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."

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 furnace 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-
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.

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 distributed 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.

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.
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 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:

- Power Generation. The unbalanced loads and fluctuating currents created by EAFs can cause problems for electric utilities because they present abruptly fluctuating demand for power.

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

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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.

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### 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*.
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).

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.

"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 electronic appliances, including immunity compatibility (EMC) of end-use 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.
- 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.

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<td>Brown</td>
<td>399-1990</td>
<td>2nd Edition</td>
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<td>Violet</td>
<td>P-551</td>
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<td>Bronze</td>
<td>739-1984</td>
<td>2nd Edition Coming Soon</td>
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<td>P-902</td>
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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.
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.

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.