

A Cement Plant's Experience in Investigating Power Sags Leads to a Reduction in Kiln Outages by Utilizing Power Hardening Methods

Alan Finch
Plant Manager
Ash Grove Cement
Chanute, KS

Abstract -- Poor power quality can be a cause of several process interruptions, including kiln outages at a cement plant. The purpose of this report is to educate the reader on voltage sags, which are the most common power quality issue faced by an industrial plant. Industrial end-users should understand why they should be concerned about voltage sags at their facility and how the severity of a voltage sag can be quantified then related to the sensitivity of the installed plant equipment. This in turn can result in applying power hardening methods to process equipment that will benefit the facility by reducing the number of power quality related process outages.

Index Terms— ITIC Curve, Power Distribution Faults, Power Disturbances, Power Hardening, Power Quality, Power System Faults, Sag Immunity, SEMI F47, Voltage Fluctuations, Voltage Sags.

I. INTRODUCTION

With an all-time record production year nearing completion in 2006, management began questioning the record number of kiln stops experienced in that same year. Power issues were a leading cause of process interruptions and therefore became a focus of reliability improvements. Because of a lack of good diagnostic data, unexplained outages were blamed on power related issues which represented one third of the total outages for the year.

Meetings were held with the electric utility provider to review the cause of these power related interruptions. A review of the year's events revealed that power related interruptions were a contributor to the process interruptions being experienced, although not every event blamed on a power interruption turned out to be such an event. During this meeting, the utility provided a number of suggestions that would eventually help the plant to better quantify power disruptions. These discussions also included exposure to the industrial standards and solutions that are available to lessen the sensitivity of process equipment to handle power disruptions.

A procedure was implemented restricting categorization of process interruptions as power related unless it was confirmed with the electric utility and was accompanied by an Information Technology Industrial Council (ITIC) graph or plot. An ITEC plot is used to measure the severity of a power quality event and compares it to the equipments' tolerance to the disruption. This can help determine if the event should have been tolerated by properly designed and power hardened electrical equipment. Through utilization of these graphs, the plant identified equipment susceptible to voltage sags and the graphs provided the support needed to generate the cost justification to correct the problem.

Additionally, process interruptions which were incorrectly blamed or misinterpreted to be power related were found and corrected. This was facilitated because external power disturbances were eliminated as the sole cause allowing for focused efforts to be spent on investigating and resolving root causes of internally generated problems. Over several years of making improvements, favorable results have led to significant reductions in short-stop kiln interruptions.

II. VOLTAGE SAGS

There are several types of power disturbances that can cause operational problems to industrial facilities. Some of these include surges, spikes, sags, harmonic distortions, and momentary disruptions or outages. Voltage sags are the most common form of these disturbances and is a significant problem facing the industrial customer. A simplified explanation of what a voltage sag is, how they are generated, and how the electric utility deals with them is discussed below. Once understood, the frequency of occurrence and impact on plant processes and equipment will become evident

A. What are Voltage Sags

A sag is the reduction of AC voltage at a given frequency where the duration is greater than $\frac{1}{2}$ of a cycle (see Fig. 1). The plot in this figure characterizes a single phase sag with a sag magnitude of 50% of nominal voltage and a duration of 4 cycles, or 0.067 seconds in a 60 hertz supply. Typically affecting process operations more frequently than actual outages, these disturbances occur whenever there is a fault on the power supply system regardless of whether the fault actually causes an outage.

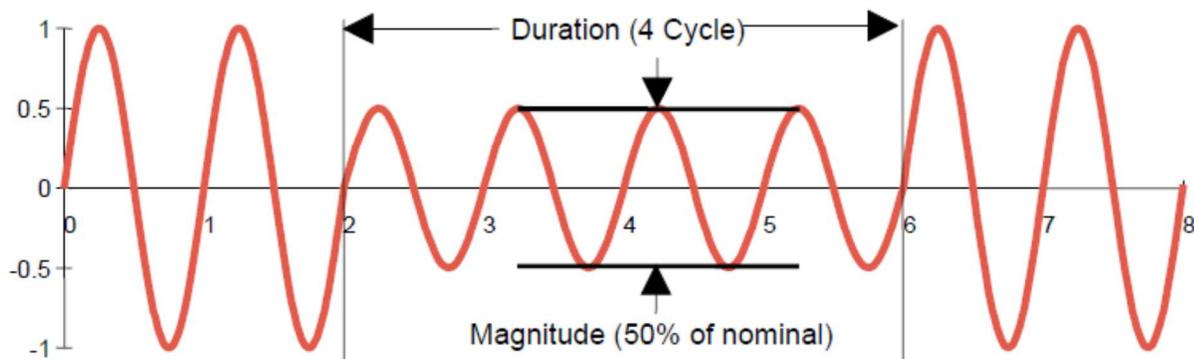


Fig. 1. Graphical Representation of Voltage Sag

It is important to differentiate between an interruption and voltage sag; an interruption is a complete loss of voltage whereas a sag occurs when the voltage temporarily drops below a threshold, typically considered to be 90% of the nominal voltage level.

B. What Generates Voltage Sag

There are two primary sources of voltage sags categorized as internal (within the facility) and external (from the power generator or grid). Internal voltage sags may occur when starting major loads such as large motors where the startup current remains high for an extended period of time. Voltage sags can also be produced by grounding or wiring problems. The majority of externally generated voltage sags are caused by short-circuit faults that occur within the power generation facility or distribution grid.

Electric utilities continuously strive to provide the most reliable and consistent electric power possible. However, in the course of normal utility operations, many complications can occur. For example, power quality is often affected when a storm passes through an area. Lightning strikes may occur on or near a power line, or high winds can send tree limbs into transmission lines. In addition to storms, utilities cope with fires that can damage power poles and contaminate insulators. Heavy smoke from large, intense, nearby fires can also cause flash-over across power lines. Other common causes of short-circuit faults are ice storms, birds or animals (such as squirrels) that come in contact with power lines, and events such as vandalism or auto accidents damaging poles, transformers or other distribution equipment.

C. How the Utility Copes with Faults

While electric utilities go to great lengths to prevent power quality issues, they cannot be eliminated completely as they have to cope with a wide variety of system faults on both the transmission and distribution grids. A typical distribution system

is configured with a number of feeders that are all supplied by a common bus. A fault on any single feeder will cause interruptions to the customers downstream of the protection device that operates the feeder. Because the supply voltage becomes depressed at this feeder, all customers on other parallel feeders experience a voltage sag until the utilities protection device opens a section of the circuit to clear the fault condition. The voltage sag lasts only as long as it takes these corrective devices to clear the condition. In addition, faults on the transmission system can affect even more customers because the transmission supplies many distribution systems or substations [1]. Perhaps this makes it easier to visualize why customers who may be hundreds of miles away from a fault will experience a voltage sag.

D. Voltage Sag Frequency

It is not unusual for an industrial facility to experience several voltage sags during a year. The Electric Power Research Institute (EPRI) conducts research on issues related to the electric power industry and is a nonprofit organization that is funded by the electric utility industry. In the early 1990s, EPRI initiated a major benchmarking study on utility distribution systems called the Distribution Power Quality (DPQ) Project. This study was initiated in the United States to observe, measure, and study the frequency and severity of power quality events. In 2001 and 2002, EPRI conducted a second study referred to as DPQII [2]. This studied showed that an average of 66 voltage sags between the range of 10% to 90% can be expected at a given site per year and the average number of momentary interruptions (complete loss of voltage) is close to seven events per year (see Fig. 2). It should be noted that at any given site, the actual yearly sag rates do vary. Some variables that will influence sag rates include the configuration of the distribution and transmission systems, customer density, geographical location, lightning activity levels, number of trees adjacent to power lines, and utility-preventative maintenance policy [3].

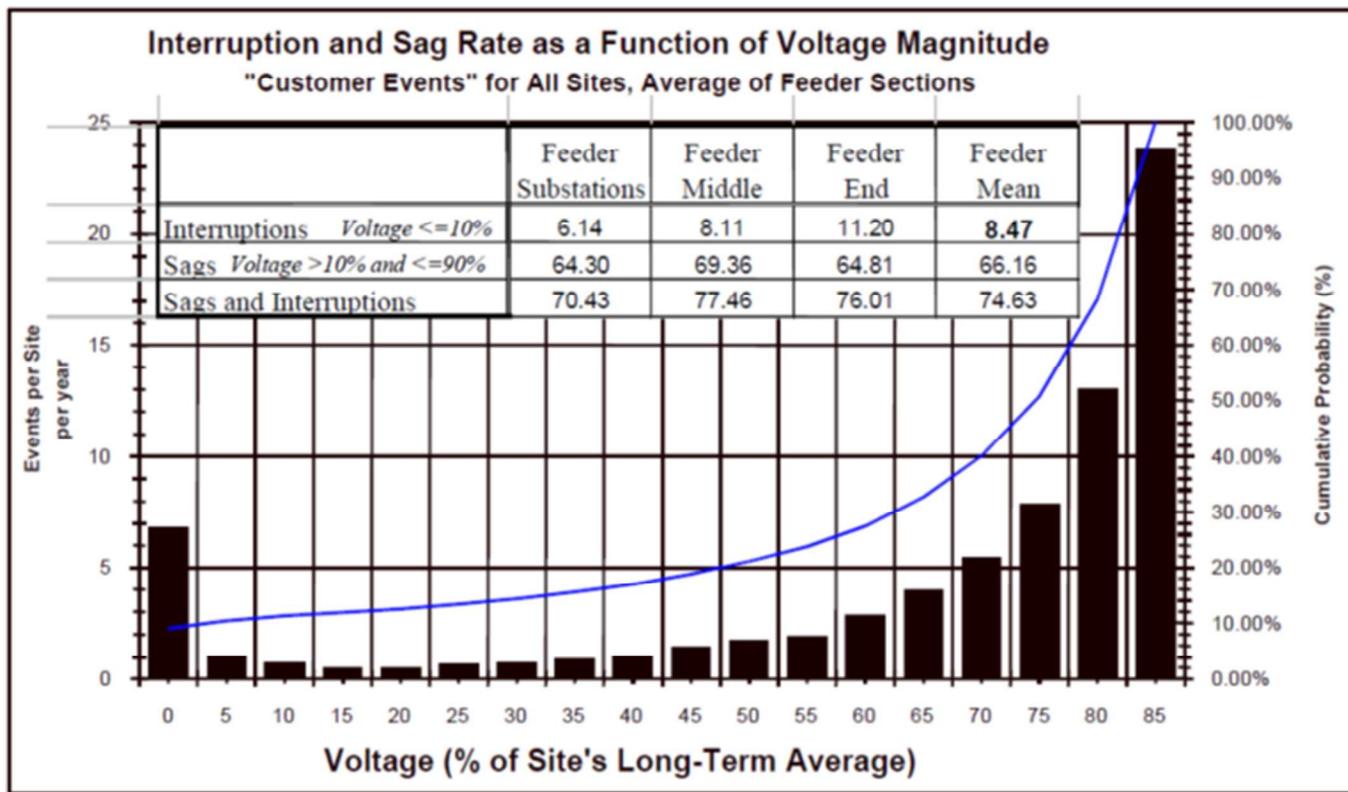


Fig. 2. Summary of Sag and Interruption Data from the DPQ Study [3]

E. How Voltage Sags Affect Equipment

Generally, electronic devices function properly as long as the voltage (or driving force) of the electricity feeding the device stays within a consistent range. The main factor that determines whether voltage sags will affect your process is the sensitivity

of the specific electronic equipment that drives your process.

During a fault, voltages and subsequent current become unbalanced (see Fig. 5). Many types of electronic equipment with fast response times are sensitive to voltage sags including adjustable speed drive (ASD) controllers, reduced voltage starters, programmable logic controllers (PLCs), power transformers or invertors, and control relays. These fast response devices usually lack sufficient internal energy storage to tolerate severe voltage sags on the supply side. Because much of this equipment is used in applications that are critical to the overall manufacturing process, equipment that trips or shuts down due to sags can lead to very expensive downtime events.

It is also worth noting that industrial facility power is commonly distributed by 3-phase 4160 volt or 480 volt feeders. While most industrial loads are 3-phase, the majority of sensitive control circuits and computer processors are single phase. The voltages experienced during a voltage sag condition depend on the equipment voltage connection. Because individual phase voltages will vary, loads at various connections will be affected differently. This phenomenon may explain why not all loads trip when a voltage sag is present on the electric utility side. [1]

III. VOLTAGE SAG IMMUNITY

Different categories of equipment, different brands of equipment, and even different models by the same manufacturer can have significantly dissimilar sensitivities to voltage sags. In past years, electrical equipment was purchased and installed throughout industrial facilities that were manufactured in the absence of standards for voltage sag ride-through. This was, in part, because electric utilities were not measuring and quantifying events on their delivery system and because customers were not demanding this type of performance from manufacturers [1].

In recent years several compliance standards have been developed with a purpose to define ‘voltage sag immunity’. These standards serve to describe how equipment can be manufactured and tested to meet certain sag ride-through criteria. Sags that fall outside the defined boundaries can cause a disruption, but will be infrequent. Sags that fall within specified boundaries should not adversely affect equipment or cause interruptions. These standards are meant to provide a compromise between higher equipment costs and the cost of facility downtime [1]. End users who address the power sensitivity issue in the facility are engaging in “power hardening” activities that will improve facility uptime.

The Information Technology Industrial Council (ITIC), formally known as the Computer and Business Equipment Manufacturers' Association (CBEMA), and the Semiconductor Equipment and Materials Institute (SEMI) have published information defining what levels of poor power quality, specifically voltage sag, equipment should be able to tolerate. In general, these curves were developed to help both manufacturers and users of electronic equipment determine what level of sensitivity this equipment should be able to ride-through when experiencing voltage sags. In recent years, other voltage sag immunity standards have been published. To limit the scope of this paper, only the ITIC curve and SEMI F47 standards will be discussed.

A. *ITIC Curve*

The power tolerance curve used throughout this report is referred to as the ITIC curve, formerly known as the CBEMA curve. The ITIC curve plots the magnitude of the disturbance (in percentage) on the y-axis and the duration of the disturbance on the x-axis (see Fig. 3). Disturbances that fall within the envelope defined by the upper and lower curve should not cause operational problems with electrical equipment that adhere to this standard [4].

While the ITIC curve has been applied to general power quality evaluations, it was primarily developed for 120 VAC computer equipment. It can be used as a reference to define the capability of various devices to withstand power quality problems, not just computer-type equipment. This is possible because the curve is generally applicable to other equipment containing solid-state devices.

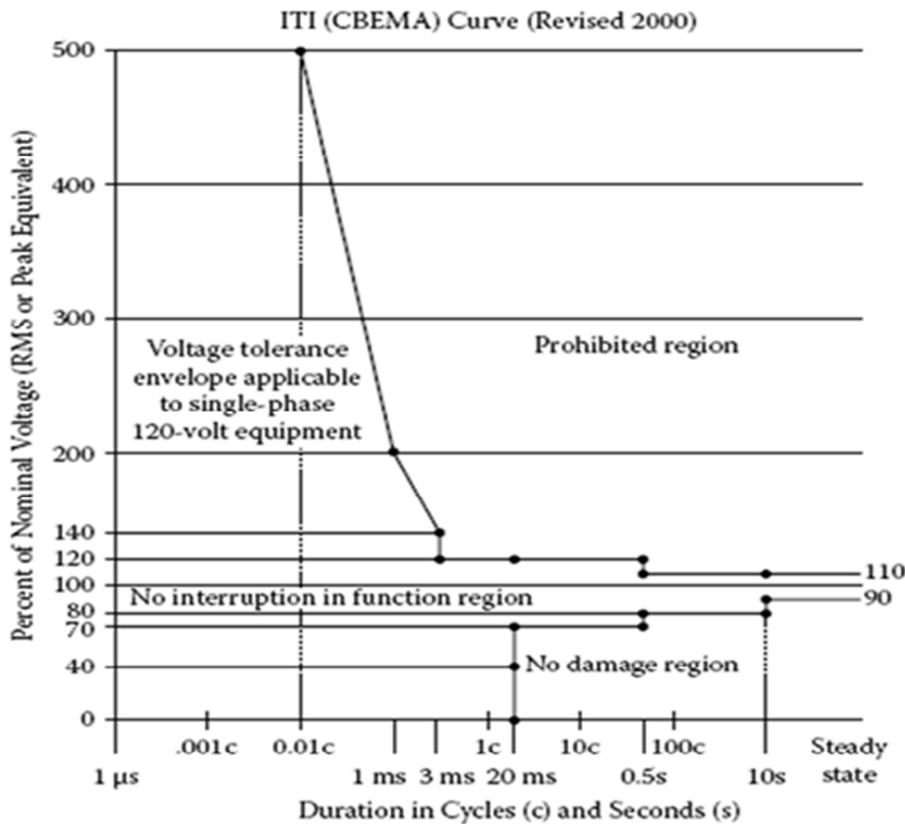


Fig. 3. ITIC Curve [4]

B. SEMI F47

The semiconductor industry, in cooperation with EPRI and electrical utilities, recognized that better equipment design would offer a great solution for voltage sag problems. This led to the development of the SEMI F47 standard which sets minimum voltage sag immunity requirements for equipment. In addition, other SEMI standards provide procurement requirements, test methods, pass/fail criteria, and test report requirements. Although this standard was developed for the semiconductor manufacturing industry, it can also apply to equipment in all industrial manufacturing environments. SEMI F47 requires that electrical equipment tolerate sags as outlined in Table 1 below [5].

TABLE I
SEMI F47 REQUIRED VOLTAGE SAG IMMUNITY

	Sag Depth	Duration at 50 Hz	Duration at 60 Hz	Duration in seconds
1	50%	10 cycles	12 cycles	0.2
2	70%	25 cycles	30 cycles	0.5
3	80%	50 cycles	60 cycles	1.0

A visualization of SEMI F47 is provided showing that equipment must be able to continuously operate without interruption during conditions identified in the area above the defined solid red line (see Fig. 4).

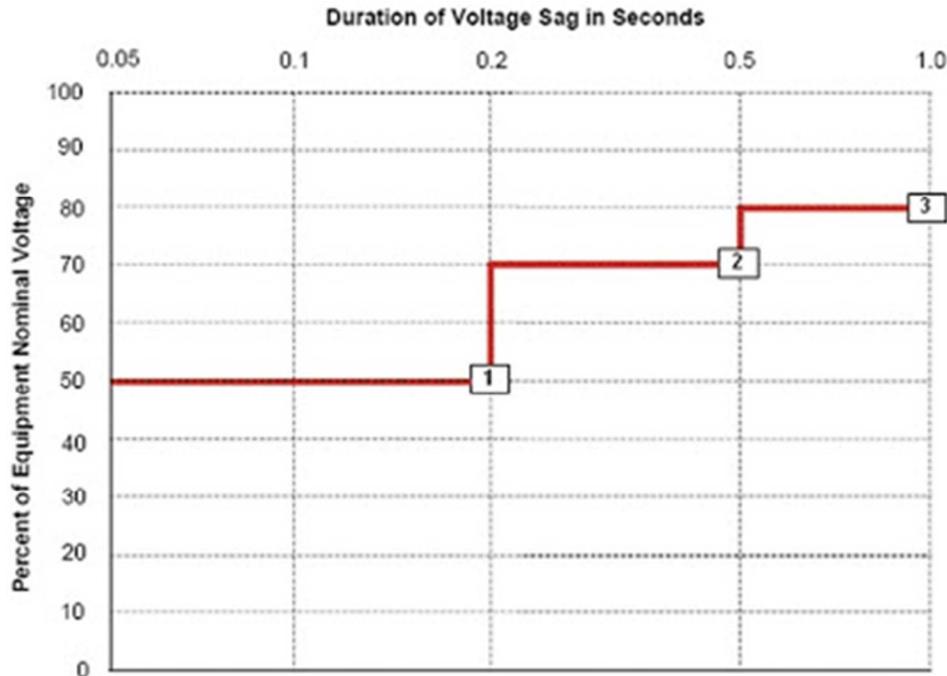


Fig. 4. Graphical Representation of SEMI F47 Standard [5]

C. Measuring and Quantifying Voltage Sags

Fig. 5 shows an actual incoming voltage disturbance on a 138 KV line that feeds a cement plant. This event was captured by the electric utility's measuring system at the plant substation. This plot provides clear detail as to what typically happens when there is a fault somewhere on the distribution line and how customers downstream of the fault can be affected. Note how the voltage sags and the current on all three phases react. This particular event lasted for six cycles, or 1/10th of a second, before the fault was cleared by the utility's protection devices and the incoming power was restored back to its normal state.

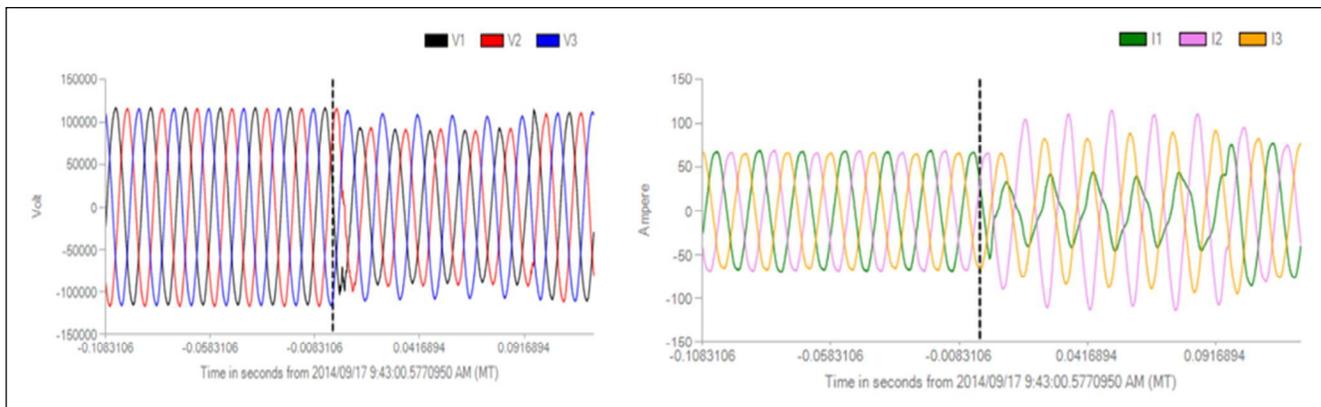


Fig. 5. Plot of Voltage and Current on a 138 KVA Incoming Line During a Sag Event

This voltage sag event can be plotted on the ITEC sensitivity curve (see Fig. 6) and provides value in that you can now quantify the fault and assess how the facility's equipment responded to it. In this particular example, if a certain process were to trip or shutdown during this event, it would indicate that there is equipment within the process that has a low sensitivity level to voltage sags. This can also signal that power-hardening principles can be applied to specific equipment that faulted and thus improve the ride-through capabilities when similar events occur in the future.

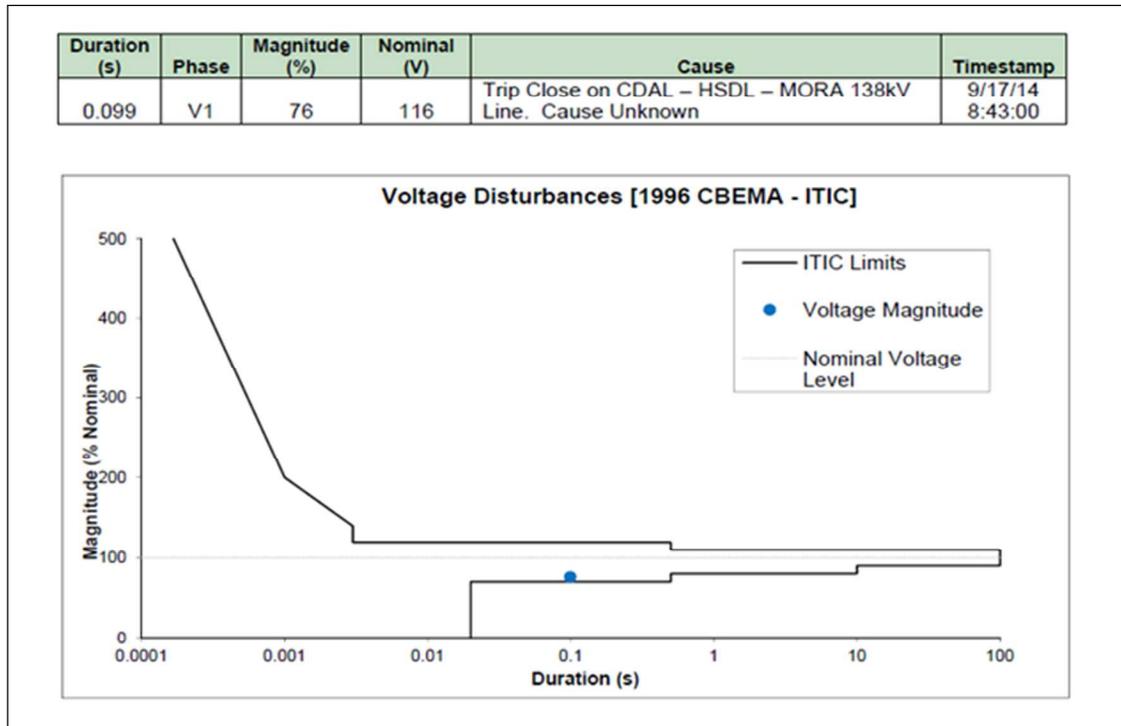


Fig. 6. Plot of Voltage Sag Event on ITEC Curve

D. How a Plant can Apply this Information

Throughout the industrial manufacturing facility there are many processes. Whenever any of these processes experience an unexplained shutdown, it is a best practice to check with the electric utility to determine if a power disturbance could have been the cause. Given the date and time of the event, the electric utility can review the data collected at the substation to determine what occurred with incoming power at the same point in time. If they report that the incoming power showed no evidence of disturbance, then it can be concluded that the interruption was not related to the incoming power and the end-user continues to investigate other potential causes. However, if a voltage disturbance was found, the magnitude and duration of the event can be collected and shown on an ITEC curve to quantify the severity of the disturbance.

This process can help the facility identify the sensitive equipment that is reacting to voltage sags and aid the facility in power hardening efforts. There are various power hardening solutions with differing price-tags. Because of this, the end-user should also quantify the costs of these events by considering expenses such as lost production, time, and damage that may occur to equipment/refractory. This provides the foundation needed to generate justification when seeking the money to correct problems. In an effort to highlight the value of this process, a cement plants experience is related below.

Following the practice as outlined above, plant personnel contacted the electric utility after a significant and unexplained plant outage had occurred. The utility confirmed there was a voltage sag event that coincided with the plant interruption and provided an ITEC plot showing the magnitude and duration of the voltage sag (see Fig. 7). As shown on the ITEC plot, the severity of the event falls outside the allowable limits of the curve as the magnitude of the sag was 56% and the duration was 0.09 seconds. Analysis of the event using the plot provided shows that even though this event occurs outside the boundary lines of the sensitivity curve, it was within the bounds of SEMI F47 standards.

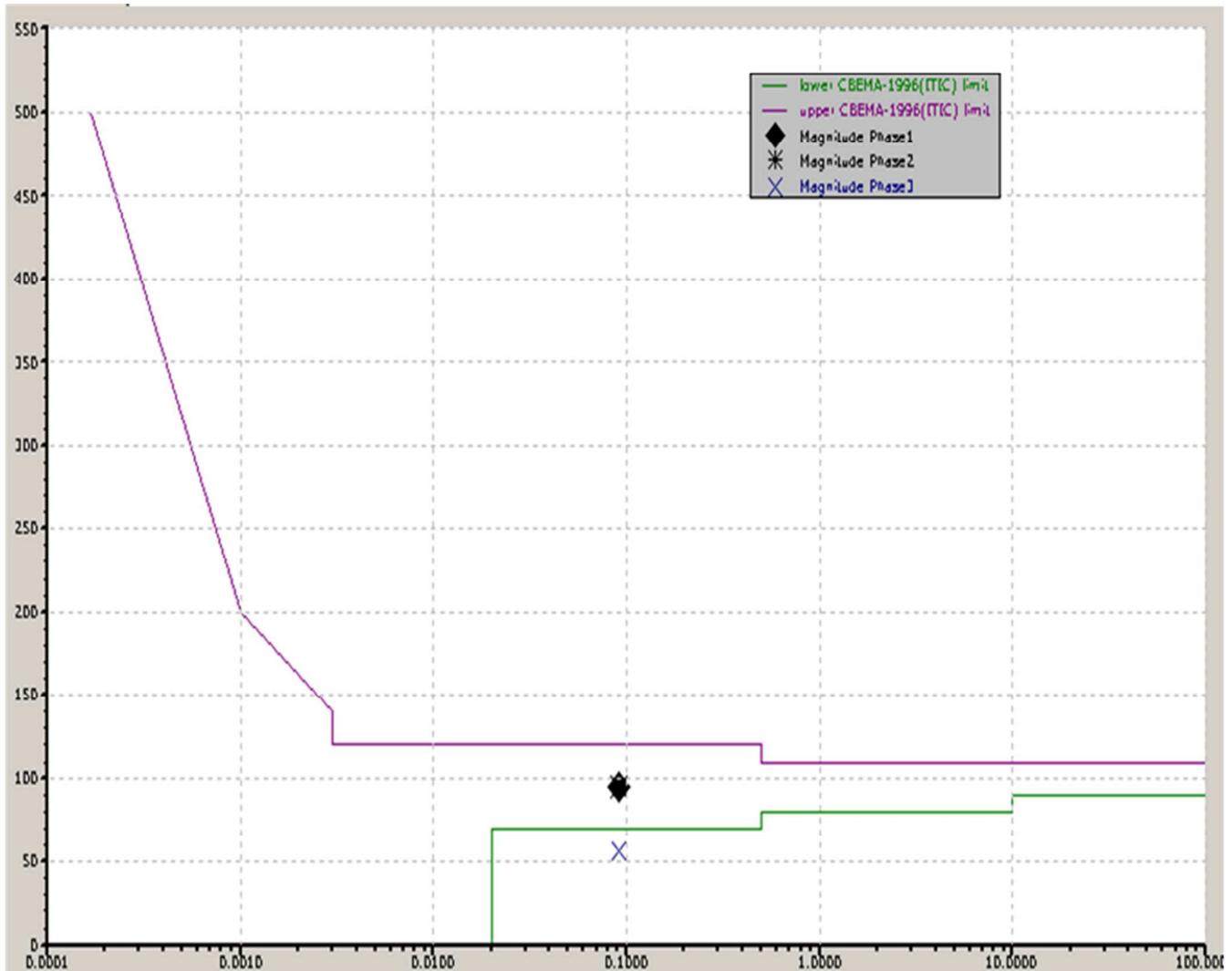


Fig. 7. Plot of Voltage Sag Event that Caused an ASD to Trip

To further explain what was occurring, when this event and others similar to it would transpire, a significant ASD that controls a main process ID fan for the pre-heat tower would fault. This would trigger a kiln outage to the plant where it was recorded. The plant was able to document that 20 of its kiln outages in the previous 12 months could be credited to voltage sags similar to the one shown in Fig. 7. The yearly cost of these combined events was conservatively estimated to be around \$78,715. After completing the justification process, it was determined that the solution to replace the ASD with a drive that had been designed to meet the SEMI F47 standards as shown in Table 1 above would result in a payback of less than three years.

IV. HARDENING EQUIPMENT AGAINST POWER DISTURBANCES

There are several solutions currently available that will provide ride-through capability to critical equipment. It is generally understood that the least expensive approach is for the manufacturer to embed the solution into the design of their equipment. However, because much of the installed base of equipment in a plant was manufactured at a time before manufacturers totally understood the problem, end users are left to provide some form of selective power conditioning in an attempt to provide voltage sag immunity to their processes [3].

Proper application of power conditioning equipment requires an understanding of the capabilities of the device along with the specific requirements of the sensitive load. There is a significant amount of published material available to help end-users understand what options are appropriate when considering the benefits, costs, and limitations associated with these solutions. A

partial list of power conditioning solutions includes:

1. Motor-Generator Sets
2. Uninterruptible Power Supplies (UPS)
3. Constant-Voltage Transformers (CVT's)
4. Magnetic Synthesizers
5. Flywheels
6. In-Line reactors
7. Coils / Relays with low drop-out voltages
8. Inverters

Manufacturers of these devices should be able to share with the end users the ride-through capabilities of their equipment. If it is not published, be sure to request it as not all equipment with the same generic function provides the same level of protection. Of course, adopting equipment specifications that specify voltage sag ride-through levels, such as SEMI F47, can help assure a minimum capability at the equipment level.

V. CONCLUSION

Voltage sags are one of the most important power quality problems affecting industrial processes and many interruptions caused by these faults are preventable. The electric utility can improve system fault performance in a limited degree, but realistically they will never be able to eliminate them all. With sufficient knowledge of the causes of these problems, several things can be done by industrial end-users, and equipment manufacturers to reduce the sensitivity of equipment to voltage sags thus mitigating their effects.

Working with the electric utility provider when unexplained process interruptions occur will better assist the facility in finding and correcting problems. Disturbance events that are power related can be shown on an ITEC curve and will assist the end-user in quantifying the sensitivity level of affected equipment within the facility. This aids in the process of determining the severity of the events that can affect your plant. Armed with this information, it becomes easier to consider the cost of voltage sags to your process, and in turn, justify the investment needed to improve voltage sag immunity through the industrial facility.

ACKNOWLEDGMENT

The author gratefully acknowledges the contributions of Terry Kerby for his assistance, support, and editing skills which were applied to the original version of this document and to Ron Vidergar for suggesting this topic had merit as a technical paper.

REFERENCES

- [1] "Short Duration Voltage Sags can Cause Disruptions," Pacific Gas and Electric, June 2000, [Online]. Available: <http://www.pge.com/includes/docs/pdfs/mybusiness/customerservice/energystatus/powerquality/voltagesags.pdf>
- [2] "Distribution System Power Quality Assessment: Phase II—Voltage Sag and Interruption Analysis," EPRI, Palo Alto, CA: 2003. 1001678.
- [3] "Power Quality Solutions for Industrial Customers," California Energy Commission: August 2000
- [4] *ITI (CBEMA) Curve in an Application Note*, Information Technology Industry Council (ITI). 2000. Washington DC, <http://www.itic.org>
- [5] *SEMI F47: Specification for Semiconductor Processing Equipment Voltage Sag Immunity*, Apr., 2011, [Online]. Available: <http://www.powerqualityworld.com/2011/04/semi-f47-semiconductor-voltage-sag.html>. NOTE: SEMI standards can be purchased through www.semi.org