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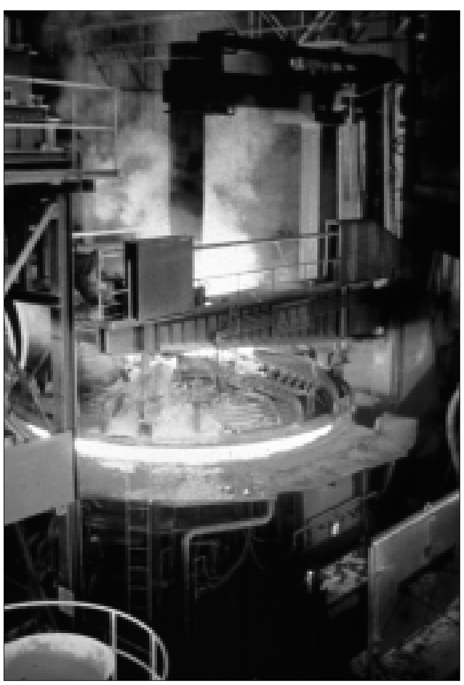
Reducing Flicker Caused By Electric Arc Furnaces

Lukens, Inc.—a steel manufacturer with facilities in the cities of Houston and Washington, Pennsylvania—has an annual production capacity of 220,000 tons. Among the equipment used at the company's melt shop in Houston are two ac electric arc furnaces (EAFs). During scrap melting, the length of the furnace arc changes rapidly and erratically, creating voltage drops in power lines supplying the furnace. The resulting variance in line voltage causes light flicker for customers connected to the same lines.

"When Lukens decided to upgrade one of their EAFs with a new 35-MVA, 55-ton furnace to increase melting capacity and production, we worked closely with them to establish new operating parameters," says John Rutkowski, major accounts manager at Allegheny Power, the serving utility. "We suspected that flicker problems might occur in the vicinity of the plant after the installation and prepared for that possibility by purchasing a flickermeter to measure voltage variations. This would allow us to verify that customers were experiencing objectionable flicker."



Electric arc furnaces can go from zero to full load many times an hour as arcs are struck and broken in the furnace. These fluctuations contribute to voltage variations in the electrical distribution system, causing flicker.

Shortly after installation of the new EAF, Allegheny began to receive complaints about flickering lights from residential customers near the Houston plant. To confirm that the new furnace was causing the problem, Allegheny installed the flickermeter at various locations—customer homes, the Lukens plant, and utility substations—and measured the effects of the furnace on the total system. The utility then compared voltage flicker measurements with Lukens' melt records, finding a perfect match.

Solving the Problem

As a temporary solution, Allegheny and Lukens worked together to determine ways to reduce furnance loading during the periods when flicker was most noticeable. Because these curtailments had a negative impact on Lukens' production, the utility assisted in the development of rate incentives to offset manufacturing losses.

Allegheny then considered several options to permanently resolve the flicker problem. These included constructing an additional parallel 138-kV line to the substation feeding the Houston plant, construct-

Reducing Flicker: Continued on page 6

Point of View

The *Harvard Business Review* recently stated that, on average, U.S. corporations lose half of their customers every five years. Does that include utilities, too? If today's answer is no, tomorrow's will be a definite yes. In the upcoming era of utility deregulation, customer defections may rapidly increase.

Many utilities today do not have insight into the causes of customer exodus—let alone the cures. They do not measure customer losses, make little effort to prevent them, and fail to use them as a guide to improvement. Some utility executives would say that the causes for customer defection—and sometimes the customer itself—are hard to determine. Even getting the right people to act within the organization can be a challenge.

The city of Roseville, California, made headlines across the nation when NEC Electronics publicly stated that it would look elsewhere to build a new $1 billion facility because of power quality problems at its chip-making plant there. City officials denied any problems with the delivery and quality of electricity and claimed to be puzzled by NEC's decision. However, other government sources said that "power problems have been an issue at the NEC plant in Roseville." What an unfortunate breakdown between the city, utility, and a customer who, since 1984, has employed 2150 city residents. Didn't city and utility officials know that any work stoppage due to power quality problems would translate into huge monetary losses for their customer? Do they now understand the intimate and causal relationship between customer loyalty and corporate profit? Roseville provides a valuable lesson for us all.

Marek Samotyj

Marek Samotyj, Manager
Power Quality Business Unit

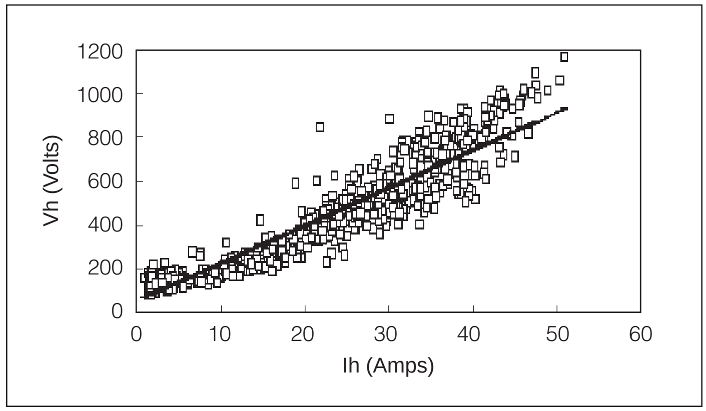
Controlling Induction Furnace Harmonics

by Mark McGranaghan, Electrotek Concepts, Inc.

Induction furnaces are used in a variety of metals-processing applications and can range in size from a few hundred kW to about 3000 kW. These furnaces typically use a six-pulse, phase-controlled rectifier feeding a frequency converter to deliver a 300- to 1000-Hz alternating current to the furnace coil. This variable-frequency ac allows for more efficient operation of the furnace and better control of the heating process.

While offering these benefits, frequency converters can also generate harmonic currents that propagate through the supply transformer onto the utility distribution system. These harmonic currents cause distortion problems at both the customer facility and on the distribution system. Electrical load can also be very sporadic because high power is needed only when material is being heated.

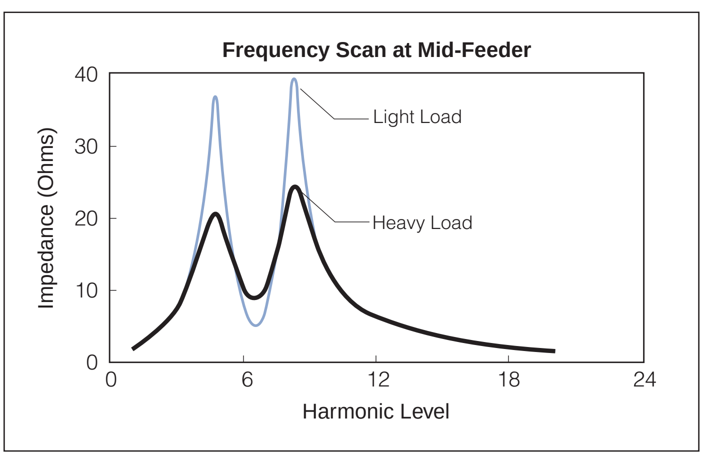
These problems are often compounded by the need for power-factor-correction capacitors. Because induction furnaces are controlled by delaying the firing angle of the thyristors, it is not uncommon for a facility without capacitors to have a power factor below 60%. Adding capacitors to the furnace aggravates the harmonic problem by creating parallel resonance between the capacitors and the source inductance. Worst-case conditions occur when the parallel-resonance frequency for the circuit corresponds to the fifth or seventh harmonic—the characteristic harmonics for induction furnaces. Parallel resonance results in higher voltage distortion at the customer facility, which can cause capacitor failures and fuse blowing. These voltage harmonics can also inject higher harmonic levels into the electrical distribution system, causing telephone interference and equipment misoperation for other customers.



Correlation between feeder harmonic voltage (Vh) and harmonic current (Ih) injected by a customer with multiple arc furnaces.

The Distribution System Response

How the utility system responds to harmonic currents is determined by several factors: the combination of shunt capacitor banks in the electrical system, the short-circuit capacity of the system, and the damping effect of resistive loads. Most systems have a number of capacitor banks distri-buted between the substation and individual feeder circuits. They may be switched by a time clock or based on load variations, resulting in a system response that changes over the period of a day.



Distribution system frequency response characteristics.

Resonance problems that intensify harmonics or cause telephone interference may only occur for a particular combination of capacitors in service. The frequency response plot below illustrates how resonances on the distribution system can correspond to the characteristic fifth and seventh harmonics of induction furnace loads. With the wide variety of possible configurations, it is usually difficult to implement harmonic control measures at the distribution level that work well for all conditions.

The utility can use monitoring at the point of common coupling between the distribution system and the customer to evaluate the relationship between system distortion levels and harmonic currents generated by the customer. Two methods can be used to evaluate the impact of a particular customer on the system:

- Compare the time variations of voltage distortion on the distribution system with time variations of the customer load.

- Plot the correlation between the feeder voltage distortion and harmonic current from the customer facility, as shown in the figure above.

Controlling the Harmonics

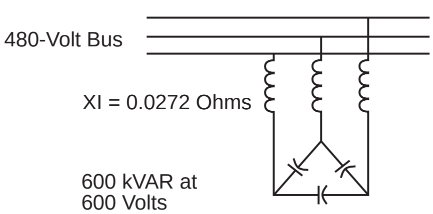
Harmonics generated by induction furnaces are best controlled with harmonic filters. The best place to locate the filters is at the low-voltage bus supplying the induction furnace. A harmonic filter consists of power-factor-correction capacitors and a series-tuned inductor to provide a low impedance near the fifth harmonic. While the filter generally reduces harmonic current injection into the distribution system for all harmonics above the tuned frequency, it provides the most benefit near the tuned frequency. The filter also provides the power factor correction for the furnace load. In fact, it is usually sized according to power-factor-correction requirements, rather than harmonic loading.

In cases where multiple induction furnaces are supplied from the distribution system, it may be more economical to implement harmonic filtering on the distribution primary rather than have multiple installations of lower-voltage filters. If so, the effect of other capacitors on the system and other harmonic-producing loads should be considered in the filter design process. This type of filtering has been successfully im-plemented at a number of locations.

Harmonic filter specifications should allow for harmonic loading from the distribution system as well as local harmonic sources. For small filters, harmonics from the distribution system can be just as important as harmonics from the specific load being filtered. Voltage rise across the series inductor at the fundamental frequency must also be considered because it increases the steady-state voltage on the capacitors.

Harmonics are clearly an important consideration for induction furnace facilities, and they should be evaluated along with power-factor-correction requirements. Institute of Electrical and Electronics Engineers (IEEE) Standard 519-1992 provides guidelines for limits and mitigation of harmonic levels. ■

Filter Configuration



Capacitor Specifications
- Voltage Rating = 600 Volts
- kVAR Rating = 600 kVAR
- kVAR Provided at 480 Volts = 384 kVAR

Reactor Specifications
- Inductance = 0.0720 millihenries
- Reactance (60 Hz) = 0.0272 Ohms
- Total RMS Current Rating = 660 Amps/Phase
- Fifth Harmonic Current Rating = 450 Amps/Phase

Harmonic filter for a 1000-kW induction furnace supplied by a 1500-kVA transformer.

Hotline Highlights

Hotline reports contain some interesting, and sometimes unexpected, customer responses to light flicker. At Puget Sound Power and Light in the Northwest, John McClaine says, "The increased use of electronic and compact fluorescent lighting in offices and heavy use of incandescent lamp dimmers in homes are creating a new set of complaints." Some customers are distressed about the flickering they see, others worry about potential damage to their house wiring or electronic appliances, and some just want to alert the utility to a possible problem in the system.

Alabama Power's Pat Coleman has found that people with new houses are more apt to complain about flicker than neighbors in older homes using the same type of lamps. "In a new house, the owners want everything to be just right and tend to look hard for possible flaws," he says.

At CINergy in Indiana, Larry Conrad says, "Some customers seem satisfied just to know that the utility is working on the situation." Like Puget Power, CINergy has found that flicker causes some customers to be concerned about the wiring in their homes. And, one customer worried that perception of flickering lights was an early warning sign for a seizure or heart attack.

With the many different types of ballasts and lamps on the market today, it is likely that more incidents and new types of light flicker will be observed and reported to utilities. Testing at PEAC has shown that some new lighting technologies reduce flicker, while others tend to increase it. Now, the easiest solution to a flicker problem may be to change the lamp type, rather than the power system.

Highlights come from the PEAC Hotline. If you have problems you would like addressed, call 1 (800) 832-PEAC.

Integration of Steel Mills Into Electric Power Systems

by Edward L. Owen, Power Systems Engineering Department/GE Electrical Distribution & Control

Among all of the process and manufacturing industries, the steel industry is unique because of its large, fluctuating electric power requirements. The electric arc furnaces (EAFs) and hot-strip mills used in steel production are high energy users, and their real and reactive power demands vary substantially within short periods of time. Other industrial plants purchase as much or more power, but their power draw does not change to the same extent.

The 1990s have become an extremely competitive decade for the steel industry, and the mini-mill—with its EAF process—is playing a key role in lowering costs and increasing productivity. Currently, some 30 mini-mill projects are on the drawing board worldwide, with about one-third of them in the United States. To assure that these projects serve their mutual objectives, utilities and steel companies need to cooperate in the planning, design, and operation of the mini-mills. They must also work together to identify, evaluate, and meet technical challenges. These challenges can be divided into two categories:

- *Transmission and Distribution*. Utilities must protect their other customers against voltage fluctuations, which cause incandescent lights to flicker, and harmonics, which may interfere with the operation of customer equipment. In addition, utilities must be prepared for increased thermal loading of their transmission facilities and a potential for voltage-regulation problems on their networks due to the relatively large power requirements of steel mills.
- *Power Generation*. The unbalanced loads and fluctuating currents created by EAFs can overheat turbine generator (TG) rotors and increase the potential for power system instability. Also, both harmonic and inter-harmonic currents generated by steel mills can stimulate torsional response, a cause of stress and fatigue on TGs. Inter-harmonics is a relatively new term which refers to spectral components at frequencies other than normal integer multiples of power system frequency. For example, the fifth harmonic of 60 Hz is 300 Hz. A spectral peak occurring at 4.7 times the fundamental (4.7 x 60 = 282 Hz) is an inter-harmonic. Institute of Electrical and Electronics Engineers (IEEE) Standard 519 prescribes protocols for coordinating integer harmonics at the point of common coupling between the utility and customer. It indirectly addresses inter-harmonics by discussing cyclo-converters but does not provide any guidelines for limits. IEEE has convened a task force to develop suggestions for addressing inter-harmonics in Standard 519.

Steel mill loads can cause problems for electric utilities because they present abruptly fluctuating demand for power.

Addressing the Challenges

Due to the substantial economic implications of these challenges, solutions now exist for just about any interface problem. Monitors and relays are available to detect and diagnose potential interactions with generators and avert equipment damage. There are devices to solve flicker and harmonics problems affecting residential and commercial customers. Static var compensation (SVC) smoothes variations in reactive power drawn by EAFs, reducing the voltage fluctuations that produce light flicker (see *Reducing Flicker* article on the front page of this issue). Shunt capacitors can be tuned with series reactors, producing a harmonic filter that diverts harmonics from the power system.

As technologies and applications undergo changes, however, so must the power engineering solutions that accompany them. For example, in the 1960s and 1970s there was little reason to worry that an EAF located near a hydro plant might cause generator heating. With today's furnace technology, it is crucial to examine this possibility when the furnace is located near one or more TGs.

Torsional Issues

TG torsional issues have mostly been associated with power system switching events such as line faults and out-of-phase synchronizing, sub-synchronous resonance due to series capacitors, and control interactions with high-voltage dc transmission and SVC systems.

However, in addition to having torsional effects on a utility's TGs, steel mill loads can also impact other industrial customers. This occurs when an industrial plant—or the plant of an independent power producer—is connected near a steel mill load. The plant's large synchronous and induction machines behave like TGs, responding to torsional excitation. This situation becomes more complex when two or more mills are located near the affected plant. Fortunately, in most cases utility generators are very large and act as a shunt to power disturbances, protecting other industrial plants on the system.

Technology is now available that allows utilities to differentiate load-caused disturbances by customer. Torsional vibration protective devices, or relays, installed on TGs detect its response to inter-harmonic currents. When an excessive response in the form of a current transient occurs, monitors placed at strategic locations can identify the source of the current.

Public Service Company of Colorado (PSCC), for example, experienced a vibration-induced, retaining-ring failure due to the electromechanical interaction of a power plant with a nearby steel mill. To identify the source of vibration, the utility conducted on-site tests, measured the vibration response of the TGs using specially developed torsional monitors, and resolved electrical waveform signals with spectrum analyzers. PSCC found a positive correlation between operating conditions at the steel mill and TG torsional vibration at their Comanche station. The link was a low-level spectral component—or inter-harmonic current—at 55 Hz. This spectral component was a lower sideband on the 60-Hz power frequency. It was produced by modulation processes similar to amplitude-modulation used in commercial radio broadcast. To prevent reoccurrence of this problem, PSCC has installed continuous on-line vibration monitors on the TGs to detect process conditions that lead to the offending inter-harmonic current. ■

Case Study

by Larry Conrad, CINergy

CINergy recently investigated a case in Indiana where a continuous welding machine at a steel fabrication plant caused light flicker problems for nearby customers. While planning for a new product line, the steel maker had found that voltage fluctuation levels caused by its welder would exceed the limit of irritation for light flicker, as published in Institute of Electrical and Electronics Engineers (IEEE) Standard 141-1993. Cost estimates clearly favored adding equipment for adaptive var compensation to lower system impedance, rather than enlarging the feeder and service capacity. The adaptive var compensator, a slower-acting cousin to the static var compensator, was purchased and installed. However, the new product line had much heavier welding requirements than anticipated, and the one-cycle response characteristics of the compensator had a tendency to double the frequency of voltage variations, causing noticeable flicker.

The main challenge for CINergy was to find the best way to modify the compensator control to eliminate complaints. Because the compensator increases flicker complexity, it prevents meaningful application of IEEE 141-1993 and makes it difficult to prove that voltage fluctuations are violating the standard. It also raises the question as to the best way to reduce flicker using standard monitoring equipment alone.

To address these challenges, CINergy tested an International Electrotechnical Commission (IEC) flickermeter that had been modified for use on 120-volt lamps (the European standard is 230 volts). The IEC flickermeter uses a sophisticated system model to evaluate voltage and provides an output in units of customer irritability. Because the system was close to the acceptable limit for flicker, it was a good test of the meter's ability to predict human irritation from a voltage measurement. The meter did accurately predict that flicker severity had surpassed the borderline of irritation.

This case also gave CINergy the opportunity to test a state-of-the-art system model developed by Purdue University, which shows the combined operations of the welder, compensator, and a lamp/eye-brain model comparable to the algorithm used in the IEC flickermeter. The model allowed CINergy to test different combinations of compensator size and control strategies by providing standard voltage and current waveforms.

Since electric power systems can be modeled with relative ease and speed, combining the use of the IEC flickermeter with the Purdue model should be a useful tool for solving future flicker problems. The final solution in this case will be reported in a future issue of *Signature*.

The Summer Meeting of the IEEE Power Engineering Society (PES)—to be held this July in Denver, Colorado—will feature a panel session on steel-making and electric power issues. Topics for discussion include the PSCC case study, impacts of inter-harmonics and torsional vibration on turbine generators, and perspectives on delivering power to and obtaining electric service for mills and mini-mills. Edward Owen will participate in the session's summary panel. For more information, call Duane Torgerson at the Western Area Power Administration, (303) 275-2006, or contact IEEE at *http://www.ieee.org/power/summer96.htm* by e-mail.

Reducing Flicker: *Continued from page 1*

ing a 500-kV substation, rewiring the existing 138-kV lines, and installing a static var compensator (SVC). Analysis showed that installation of the SVC had the lowest cost and could be done in the most timely manner.

The SVC supports power system voltage by reacting to changes in var flow to the plant and supplying the var requirement that otherwise would come from the Allegheny transmission system. This resulted in decreased voltage variation on the 138-kV transmission due to the reduction in var loading. Var loading is the reactive power requirement of the Lukens furnace.

Allegheny supplies power to Lukens at a nominal 25 kV, which is derived from a 138- to 25-kV transformer bank in a substation located away from the steel plant and near a residential area. The natural location of the SVC was adjacent to the substation, but noise created by the unit's large shunt reactors—which enable the SVC to supply inductive loading when needed—was likely to disturb the neighbors, just 100 feet away. The utility determined that the neighbors could tolerate without complaint a noise level of 50 to 52 decibels (dBa).

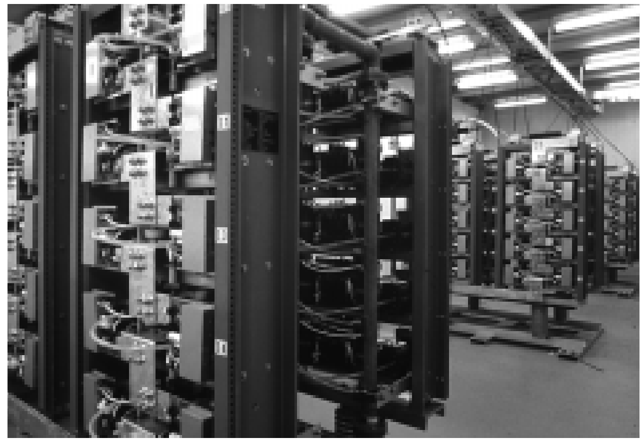
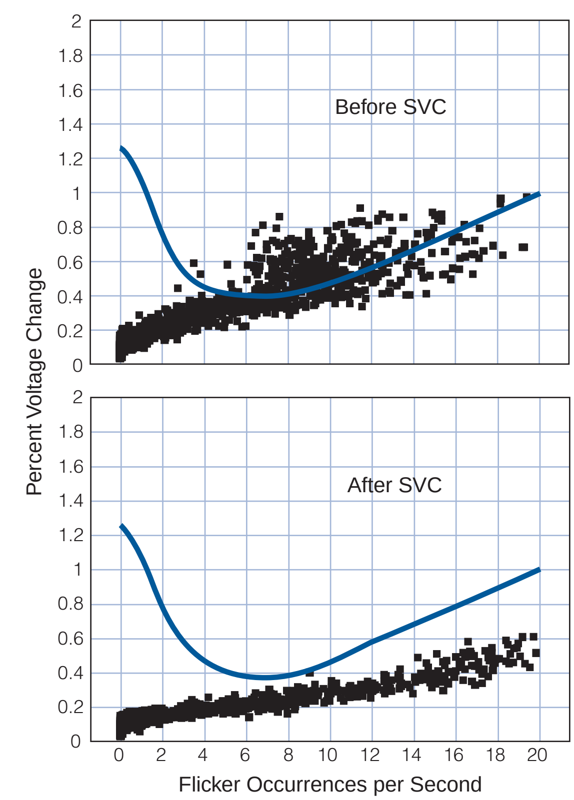


Photo courtesy of CANA

Static var control system.

Because this was the utility's first SVC installation, they contracted with CANA—a division of Cegelec—to design, supply, install, and commission the SVC. CANA worked with the equipment manufacturer to obtain the necessary noise limit for the SVC.



Installation of a static var compensator (SVC) at the utility substation serving the Lukens plant reduced flicker to the point that it is no longer considered objectionable. Nonobjectionable flicker is depicted below the curve.

"The shunt reactors for the SVC were the largest the manufacturer had ever produced dictating this degree of noise reduction," says Bob Coates, manager of sales at CANA. "They required extensive new engineering and design modifications by the reactor supplier."

To further reduce noise, the SVC site was arranged with noise sources away from the nearest neighbors. The shunt reactors were also mounted at ground level rather than on elevated structures.

Because SVCs can generate a third harmonic, Allegheny and CANA conducted a power system study to determine where tuned filters would need to be installed. A damping filter tuned to the second harmonic was installed to help suppress harmonics across the whole spectrum.

Eighteen months after the initial order, the SVC was tested to verify that performance requirements had been met—and placed in service. "It has been designed to handle the full EAF load, giving Lukens the ability to melt at capacity without causing flicker," says Coates.

Pretesting by CANA had revealed that there must be no load on the power delivery system during energization. Therefore, the SVC was energized when the furnace was being tapped or charged. During these periods, the furnace electrodes are retracted and the furnace is turned off. Once the SVC is energized, the electrodes can be lowered and the furnace operated.

Close cooperation between Allegheny, CANA, and Lukens resulted in minimal disturbance of production during SVC startup. Lukens varied its operation of the furnace to test the total range of possible operating levels. Allegheny and CANA coordinated the testing to minimize the effect on Lukens' operations. CANA also provided SVC-operator training, and demonstrated how the more stable voltage from the

Reducing Flicker: *Continued on back page*

Standards Update

by Tom Key, EPRI PEAC

Recent *Standards Updates* have covered emerging power quality standards in the international arena. Most new standards are related to the general characteristics of public power supply, such as harmonics or surges, and to the electromagnetic compatibility (EMC) of end-use electronic appliances, including immunity and emissions limits. The current interest in EMC is being fueled by increasing applications of micro- and power electronics equipment, especially in the commercial and residential sectors, where customers need both the uniformity and protection afforded by standards.

In comparison, the industrial sector has historically dealt with extreme power conditions and unique equipment requirements. The demand for proven practices to meet these requirements has been around for many years. The Institute of Electrical and Electronics Engineers (IEEE) has met this demand for the last 50 years with its series of standards called the *IEEE Color Books*. This series—which is produced by the Industrial and Commercial Power Systems Department of the Industry Applications Society—provides recommended practices for all aspects of power systems in industrial and commercial facilities.

The first standard, the *IEEE Red Book*, "Recommended Practice for Power Distribution in Industrial Plants," was published in 1945 and is now printed in its seventh edition. As the table shows, the series has grown to ten color books, including one specifically for commercial buildings and one for healthcare facilities.

Color books provide a wealth of guidance for designing high-quality power systems. They touch on power quality directly, with coverage of battery systems for critical loads in the *Orange Book* and grounding for sensitive electronics in the *Emerald Book*. Discussions are now under way to make the next edition of IEEE Standard 1159, "Monitoring Power Quality," a new color book.

In Europe, several industrial standards related to power quality have been published by the International Union for Electroheat (UIE). These include the original flickermeter standard—now International Electrotechnical Commission (IEC) Standard 1000-4-15—and the limits related to voltage fluctuations, as published in IEC EMC Standards 1000-3-3 and 3-5. UIE is currently preparing a four-part publication, *Guide to Quality of Electrical Supply for Industrial Installations,* which introduces EMC and includes sections on voltage dips and short interruptions, harmonics, and unbalance. Other UIE power quality publications are:

- *Connection of Fluctuation Loads*, 1988, which covers flicker measurement, evaluation, prediction, and assessment and provides compatibility limits and practical examples.
- *Flicker Measurement and Evaluation*, 2nd edition, 1991, the basic document behind IEC flickermeter standard development.
- *Dips and Short Interruptions Occurring in Industrial Installations*, 1992, which supports other power quality guides.

Today's concerns about point-of-use power quality are bringing renewed interest to some tried-and-true industrial power standards. Although many have been around for years, they just keep getting better. So, let's not reinvent the wheel! The recent attention to these standards can be expected to promote faster updating and encourage even better information in power quality-related standards. Many of these classic industrial power standards deserve a fresh look. Your comments and other points of view are welcome.■

This column serves as an open forum on power quality standards activities and developments. Please send your comments to *tkey@eprinet.epri.com* for e-mail.

Facility Electrical Topic	Color	IEEE Standard Number	Status
Plant Power Distribution	Red	141-1993	7th Edition
Power System Grounding	Green	142-1991	5th Edition
Commercial Building	Gray	241-1990	4th Edition
Protection and Coordination	Buff	242-1986	3rd Edition
Power System Analysis	Brown	399-1990	2nd Edition
Emergency and Standby Power	Orange	446-1987	4th Edition Coming Soon
Reliable System Design	Gold	493-1990	2nd Edition
Application of Circuit Breakers	Violet	P-551	1st Edition in Process
Healthcare Facilities	White	602-1996	2nd Edition
Energy Conservation	Bronze	739-1984	2nd Edition Coming Soon
Maintenance, Operations, and Safety	Yellow	P-902	1st Edition in Process
Short-Circuit Calculations	Blue	P-1015	1st Edition in Process
Power/Grounding Sensitive Electronics	Emerald	1100-1992	1st Edition

These IEEE Color Books alert the design engineer to items that must be considered in a facility design. The standards, while not regulatory codes, also establish what can be classified as the best design practices at the time of publishing.

EPRI R&D Corner

The characteristics of electric arc furnaces (EAFs) along with the growing use of these furnaces in the steel industry may be a major cause of voltage fluctuations in electrical distribution systems. The EPRI Power Electronics Applications Center (PEAC) and the EPRI Center for Materials Production (CMP) have proposed a joint project to evaluate flicker associated with EAFs and the steel industry.

This joint effort will allow EPRI members to get help with specific flicker-causing loads at sites in their service areas. The project is designed to identify and share innovative and cost-effective solutions to flicker problems, such as the one described in the *Reducing Flicker* article in this issue.

Through its contacts within the steel industry and related technical associations, CMP will determine steel mill operating conditions associated with voltage fluctuation. PEAC will measure voltage fluctuations in electrical distribution systems near various steel mills and perform laboratory analysis of the measurements. Utilities serving the steel mills will furnish information on their distribution systems.

The project will include a worldwide literature review. Project data will be presented at a workshop, and a report on all facets of steel industry-related flicker will be distributed to participating organizations.

For more information, contact Tom Key at PEAC, (423) 974-8289 or *tkey@eprinet.epri.com* for e-mail. Or, contact Joe Goodwill at CMP, (412) 268-3435.

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SVC could make furnace operation control more efficient.

Benefits of the SVC

For Allegheny, the SVC moderates voltage fluctuation and allows the utility to optimize its transmission lines by increasing power factor. More specifically, its benefits include:

- *Reduced Flicker*. Installation of the SVC has reduced light flicker as the figure on page 6 illustrates. Also, neighbors no longer complain about the problem.
- *Acceptable Noise Levels*. Sound measurements indicate the SVC's noise level to be 52 dBa at a distance of 100 feet, meeting project specifications. There have been no complaints from neighbors.
- *Enhanced Power Factor*. In addition to suppressing voltage fluctuation with a fast open-loop control, the SVC provides a slower closed-loop control which utilizes transformer current to regulate the power factor to near unity. This has been verified through upstream metering by the utility.

For Lukens, the SVC provides a more stable arc in both of its EAFs, resulting in a more efficient manufacturing process. Specific benefits include:

- *Improved EAF Operation*. Furnace operators have been able to reduce the tap setting on the EAF because more power is now being delivered to the furnace. This has enabled them to increase the refractory life of the furnace shell lining. Also, the scrap mix is now less critical.
- *Increased Productivity*. Lukens reports an increase in productivity, which it attributes to changes in melting practices, new operating procedures, and the SVC installation. In addition, the operating-period curtailments enacted by the utility have been eliminated. ■

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