended March 31, 2006, with operating profit of $20 million.

The building automation and control systems market represents significant growth potential for Schneider Electric. The acquisition of TAC in June 2003 enabled Schneider Electric to become a major player in this market.

Understanding harmonics:

Winning the fight against ’electrical pollution’

Rudy T. Wodrich, Schneider Electric/Square D -- Plant Engineering, 8/15/2007

Sections:

By now, every electrical engineer has heard something about harmonics. Harmonics are generated by nonlinear loads such as traditional variable-speed drives, uninterruptible power supply (UPS) systems and any other power conversion device that changes ac into dc with some form of rectifier bridge. Any device that draws a pulse of current from the electrical network for less than the entire voltage wave generates harmonics (Fig. 1). Harmonics are simply a mathematical representation of these distorted waveforms that allow us to model electrical network response at multiple frequencies, and better understand and predict how the electrical network will react to this high-frequency content – or 'electrical pollution.’

Harmonics: Bad

We care about harmonics for several reasons. First, harmonic current generates heat in all the current carrying components of the electrical distribution system: switchgear, breakers, fuses, cabling, capacitors, busduct, busbar and transformers. Harmonic current generates more heat on a per-Amp basis than current at the fundamental frequency (60 Hz). Although the distribution system is often conservatively designed for overcurrents, harmonic heating contribution must be taken into account.

Second, harmonic current flowing through the system impedances generates harmonic voltage distortion. Think of harmonic current as flowing from the utility supply down toward the non-linear loads. As current crosses major system impedances, such as distribution transformers or line reactors or even long-cable or bus-duct runs, it generates voltage drops. The closer you get to the non-linear loads, the more distorted the voltage waveform becomes from a true sinusoid. In severe instances, voltage distortion can cause operational problems with sensitive electronic equipment such as programmable logic controllers (PLCs) and, ironically, variable-speed drives (VSDs).

Voltage distortion – a function of harmonic current and system impedance – is worse on 'soft’ electrical systems with low available fault levels. So, users at the end of the utility distribution in remote locations or users who operate under generator power are more likely to experience issues relating to excessive voltage distortion.

The other issue with voltage distortion is that it causes harmonics to propagate throughout the network to the linear loads as well. Linear loads are just that – linear. If you apply a triangular voltage wave to a linear load, such as a full-voltage across-the-line motor, it will try to draw a triangular current waveform. Consequently, as voltage distortion increases, linear loads begin to draw harmonic current.

In the case of motors, some of these harmonic voltages – most notably the 5th and 11th harmonic – generate back EMF in the motor and therefore decrease the motor efficiency. The extra heating in the motor caused by the harmonic current flow may also cause additional wear and tear and shorten motor life.

Third, harmonics present on the electrical system make correction methods for poor power factor more complex and expensive. Traditionally, capacitors are installed to improve power factor, thus increasing system efficiency and usually resulting in some form of savings on the monthly electrical bill. While capacitors do not generate harmonics, they can interact and magnify harmonic levels through a condition called resonance, increasing both harmonic current and voltage distortion levels.

Power Factor Corrections

While harmonics are thought of as a steady-state phenomenon, harmonic levels on the electrical network are really dynamic in nature, changing rapidly as various loads are cycled on and off, and varied in magnitude such as with VSDs. Power factor correction systems must be designed to avoid resonance and also to cope with the varying reactive power requirements and varying harmonic levels on the network.

Also, a power factor correction system must be designed not only for the harmonic levels present on the network today, but also for possible future increases with load additions. Failure to consider harmonics in the design phase of a power factor correction project will inevitably result in a premature failure. Remember, harmonic current generates heat in the current carrying components of the network, and capacitor systems tend to absorb harmonics and thus bear the brunt of this effect.

Finally, the IEEE 519-1992 standard requires that end users limit harmonic levels to ensure network stability for all users. It outlines acceptable levels of harmonic distortion (both voltage and current) and the Point of Common Coupling (PCC) with the utility.

The truth is that customer X rarely affects customer Y on the grid, but rather, that usually customer X causes problems for himself within the four walls of his building. A more practical approach is to apply the harmonic limits spelled out in IEEE 519, but within the customer's electrical network (usually at the low voltage level). This will ensure that harmonic problems will not occur.

People in industry have said that, "Harmonics are not a problem until they are a problem." However, we tend to put off dealing with little problems until they become big problems. In this way, harmonics are similar to most other types of pollution. The trick is to realize there is a problem before it's too late. As with most other types of pollution, an ounce of prevention is often worth a pound of cure.

Mitigation Techniques

Now that we recognize the problems harmonics can cause, how do we minimize them? Mitigation methods for harmonics fall into two groups: device level and systems level. Device-level solutions include:

- Inductors and isolation transformers
- 5th harmonic filters
- Broadband filters
- Multi-pulse drives
- Active front end (AFE) converters.

System-level harmonic mitigation approaches include:

- Passive filters
- Active harmonic filters.

The simplest technique for reducing harmonics is adding impedance in front of the major nonlinear loads. This technique is inexpensive and relatively simple to implement. Adding a 3% (or greater) inductance in front of a VSD can yield a current-smoothing effect, reducing total harmonic current distortion from 90% to around 35%. In addition, this technique provides a small measure of transient suppression to the load and is also complementary to active harmonic filtering.

The two disadvantages of the technique are that the actual harmonic reduction depends somewhat on source impedance, and that only the first incremental impedance has a significant impact. In other words, adding a second 3% inductance does not make things substantially better than the first inductance.

The second device-level technique is the addition of a tuned filter at the device input terminals (Fig. 2). The inductor (Lp) and the capacitor (C) provide a low impedance path at one tuned frequency (typically 5th) while the second inductor (Ls) acts like the inductor mentioned above, which reduces harmonics from the load via the current-smoothing effect, while also decoupling the filter branch from the rest of the electrical network – so that there is little risk of the tuned filter drawing harmonics from other sources on the network and becoming overloaded.

The drawback of the device-applied passive filter is, unless it is somehow switched, it injects a fixed amount of reactive power (VARs) into the network at all times – even if the load is not operating. This technique works reasonably well for dc VSDs because they have high reactive power requirements. However, for ac VSDs or UPSs that have little or no need for reactive power compensation, this technique is less practical because it can cause leading power factor.

A broadband filter is another device-level solution that uses inductors and capacitors (Fig. 3). A broadband filter employs three separate inductors and one capacitor carefully selected to be reasonably effective at reducing harmonics up to the 13th order.

The disadvantages of the broadband filter are that it can be safely employed only with diode front-end conversion devices, it is physically large and the losses of the device exceed 5%. As series connected devices, both broadband and tuned filters have the possibility of interrupting power to the load in the event of a component failure within the filter. For critical loads, this may be a significant drawback.

Multipulse drives employ a phase-shifting scheme with multiple power converters to take advantage of harmonic cancellation that occurs through a phase shift (Fig. 4). Current distortion levels from 12 and 18-pulse configurations are substantially improved versus 6-pulse. However, this comes at a cost. The physical size of the drive is much larger and initial purchase price is at a premium. In addition, there are substantial losses associated with the magnetic phase shift that contribute to higher operating costs of multipulse drives.

These heat losses must also be taken into account when calculating the cooling requirements of the room in which the devices are installed.

Active front end (AFE) converters are a relatively recent development and are being employed in both VSDs and UPSs. In an AFE device, an insulated gate bipolar transistor (IGBT) converter is used, which can reduce harmonic output of the device and maintain near unity power factor. Furthermore, the IGBT can allow 4-quadrant operation of a VSD, allowing regenerative braking, which is useful in many process applications and provides even greater energy efficiency. In order to ensure voltage distortion is not excessive, a mains filter is employed as part of the topology.

There are some severe restrictions on the types of loads permitted on the same bus as the AFE device, which make it impractical to use in many instances. Other IGBT-based or silicon-controlled rectifier-based converters, capacitors and switch-mode power supplies are prohibited. The AFE VSD is also very large and expensive compared to traditional drive topologies and the input inductors on the AFE increase operating losses substantially versus conventional VSDs.

A passive harmonic filter may contain a series/shunt capacitor/inductor network and a series inductor or transformer. This type of filter often is added to an electrical system as a peripheral to a drive system. However, it must be tuned to the individual drive. Multiple drives require multiple filters.

Active harmonic filters are sometimes called active power line conditioners. Rather than block or shunt harmonic currents, active filters attempt to condition them. Active harmonic filters monitor and sense harmonic currents electronically and generate corresponding waveforms to counter the original harmonic currents. The generated waveform is injected back into the electrical supply to cancel the harmonic current generated by the load.

Author Information

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Basics of how to minimize harmonics

Jack Smith, Senior Editor, Plant Engineering Magazine -- Plant Engineering, 10/1/2003

Key Concepts

- Harmonics are multiples of a fundamental frequency.
- Nonlinear loads cause harmonics.
- Harmonics cause transformers, power cables, motors, and drives to overheat.
- Active and passive filters help minimize harmonics.

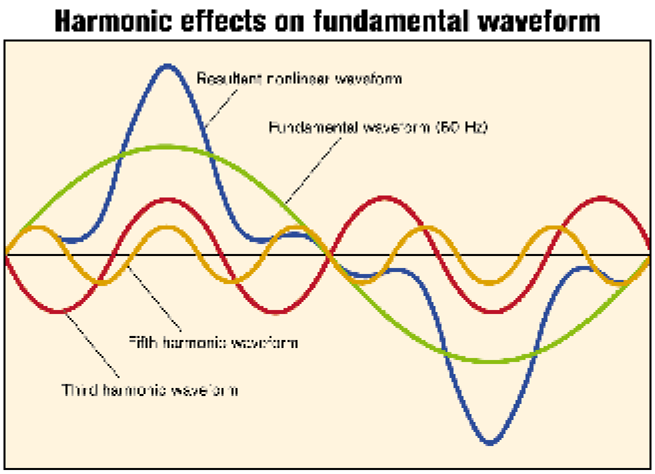
The August 14, 2003 blackout emphasized that power quality should not be taken lightly. The blackout was caused by, and affected the power grid — our nation's electrical infrastructure. The issues raised by this event should and will come under scrutiny. Just as the nation looks at its power quality issues, plant engineers must look at power quality issues inside the plant.

Harmonics is a buzzword thrown about freely these days. But what are harmonics, and why do we hear so much about them? What is the big deal? Why are they so important?

What are harmonics?

Harmonics are multiples of a fundamental frequency. In music, they are called octaves, and are usually desirable. But in a plant's electrical power distribution system, they are unwanted.

Harmonics cause trouble when combined with the fundamental electrical waveform. Since these harmonics are multiples of the 60-Hz fundamental power frequency, harmonic frequencies can be 2-times at 120-Hz, 3-times at 180-Hz, and so on. When harmonics mix with the fundamental, they distort the sine wave (Fig. 1).



IEEE defines harmonic content as "a measure of the presence of harmonics in a voltage or current waveform expressed as a percentage of the amplitude of the fundamental frequency at each harmonic frequency. The total harmonic content is expressed as the square root of the sum of the squares of each of the harmonic amplitudes."

What causes harmonics?

Nonlinear loads are the primary causes of harmonics. These nonlinear loads include, but are not limited to, variable speed drives, solid-state controls for heating and other applications, switched-mode power supplies like those found in virtually every computerized piece of equipment, static uninterruptible power supply (UPS) systems, electronic ballasts, electronic test equipment, and electronic office machines.

Nonlinear loads draw short bursts of current each waveform cycle, thereby distorting the sinusoidal waveform. Harmonic voltages are the result of harmonic currents interacting with power system impedance.

Why are they harmful to equipment?

The detrimental effects of harmonics include overheating of transformers, power cables, motors, and drives. They cause inadvertent thermal tripping of relays and protective devices. Harmonics can even cause logic faults in digital devices and incorrect voltage and current meter measurements. Any of these damaging results can cause downtime in your plant.

Section 6 of IEEE Standard 519-1992 describes how harmonic currents increase heating in motors, transformers, and power cables. According to the specification, harmonics can cause electrical losses in transformer cores and motor rotors resulting from hysteresis and eddy currents, making them overheat. Motors experience torque reduction. High harmonics cause electronic equipment to operate erratically.

Harmonics affect different equipment differently. Some of the detrimental effects caused by harmonics are:

- **Capacitors** — Capacitors operate as sinks to increased harmonics and harmonic frequencies. Supply system inductance can resonate with capacitors at some harmonic frequencies, causing large currents and voltages to develop at these frequencies. Increased currents and voltages cause breakdown of dielectric material within capacitors, which, in turn, causes the capacitors to heat. As capacitor dielectrics dry out, they are less capable of dissipating heat, and become even more susceptible to damage from harmonics. As this deterioration continues, short circuits or capacitor explosions can occur.

- **Transformers —** Harmonic voltages cause higher transformer voltage and insulation stress, resulting in transformer heating, reduced life, increased copper and iron losses through hysteresis and eddy currents, and insulation stress.
- **Motors** — Harmonic voltages produce magnetic fields that rotate at speeds corresponding to the harmonic frequencies, resulting in increased losses, motor heating, mechanical vibrations and noise, pulsating torques, increased eddy current and hysteresis losses in stator and rotor windings, reduced efficiency, reduced life, and voltage stress on motor winding insulation.
- **Circuit breakers —** Harmonics may prevent blowout coils from operating properly; circuit breakers could fail to interrupt current properly; or breakers could fail completely.
- **Watt-hour meters** — Induction disks are calibrated for accurate operation on the fundamental frequency only. Harmonics generate additional torque on these disks, causing improper operation and incorrect readings.
- **Electronic and computer-controlled equipment** — Some electronic equipment depends on zero-crossing or voltage peaks for proper operation. Harmonics can alter these parameters, causing erratic operation and premature equipment failure.

Besides equipment damage, you could be smacked with stiff penalties from your power company for noncompliance with IEEE Standard 519. The IEEE specification requires that harmonic distortion of the current waveform be limited to 5%. However, some engineers feel that operating a plant with harmonic distortion this high can cause significant energy losses and shortened equipment life; and recommend that total harmonic distortion should not exceed 1.5% under normal conditions.

How can you minimize harmonics?

A power quality site survey can help you determine what, if any, power quality problems your plant has on both sides of the power meter. Most surveys require the installation of power quality monitoring equipment or software. Not only does the survey help determine the presence and the extent of harmonics, but it also reveals other power quality problems such as voltage sags, power interruption, flicker, voltage unbalance, transients, poor wiring, and poor or inadequate grounding.

Harmonics can be minimized — and to some extent prevented — by:

- Designing electrical equipment and systems to prevent harmonics from causing equipment or system damage
- Analyzing harmonic symptoms to determine their causes and devise solutions
- Identifying and reducing or eliminating the medium that is transmitting harmonics
- Using power conditioning equipment to mitigate harmonics and other power quality problems when they occur.

When the electrical transmission and distribution system acts as a conduit for harmonics, any user connected to the grid could be responsible for generating them. In this case, work with your utility to identify sources of harmonics and minimize their influence on your plant's electrical system.

However, if harmonics are generated within your plant, it's up to you to mitigate them effectively. Attacking the harmonics problem at the source is always the best way to go. At your plant, minimizing harmonics is better for your equipment and the price you pay for electricity. Beyond that, it is your responsibility to keep your harmonics from feeding back into the electrical distribution medium, thereby affecting power quality of others connected to the grid.

Prevention

One way to minimize harmonics that are generated inside your plant is to reduce or eliminate them before they occur. Variable-speed drives traditionally have been harmonic-generating culprits. However, companies are designing drives that operate at reduced harmonic levels (Fig. 2).

A delta-wye transformer can be installed in parallel with a delta-delta transformer to effectively convert two synchronized 6-pulse VFDs to a 12-pulse application. Some drive applications are specified with line reactors and isolation transformers to provide additional inductive reactance that helps minimize harmonics.

Filters

Utilities use harmonic filters to minimize harmonics on their distribution systems. Filters can be used inside the plant as well. Typically, harmonic filters are either passive or active. Passive harmonic filters use inductors and capacitors to block harmonics or shunt them to ground, depending on the configuration and application. As frequency increases, the impedance of an inductor also increases, whereas the impedance of a capacitor decreases. Passive filters may become ineffective if harmonics change due to varying loads.

Line reactors and transformers are used for limited harmonic control with ac drives. However, most of them are installed to protect the drive from transients. Significant harmonic control can only be achieved when the inductor has been sized correctly, when the source impedance is low, or when the drive does not contain an integrated dc bus choke.

A passive harmonic filter may contain a series/shunt capacitor/inductor network and a series inductor or transformer. This type of filter often is added to an electrical system as a peripheral to a drive system. It must be tuned to the individual drive. Multiple drives require multiple filters.

Active harmonic filters are sometimes called active power line conditioners. Rather than block or shunt harmonic currents, active filters attempt to condition them. Active harmonic filters monitor and sense harmonic currents electronically, and generate corresponding waveforms to counter the original harmonic currents (See sidebar titled "How active harmonic filters work"). The generated waveform is injected back into the electrical supply to cancel the harmonic current generated by the load.

Ideally, electrical systems would be designed so that harmonics are not produced. Some equipment available today features circuitry that can reduce the generation of harmonics. Active and passive filters can help minimize harmonics.

Acknowledgements

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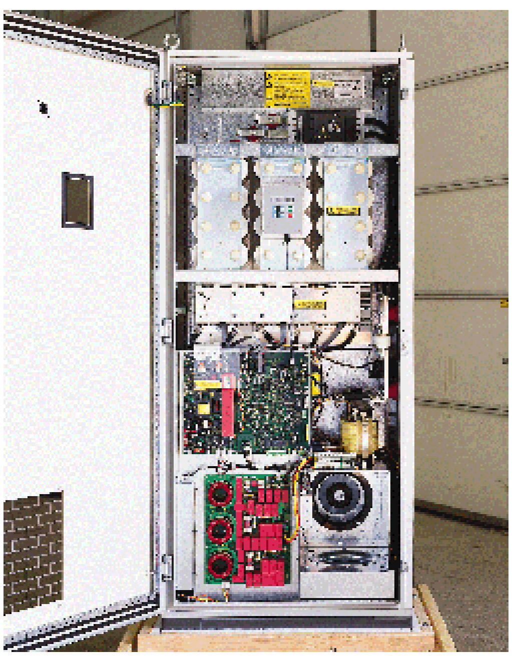
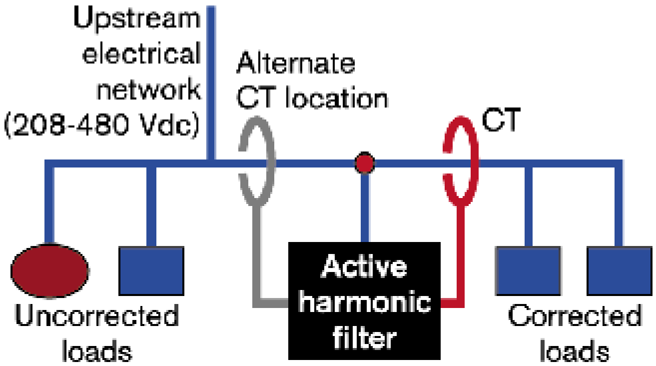
How active harmonic filters work

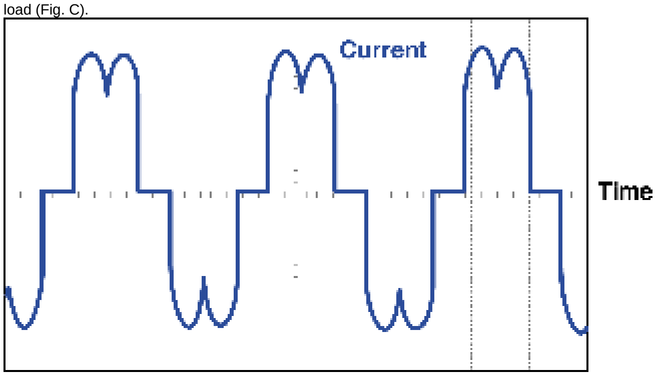
Typical active harmonic filters use analog power electronics and digital logic to sense and inject current, cancel harmonics, and provide reactive power. If sized properly, active harmonic filters can reduce harmonics below the limits specified in IEEE 519-1992 and improve power factor within your plant. Active harmonic filters cancel harmonics by dynamically injecting inverted (180-deg out of phase) current into the ac line, improving electrical system stability (Fig. A).



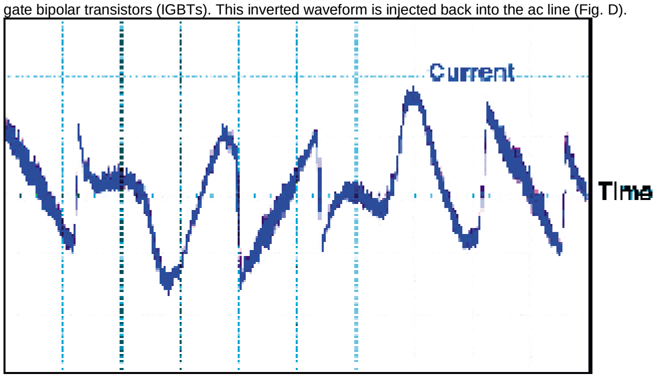
Generally, an active harmonic filter is installed on the ac lines in parallel to the loads that produce the offending harmonics (Fig. B).



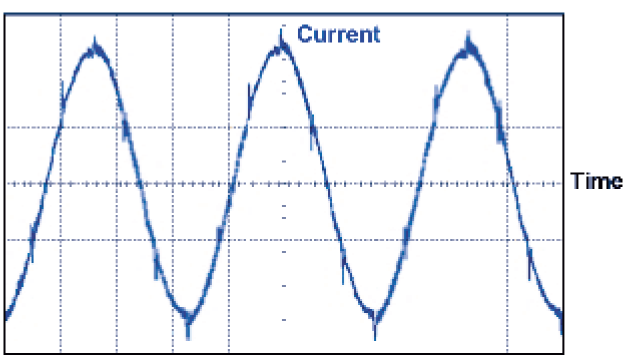
For 3-phase, 3-wire power systems, current transducers (CTs) on two of the three phases provide the control logic with the shape of the current waveform just upstream of the load (Fig. C).



The active harmonic filter logic removes the 60-Hz fundamental frequency from this waveform. The resulting waveform is inverted and used to direct the firing of the insulated gate bipolar transistors (IGBTs). This inverted waveform is injected back into the ac line (Fig. D).



The result is a cancellation of the current harmonics in the upstream electrical system (Fig. E). Since voltage harmonics are the result of current harmonics flowing through source impedances, they are also dramatically reduced.



Modern active harmonic filters are designed using components similar to those found in VFDs, including power semiconductors, dc link capacitors, buses, and fuses. The IGBTs use pulse width modulation (PWM) at an appropriate switching speed. An internal filter blocks this frequency from entering the ac lines and decouples the active harmonic filter from the rest of the system so no harmful interaction occurs.

Most active harmonic filters are scalable and can be sized to control existing or anticipated harmonic current in a system for one or many loads. The rated output current of an active harmonic filter is equal to the square root of the sum of the squares of the harmonic and reactive currents at the bus. When the total harmonic current exceeds the rating of a single active harmonic filter, additional units can be installed in parallel. Active harmonic filtration is just one of the benefits of a power correction system.

Identifying problems from transients in power systems

By Jon Bickel, Square D/Schneider Electric, LaVergne, TN -- Plant Engineering, 9/1/2004

Utility industry experts estimate that problems resulting from transient overvoltage costs U.S. companies $26 billion annually due to direct damage to electrical distribution systems, electronic equipment, software, tools, and the cost of lost productivity.

Electrical transient voltages can originate inside your plant or on the utility grid. They can propagate through various levels of electrical and data systems. Destructive transient voltage sources can be obvious, such as a lightning strike during a thunderstorm, or subtle, such as static discharge from a human finger. At least 60% of transient overvoltage events occur inside the plant; the rest come from outside in the form of lightning and fluctuations in utility power.

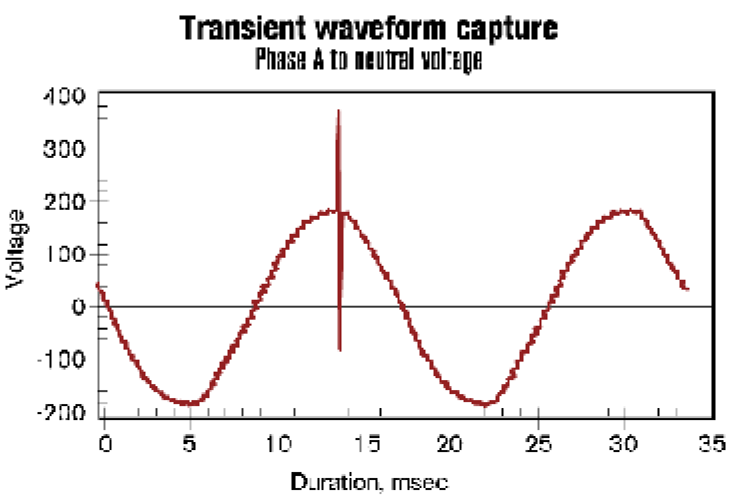
Transient overvoltages can stress electrical insulation if its rating is exceeded, leading to abrupt failure or gradual breakdown of the dielectric. Some industrial plants may experience thousands of transients per hour with voltage impulses exceeding 5-10 times the nominal system voltage in some cases (Fig. 1). Surge protective devices (SPDs), sometimes referred to as transient voltage surge suppressors (TVSSs), reduce the magnitude and duration of voltage transients and extend the life of equipment insulation (see "Surge suppression extends equipment life").

Key Concepts

- Many facility personnel never recognize voltage transients, but notice resulting damage.
- Reducing the magnitude and duration of voltage transients extends the life of equipment insulation.
- Voltage transients caused by capacitor switching typically are more common than those caused by lightning.
- The transient voltage waveforms should be evaluated with a power analyzer or meter with a high sampling rate.

Sections:
Effects of transients
Sources of transients
Recognizing transients
More Info:

Sidebars:
Surge suppression extends equipment life



Transient voltage events typically last from less than one microsecond (µsec) to several milliseconds (msec). Typically, these events are classified into two different types — normal mode or common mode — according to where they occur in the power system. Normal-mode transient voltage events appear between any two power or signal conductors. Common-mode transient voltage events appear equally and in phase from each power or signal conductor to ground.

Because the damage from transient voltage events may not be obvious, the cause of a component's damage is often misdiagnosed and entered on the work order as *unknown*. As many as 75% of integrated circuit failures can be attributed to voltage transient events. Furthermore, billions of dollars in electronic equipment losses occur each year due to voltage transients, with these casualties increasing each year.

Effects of transients

Engineers can use several factors to characterize voltage transients, including crest (or peak) value, area, energy, maximum rate of rise, duration, and the frequency of the transient. The effect of a transient overvoltage event on a specific load depends on the level of susceptibility of that load to one or more of these factors. The influence of a transient on electronic equipment generally falls into one of four categories:

- Intermittent interruptions occur when a transient event is introduced into a data or control network resulting in lost or corrupted data. This may cause the load or device to lock up, trip off, or operate improperly. Some factors that affect a transient's ability to disturb a load include design and operating speed of semiconductors, system filters, grounding configuration, susceptibility to electromagnetic interference (EMI) and radio frequency interference (RFI), and the configuration of the data or control cables.
- Chronic degradation occurs when repetitive transient events diminish the integrity of an exposed component or components. Over time, the cumulative effect of transient voltage events causes the eventual failure of the vulnerable component. Because the transient voltage events typically are frequent and relatively consistent in this case, it's feasible for technicians to locate the source with the appropriate troubleshooting tools.
- Latent failures are similar to chronic degradation, except that they are precipitated by a significant transient event that damages components, but does not cause failure. Normal operation will eventually cause the stressed components to fail. This type of failure is more difficult to troubleshoot because the root cause may have occurred at some unknown point in the past.
- Catastrophic failures that are caused by transient voltage events usually are obvious because the affected components fail immediately. In those cases, the magnitude, energy, or rate of rise of the transient exceeds the rated threshold of the component, creating a permanent open or short circuit within the component. The probability of correlating component damage with a specific system event is higher with this type of failure.

Solid-state products, microprocessor based devices, and programmable logic controllers (PLCs) are especially susceptible to damage from voltage transients. Accordingly, exposure to voltage transients can reduce the reliability and shorten the life of components in this type of equipment. As technology evolves and the scale of these devices shrinks, their susceptibility to damage from voltage transients increases.

Voltage transient events also can affect the quality of the products your plant manufactures. These events can interfere with the normal operation of equipment, resulting in erratic equipment functioning and diminished product quality. Interruptions in continuous manufacturing processes can cause revenue losses due to production downtime.

Sources of transients

The total electrical system includes many devices — both on the utility grid and within the plant.

External sources

Several sources of transient voltages on the utility's electrical system include:

- Lightning
- Capacitor switching
- Line/cable switching
- Transformer switching
- Current-limiting fuse operation.

Although voltage transients originating on the utility's electrical system can affect your plant's operation, transient voltage sources within the facility are more common.

Internal sources

The normal, daily operation of loads within the plant such as electric furnaces, ovens, induction heaters, welders, or motors can produce voltage transients that may effect adjacent equipment. Within the plant, transformers and motors, which are inherently inductive, introduce transients into electrical systems. Disruptions in the flow of current to these devices concurrently with the collapse of the devices' magnetic fields cause voltage impulses or transients. Transient voltage sources *within* the plant include:

- Capacitor switching
- Interruption of current to motors, transformers, and other inductive components or equipment
- Operation of power electronics components such as silicon-controlled rectifiers (SCRs), triacs, etc.
- Electrostatic discharge (ESD)
- Arc welding
- Copy machines
- Faulty wiring and circuit breakers
- Contact and relay closure
- Load startup or disconnect.

When a transient voltage event occurs on the utility's electrical system, the transient overvoltage's magnitude at a given point within the facility depends on location of the transient source, magnitude of the transient voltage event, configuration of the electrical system, and mitigation devices within the plant.

Transient overvoltages due to capacitor switching are common. When a capacitor bank is energized, a large inrush current charges the capacitors resulting in an initial notch into the voltage waveform. The system voltage recovers quickly, overshoots the original position, and continues to oscillate or ring. System voltage ringing is caused by the resonant circuit created by adding capacitors to an inherently inductive system and typically lasts about 1/2 cycle. Adjustable speed drives are sensitive to this ringing, which could cause them to trip.

Recognizing transients

Because transients have an extremely short duration, many events can either be missed or not accurately quantified because some meters use fewer samples than are necessary to accurately represent the analog signal. The transient voltage waveforms should be evaluated at a high sampling rate to perceive these occurrences. However, standard available metering equipment may not be fast enough to capture transient overvoltage events accurately.

Sophisticated monitoring devices or meters sample the analog signal at a much higher frequency than standard meters. A sample rate of 5 MHz or 83,333 samples-per-cycle (based on a 60-Hz system) during a high-speed event, is considered to be a good rate, compared to 512 (or less) samples-per-cycle in a standard meter (Fig 2). The higher rate results in data that have 162 times higher resolution than the standard available data from a meter sampling at 512 samples per cycle. Because the initial polarity is extremely important in determining the source of (and thus, the solution to) the transient, it is important to provide a high enough resolution to correctly determine the initial polarity of the event. While many longer duration events (such as voltage sags) can be properly diagnosed using lower sample rates, many transient overvoltage events cannot.

Figure 2a Phase A to neutral voltage

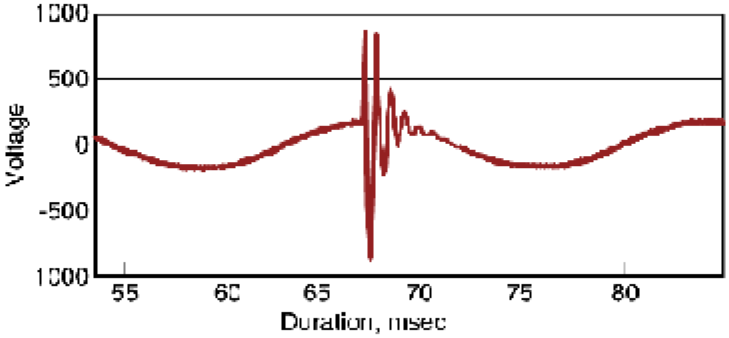
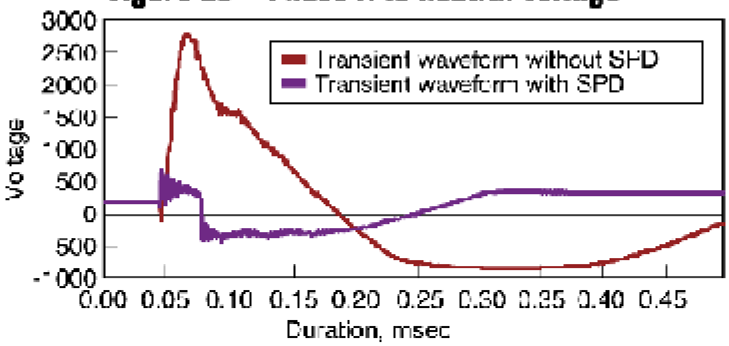
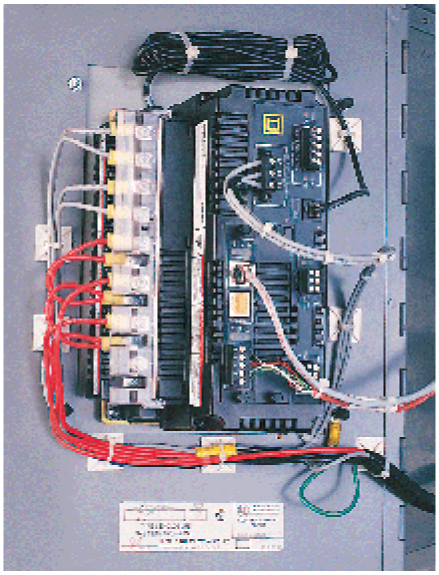


Figure 2b – Phase A to neutral voltage



Faster monitoring instruments make it easier to determine the sources and effects of transient overvoltages. At a minimum, the voltage transient monitoring instrument should have sufficient resolution to detect and record a transient overvoltage's true amplitude and duration, as well as the time of the event (Fig. 3).



Recording the time of day is important, because it helps you correlate internally or externally originating transients that occur as a function of the respective system's operating mode (plant or utility). The leading edge of a voltage transient has a polarity either into the waveform or out of the waveform. With a high-resolution transient waveform capture, you can use the initial polarity of the transient's leading edge to determine the type of device causing the transient. Given the current and voltage waveform, you can determine the direction — either load-side or source-side of the meter — of the transient source.

Due to metering limitations, and the rapid duration and nonperiodic nature of many transients, you may be unaware of the existence of voltage transients on your electrical system. Eventually, these transients might be responsible for unexplained equipment problems and damage. A myriad of transient voltage sources can affect equipment operation. Transient voltages may originate inside or outside of the plant. To preempt equipment damage and resolve effects of transients, plants should use circuit monitors that adequately measure and represent the true likeness of the original transient waveforms, and devices such as SPDs to mitigate transient problems.

More Info:

If you have questions about transients in plant electrical systems and how to measure and mitigate them, contact the author. Jon Bickel can be reached at **bickelj@squared.com**. For more information about transients, go to **SquareD.com** or **plantengineering.com**. Article edited by Jack Smith, Senior Editor, 630-288-8783, **jsmith@reedbusiness.com**.

Surge suppression extends equipment life

Surge protection devices (SPDs) have become important components of plant electrical systems because they improve power quality (Fig. 2b). The fundamental functions of SPDs include:

- Limiting the damage of electrical and electronic equipment caused by transients in the electrical system that exceed the intended operational characteristics of the equipment
- Extending the life of equipment that can be stressed over time due to transients introduced into the power system
- Removing transient events before they can affect the power quality of the electrical system in other areas of the plant.

The fundamental function of any SPD is to detect (in a fraction of a cycle) an overvoltage on the electrical system, and divert it in order to protect other equipment on the system. Plant personnel expect that an SPD will perform this function many times over the life of the device. However, the electrical industry recognizes that SPDs may have a limited life in comparison to the plant's entire electrical system. Understanding a few basics will ensure a better performing and more reliable electrical installation.

Connecting the SPD to the electrical system with the shortest conductor lead possible and minimal bends in the SPD lead provide the most effective protection. SPDs installed as an internal part of a panel or switch should provide the optimal design, which ensures:

- Impedance in the conduction path is minimized
- Protection levels do not become a variable based on the proximity of the SPD outside the equipment
- Conductor length and configuration characteristics are no longer an installation issue.

Connection requirements for an SPD at the service entrance are clearly defined in the 2002 *NEC* (Article 285), but those requirements continue to be misunderstood.

To ensure a properly protected and reliable electrical system with enhanced power quality, you need a basic understanding of SPD design and application as a component of the overall electrical system. To achieve a reliable electrical system with enhanced power quality, focus on the fundamentals, which include:

- NEC-compliant installation — including the short-circuit current rating and the number of disconnects at the service
- Performance — appropriate surge ratings, lead length, internally mounted SPDs and placement in the system
- UL1449 Listed — meets approved fire and electrical safety testing requirements for SPDs.