THE JOURNEY OF AN ENTERPRISE IN A PROCESS INDUSTRY TOWARD IMPROVED ELECTRICAL WORKPLACE SAFETY

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ABSTRACT

This paper is a case study outlining the experience of a multi-site cement producer and their experience in implementing an enterprise wide electrical workplace safety program including compliance with the National Fire Protection Association (NFPA) 70E-2012 standard. Following a brief primer regarding arc flash hazards, the paper outlines how the company first established a case for change and buy-in across the enterprise which includes 13 cement plants located across the USA and Canada, and then proceeds in describing the processes used to identify the defined work scope, select a supplier partner and then complete arc-flash studies at each site. Advantages of scale in areas including common methods of data collection, selected software, standardized labels, site training and energized work permits are addressed. Finally, lessons learned during this project and a phased remediation plan at each site, developed to reduce or eliminate potentially hazardous conditions will be discussed. Finally, a few concepts based on "safety by design" will be explored where there might be an opportunity to design the hazard out or down for new plant projects or expansion.

INTRODUCTION

The reliability, cost, and safety of electricity and industrial power systems are critical ingredients in achieving business goals. As intuitive as this statement is, it is equally intuitive that by its very nature electricity poses an inherent danger - particularly to the men and women maintaining and operating energized electrical systems and equipment. Electric shock hazards, including electrocution, have been understood for as long as electricity has existed. A newer electrical hazard, the arc flash, has recently come to the forefront. Governing bodies and organizations in the United States (U.S.) such as the Occupational Safety and Health Administration (OSHA) and the National Fire Protection Association (NFPA) have been working over the past several years to develop procedures and standards like NFPA 70E-2012 *Standard for Electrical Safety in the Workplace* [1], to protect personnel and equipment from the dangers of this newly recognized rapid energy release. The NFPA 70E-2012 is applicable across the United States. In Canada, a fully harmonized standard CSA Z462-12 [2] *Workplace Electrical Safety applies* across all Canadian Provinces.

Although many industrial manufacturing facilities in the U.S. are regulated by OSHA, the cement industry is considered a part of the mining sector, so these facilities are regulated by the Mining Safety & Health Administration (MSHA). Although neither OSHA nor MSHA include specific language regarding electrical workplace safety, both regulations consider the NFPA70E as a consensus standard and both have considered this as evidence of whether an employer acted reasonably following a site investigation and in considering actions resulting in a citation.

Considering the importance of both standards and regulations to the business, and focused on improving workplace safety across the enterprise, the cement producer in this case study wanted to move toward compliance to the latest electrical workplace safety standards. The company cement plants are also included in one of the process industries, where the need to perform energized work while the process is running can at times be the necessary tradeoff to shutting the process down and potentially causing greater risk. Driven by both the new standards and the enhanced chance of energized electrical work, the company pushed forward and implemented a comprehensive arc flash compliance program for all 13 facilities across the U.S. and Canada.

A PRIMER ON ARC FLASH HAZARDS

Arc flash is the result of a rapid release of energy due to an arcing fault between a phase bus bar and another phase bus bar, neutral or system ground. The arc fault has to be manually started by something creating the path of conduction, such as accidental contact of a test probe between an energized conductor and ground or a failure like a breakdown in insulation. The energy discharge from an arc flash is massive, resulting in an energy release at temperatures exceeding that of the sun's surface, as well as explosive pressure waves, shrapnel, and toxic gasses. Most frequent occurrences of arc flash events take place when employees are working on or near energized electrical conductors or circuit parts and they trigger an electric arc flash from inadvertent movement or accidental contact causing a phase-to-ground and/or phase-to-phase fault. The destructive power of an arc flash can be immense. An enormous amount of concentrated radiant energy explodes outward from electrical equipment in an arc flash event, creating pressure waves that can damage a person's hearing, a high-Intensity arc flash can harm eyesight, and a superheated ball of plasma gas during an arc flash event can severely burn a worker's body and melt metal.

If the arc releases sufficient energy, a worker's non flame resistant clothing will ignite. Workers wearing flame resistant clothing can also sustain burns if the arc releases energy above the thermal rating of the flame resistant fabric. The pressure waves can often send loose material including pieces of damaged components, tools, and other objects flying through the air as shown in Figure 1.

Figure 1: An electrical arc flash delivers an extreme heat and pressure wave with deadly force.

According to industry medical research statistics focusing on preventing workplace injuries and deaths [3], an average of over 1000 electrical burn injuries occur in electrical equipment every year across the United States. These statistics are likely undersubscribed, because the numbers don't include cases when the victim is sent to a hospital or clinic for medical treatment. Instead, these recorded incidents typically involve severe injuries where the incident victim requires treatment from a specialized burn center. Adding unreported cases and "near misses" would result in total injuries many times this number.

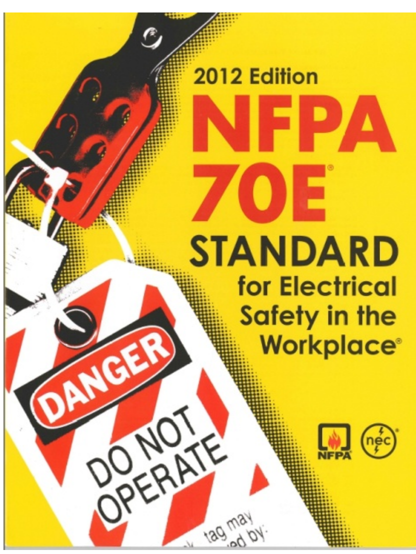
A LOOK AT CODES AND STANDARD DEALING WITH ARC FLASH

The NFPA, the National Electric Code (NEC), the Institute of Electrical and Electronic Engineers (IEEE), OSHA and MSHA have worked together for many years to develop regulations and standards that best protect personnel and equipment against electrical hazards, including arc flash. In the U.S., four separate Industry standards focus on the energy release and reduction/prevention of arc flash incidents:

- OSHA 29 Code of Federal Regulations (CFR) Pan 1910 Subpart S
- NFPA 70-2011 National Electrical Code (NEC)
- NFPA 70E-2012 Standard for Electrical Safety in the Workplace
- IEEE Standard 1584-2002 Guide for Performing Arc Flash Hazard Calculations

The NEC which is primarily an equipment installation standard, referenced the industry electrical workplace safety standard NFPA70E for the first time in 2002. The more recently published NEC 2011 strengthened the NEC-2002 language in Article 110.16 titled *Flash Protection*, stating: *"Switchboards, panelboards, industrial control panels, meter socket enclosures, and motor control centers that are in other than dwelling occupancies and are likely to require examination, adjustment, servicing, or maintenance while energized, shall be field marked to warn the qualified person of the potential of arc flash hazards."* Fine Print Note #1 that follows 110.16 refers the reader to NFPA 70E for assistance in determining severity of potential exposure, planning safe work practices, and selecting personal protective equipment (PPE).

It is possible and In fact likely, that future code changes in both the U.S. and Canada will strengthen the language in the respective installation codes and will one day require specific information on field labels such as flash boundaries and PPE requirements, which are addressed in NFPA 70E/CSA Z462 (see Figure 2). If this happens, facilities expecting compliance with the NEC (or CSA in Canada) will need flash hazard analyses completed for all equipment or will need to default to use of generic formulas and PPE recommended in NFPA 70E/CSA Z462 to determine the boundaries and PPE requirements.



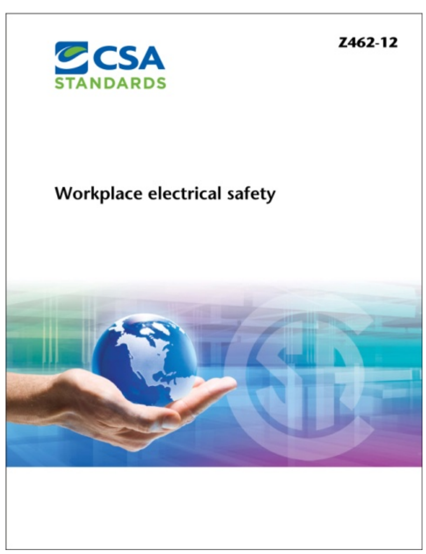


Figure 2: Front covers of the latest editions of harmonized electrical workplace safety standards NFPA70E-2012 and CSA Z462-2012.

In terms of current safety standards, both the NFPA 70E and the harmonized CSA Z462 (Fig. 2) mandate required safety practices for personnel working on or near energized electrical equipment. These standards determine the circumstances in which workers should wear specific clothing to protect them from the dangers posed by electrical arcs, while IEEE Std. 1584-2002 [4] presents methods for the calculation of arc flash incident energy and arc flash boundaries. OSHA's standards include a six-point plan to minimize the potential arc flash danger for personnel:

1) A facility must provide and be able to demonstrate a safety program with defined responsibilities
2) Use of calculations or other methods to determine the degree of arc flash hazard
3) Provide correct PPE for workers
4) Training for workers on the hazards of arc flash
5) Appropriate tools for safe working
6) Include warning labels on equipment

Companies not in compliance with these requirements could be cited and fined following the investigation of an electrical workplace incident in the facility.

ARC FLASH HAZARD ANALYSIS AT CASE STUDY CEMENT PLANTS

In order to accurately determine the arc flash hazards at each electrical assembly in the 13 cement plants and thus determine how best to protect people and equipment, it was first necessary to conduct a short circuit study, coordination study, and then an arc flash hazard analysis. To perform an arc flash hazard analysis, data was collected across the facility power distribution system for each plant. The data is typically derived from the existing plant one-line drawing. However, actual installed equipment, conductor lengths and protective device settings were verified by an engineer surveying the site for each electrical device in the system. The utility serving each plant was also be contacted for system information including the minimum and maximum fault currents that can be expected at the entrance to the facility.

Once the data are collected, a short circuit analysis followed by a coordination study was performed. The resulting data can then be fed into the equations described by either NFPA70E-2102 and IEEE Standard 1584·2002. These equations produce the necessary flash protection boundary distances and incident energy, which are then used to determine the minimum PPE requirement. Once the data are prepared and a flash hazard analysis has been performed, the calculated arc flash energy analysis yields a PPE requirement for persons working on or near each energized electrical panel across the facility. Typically, the higher levels of PPE are required at the main cubicle of a 480V unit substation and for some medium voltage circuits. Because an arc flash event is generally limited to systems where bus voltage exceeds 240 volts, the system model accounted for system busses only at 480 volts and above.

After the hazard at each electrical panel was determined, the applicable safety standards recommend a label as shown in Figure 3, quantifying the hazard in calories per centimeter squared (cal/cm^2) be posted

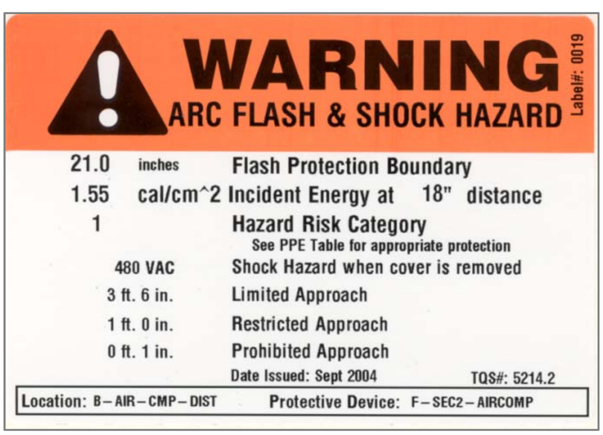


Figure 3: Typical equipment label designating arc flash in cal/cm^2 and shock hazard along with flash protection boundary and PPE.

on each electrical panel along with the appropriate PPE required to perform work in the panel while the system is energized. The label is unique for each electrical panel across the system. With the calculated arc flash hazard clearly marked as shown at 1.55 cals/cm^2 on the sample label shown in Fig. 3, electrical workers can select PPE rated for a higher level, for instance 4 cals/cm^2, and be assured they will be protected should an arc flash occur while work is being performed. Note that the NFPA70E-2012 and CSAZ462-2012 both assure appropriate PPE (rated at or above the calculated value from the study) will protect only against the onset of a second degree burn, so full protection from injury is not assured. Both Standards define the onset of a second degree burn to be a "just curable burn" or one that can completely heal. As a reference point, the heat energy in 1 cal/cm^2 is approximately equal to the heat from a lit match held 1 inch from the unprotected skin of a person's finger for the period of 1 second.

Although the highest levels of PPE inherently offers the highest degree of protection from the heat energy of an arc flash event, this level of protection is typically very unwieldy and can be costly in terms of time required to perform energized work. It can also introduce added risks such as heat stress and personnel are more prone to make mistakes working in restrictive safety clothing. So in general, if energized work is necessary, working on energized equipment with a lower arc flash hazard and suitable lower levels of PPE, is the best alternative.

The project team realized that successful completion of plant arc flash studies represented only the beginning. After each panel was labeled and site electrical personnel trained on understanding arc flash, PPE and the equipment labels, most plants would implement next steps to reduce arc flash hazards. Review of the site wide results would allow facility operations to identify electrical panels that represent the highest level of incident energy as defined by the calculated cal/cm^2 value and also identify panels that required frequent energized access for maintenance and troubleshooting. These panels will be considered as candidates for system improvements, using various technology based solutions discussed later in this text, to implement electrical system changes required to manage the hazard down to lower the PPE requirement. To achieve this, existing circuit protective devices may need adjusted or more likely replaced, generally by more modern counterparts. The goal is to reduce the worker PPE requirements, perhaps moving the worker from PPE rated at 40 cals/cm^2 to 8 cals/cm^2 as shown in Figure 4, reducing both the hazard and the risk of performing energized work.

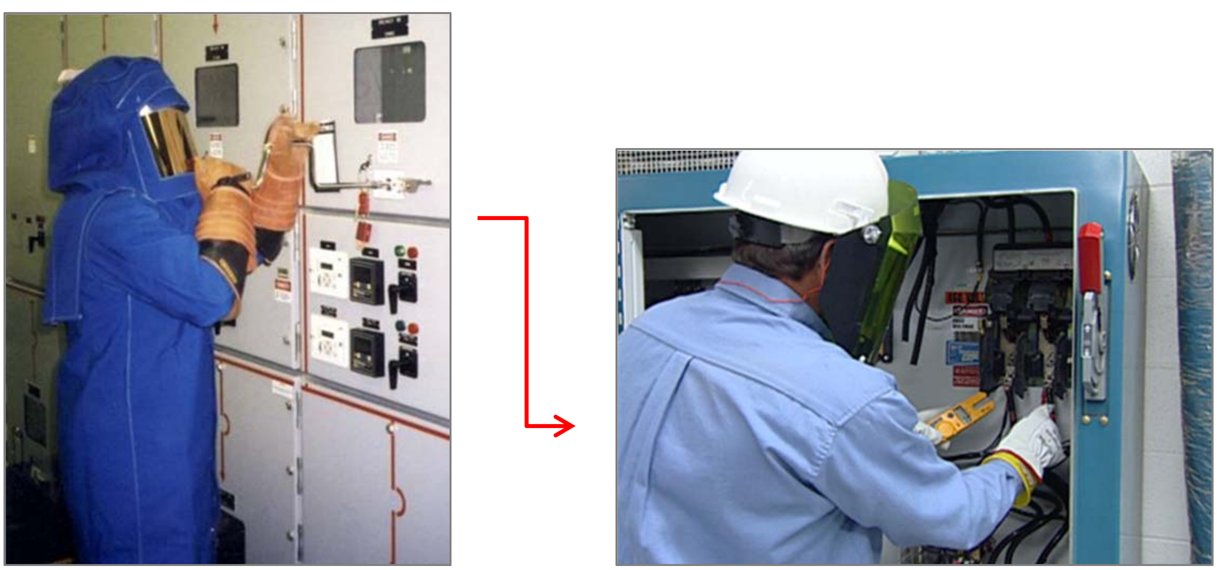


Figure 4: After the arc flash study is complete, facility reviews the results and identifies areas of the electrical system where incident energy should be reduced, so workers can move from an unwieldy level of PPE (40 cals/cm^2 shown at left, to a more manageable level of PPE (8 cals/cm^2 shown at right).

A CASE FOR CHANGE

One of the core values of the multi-site cement producer was and is a culture of driving towards industry leading safety standards that are designed to keep all employees out of harm's way. As a safety leader in the industry; the company's North American Cement Technical Group teamed with Plant Operations to implement an arc flash compliance program for all facilities in the U.S. and Canada. Because the primary business was producing cement, not performing arc flash studies, the company solicited assistance from a global engineering services provider with extensive experience conducting multi-site power systems and arc flash studies. The service provider was also a major electrical equipment manufacturer, offering various power systems upgrade solutions to reduce arc flash hazards.

Before the new electrical workplace safety program was implemented, the cement producer's corporate engineering group recognized the importance of buy-in at all levels to ensure effective execution. The project leadership team believed it was important to establish a case for change across the enterprise's cement business line. Following review and approval at the executive level to implement the program for the company's 13 cement plants in the U.S. and Canada, an Arc Flash Compliance Concept Document was created and shared with each plant for comment and approval. Through several iterations and internal seminars, the Concept Document was approved and delivered to regional and plant management. This document was effectively used to frame the purpose of the program and communicate the expected results. Issues outlined in this concept document included:

- Review of the applicable codes and standards and the regulations in place supporting new electrical workplace safety standards.
- Definition of arc flash hazards and hazard levels defined in electrical workplace standards
- Required electrical system documentation necessary to complete arc flash studies
- Plans for equipment labels on all electrical panels and how labels would be used
- An overview of personal protective equipment that would be necessary at each facility
- Expected changes in work procedures following completion of the project
- Potential changes in maintenance practices following completion of the studies
- Suggestions on change in practice for purchase and installation of new electrical equipment that could potentially minimize the risk

Establishing expectations with the Concept Document took place over six months prior to the beginning of any activity associated with the project – an important first step in assuring that all stakeholders understood the purpose, planned activities and expected results. This approach requiring understanding of the Arc Flash Compliance program was essential for all company cement facilities. Of the 13 cement plants, some facilities had completed preliminary studies and started with their own site specific arc flash implementation, while others had not yet started. Because of this, the headquarters based project team took precautions to assure that all facilities would implement a common process to assure consistent results at the completion of the project.

IMPLEMENTING A NEW DIRECTION TOWARD SAFER OPERATIONS

After establishing buy-in at all levels of the organization, the project team committed much energy to carefully define the specific tasks necessary to assure project success. Another document was completed by the project engineering lead, this one titled Authorization for Expenditure (AFE) Scope of Work – Arc Flash Compliance. This document served as a technical specification outlining the expected deliverables and included sections:

- Background & Narrative (referencing back to the Arc Flash Compliance Concept document)
- Supplier scope of work for
  - Field Data Collection
  - Power system modeling & recommendations
  - Field implementation including labels
  - Site safety training
- Owner project management and plant responsibilities
- Project Schedule and Milestones

This document offered all parties involved a clear understanding of the project scope. The AFE was effectively used in supplier selection and throughout the duration of the project to remind all stakeholders of their roles and responsibilities during the execution phase of the project.

The global engineering services provider selected for project execution was a company with extensive experience in the mining and cement industry. The services provider maintained a large and experienced team of over 100 power systems engineers, located both at the company headquarters and also in field offices across both the U.S. and Canada, several that were in close proximity to the 13 cement plants where the work was to be performed. The service supplier maintained both power systems engineers, with skills primarily focused on system modeling and completion of engineering studies, and also field service engineers, with skills that were focused more around site commissioning and troubleshooting of electrical equipment. The project team decided to utilize power systems engineers for both the site work in collecting data and also to complete the systems studies. Field based power systems engineers were used for site data collection. Their experience in performing power systems studies assured that the information needed to complete the studies was collected on the first site visit, eliminating the need for multiple return trips. A centralized power systems engineering group led by a project engineer was deployed to support the systems studies effort following the data collection phase. This group was intentionally selected to be only a few people at the same location, which assured that the study methodology used and the resulting reports would be consistent across all of 13 plant sites.

The engineering services field engineers first collected circuit and equipment data at all facilities, developing updated electrical system diagrams. As a part of the site surveys, field based power systems engineers also identified equipment installations which did not meet code requirements and recommended improvements for increasing the operational reliability. Following completion of the field work, power system studies were performed by the central group to identify the arc flash hazard at each "openable" electrical panel. The power system study also identified older equipment that was “over-dutied”, where power system changes over time had rendered ratings of overcurrent protective devices inadequate. Each site study also included engineering recommendations that could be implemented to reduce the hazard. In several cases, the service provider was able to identify areas where the plants could upgrade fuses, circuit breakers, and other electrical components to reduce the potential arc flash energy to a lower level, thus eliminating the need for unwieldy PPE and its associated risks.

A pilot site was selected for the initial effort. The supplier deployed local field based power systems engineers from a nearby operations center to visit the pilot site, collecting data necessary to complete the studies. In many cases, current documentation of the existing electrical system was incomplete, not up to date, or not available. Plant operations assisted the local service engineer in the process of identifying the location and identification of each electrical panel. Data from circuit breaker nameplates, including existing settings, fuses and conductor sizes and lengths, were collected for the entire facility. Because collection of data required opening all electrical panels and exposing personnel to potential arc flash hazards, the supplier’s engineer was deployed with appropriate PPE. Some of the data gathering effort was completed during scheduled electrical outages to assure the safety of individuals involved. Standard templates to record the data were used by the supplier and each plant required a four to five-day period for data collection.

After the study was completed, it was delivered to the pilot plant and the company central engineering group for review and approval. The review process included meetings between corporate engineering and the service provider and then meetings with the referenced plant personnel prior to final approval. Since completing the studies was planned for multiple facilities each with varying degrees of system modeling and different modeling software, both groups worked together to select a common software and study format so that completed studies for all of the surveyed sites looked the same. This also allowed the producer to establish a common electronic database for all system documentation and completed studies, while establishing a process to keep the information current with future system changes. Finally, arc flash warning labels unique to each electrical panel in the facility were sent to the site. These labels clearly identified the electric shock hazard, arc flash hazard and appropriate PPE necessary before personnel could safely perform work within the energized panel. The service provider scheduled a final visit to each site to deliver the labels, review the new facility one-line diagram and system studies, and provide final review of recommendations for system changes necessary to reduce arc flash hazards. Plant representatives participated in a one-day structured training course for qualified personnel, conducted by the service provider at each plant site. The training sessions focused on:

- Arc flash and electrical safety
- Working on and near energized electrical equipment
- Making unqualified personnel aware of the hazards
- Arc flash study results
- Changes to the company electrical safety policy based upon 2012 NFPA 70E and the arc flash study results.

A “facility champion” was selected from each plant for an intensive session on NFPA70E and arc flash hazards including a review of workplace and maintenance changes for each facility based on compliance with the new safety standards. The champion at each local facility was left with the training materials including instructor led presentations, video and web-based tools, to educate new facility employees on the updated safety initiatives within the organization. The pilot site efforts were completed in the summer of 2010, and work was completed in the balance of 13 plants during 2011.

UPDATED TECHNOLOGY OFFERS SYSTEM IMPROVEMENT OPPORTUNITIES

The completed studies identified the electrical hazard at each openable electrical panel, along with the required PPE to assure the worker was protected. In some cases, the overcurrent protective device setting was adjusted to lower the arc flash energy prior to printing the labels. However, most device settings remained in an “as found” state, so the studies effectively modeled the existing plant arc flash hazards. In some cases, the existing hazards were very high, some exceeding hazards above 40 $cals/cm^2$, the practical limit for PPE that is commercially available. Figure 5 shows a typical study result from one of the cement plants modeled. Note from the data table that the first Device FDR-5B is protecting a 2.4 kV bus and yields 13.39 kA Bus Bolted Fault, 12.94 kA Arcing Fault and Incident Energy at 30.0 $cals/cm^2$ arc flash hazard. A worker at the panel protected by this device would need to wear PPE rated in excess of 30.0 $cals/cm^2$ to assure protection from the calculated arc flash hazard. The next device in this table, Device FDR-4B is protecting a 480 V bus and yields 31.63 kA Bus Bolted Fault, 14.06 kA Arcing Fault and Incident Energy at 100.5 cal/cm^2 arc flash hazard. The arc flash hazard at this point in the system exceeds the rating of any commercially available PPE. The bus is labeled DANGER, designating that it is not safe to work in the panel protected by this device, regardless of PPE.

Device Name	Bus kV	Bus Bolted Fault kA	Device Bolted Fault kA	Arcing Fault kA	Trip Time (s.)	Bkr. Opening (s.)	AF Boundary	Working Distance (in.)	Incident Energy (cal/cm^2)	HRC
50/51/N FDR-5B	2.40	13.39	13.39	12.94	1.917	0.083	988	36	30.0	#4
50/51/N FDR-4B	0.48	31.63	25.37	14.06	1.917	0.083	268	18	100.5	DANGER
B2_802_102B	0.48	29.9	28.58	15.97	0.19	0	65	18	9.9	#3
MaxTripTime @2.0s	12.47	15.65	10.8	10.47	2	0	967	36	29.4	#4
EPP_1	0.208	3.74	3.74	2.18	1.934	0	75	18	12.4	#3
T_M1-205 FUSE	0.48	22.68	18.84	10.35	2	0	281	24	44.8	DANGER
50/51/N FDR-6B	0.48	27.5	26.79	15.16	1.917	0.083	187	18	55.9	DANGER
50/51/N FDR-6B	0.48	27.5	26.79	15.16	1.917	0.083	187	18	55.9	DANGER
M3_003_2A	0.48	30.47	30.47	16.98	0.32	0	97	18	18.8	#3
50/51/N FDR-5B	2.40	16.42	13.65	13.13	1.917	0.083	971	36	29.5	#4
50/51/N FDR-5B	2.40	9.96	8.13	7.89	1.917	0.083	600	36	18.5	#3
M3_002_2A	0.48	20.21	19.3	11.42	0.32	0	72	18	11.7	#3

Figure 5: Typical output from arc flash study. Incident energy varies from 12.4 to over 100 cals/cm^2 in this table.

As mentioned in previous sections the completed studies included recommendations to reduce the arc flash hazard, in particular for panels such as Device FDR-4B where there is no PPE available that would protect a worker should live work be necessary. Recommendations common to many of the sites included: 1) Modifying setting of existing relays and circuit breakers to reduce tripping time, thus reducing arc flash energy, while maintaining coordination and reliability, 2) Replacement of circuit breaker trip units with a modern trip unit offering an instantaneous trip setting while in a maintenance mode (Figure 6), a recommendation in the latest edition of the U.S. National Electric Code [5], and 3) Recommending replacement of traditional medium voltage substation primary fused load-break switches with a vacuum circuit breaker (Figure 7). The protective device technologies described here are just a few of those available that can significantly reduce arc-flash hazards. In addition, new industry standards [6] require testing of low and medium-voltage arc-resistant switchgear assemblies, allowing the heat energy from an internal arc flash event to be effectively channeled up and away from persons performing energized work. Although discussion of the functionality for these arc flash reduction solutions is beyond the scope of this paper, further information can be found in [7] and [8]. It is important to recognize that modifying existing

Figure 6: Low-voltage power circuit breaker trip unit with Arc Flash Reduction Maintenance setting.

Figure 7: Medium-voltage load-break switch with fixed-mounted vacuum circuit breaker.

power systems to reduce arc flash energy has limitations. The power systems engineer has limited options, primarily defined by the electrical equipment installed in the existing facility. A greater opportunity to impact the magnitude of both shock and arc flash hazards comes with designing systems for expansion of existing facilities or building new facilities. The power systems engineer can apply a "safety by design" strategy to effectively reduce or eliminate the possibility of an electrical arc flash incident – an approach highly recommended by the authors and in fact, the topic of a new industry standard currently being developed by industry engineers [9]. Fortunately, increased awareness of the dangers of arc flash hazards has been met by a response by many electrical equipment suppliers who have introduced many new technologies to address these issues.

CONCLUSION

Although the scope of this enterprise wide initiative to improve electrical workplace safety was extensive and involved literally hundreds of stakeholders, the program was a great success by most every measure. The project team did an excellent job up front in assuring buy-in across the organization, executing based on a well-defined work scope. Along with setting the table with clear expectations, other key success factors included selecting a supplier with the appropriate scale, using power systems engineers that were de-centralized in data collection but centralized in systems studies, and standardizing process across the enterprise including data collection methods, system analysis software, study results/recommendations and site safety training. The title of this paper includes the word "journey" for a reason. All involved recognize that engaging in this effort to assure compliance with emerging standards like NFPA70E and CSA Z462 is only the beginning of a never-ending effort to improve electrical workplace safety and continue to improve the safety of employees working in company facilities.

Completion of this enterprise-wide project for the cement producer yielded a number of unexpected benefits beyond the primary objective of improving personnel safety. One of these areas was improved knowledge of existing electrical systems by facility operations. With each plant's electrical system accurately modeled plus improved awareness and understanding, a clear path forward identifying system improvements to reduce electrical hazards was realized. All plant sites benefitted from the value that electrical system documentation provided, enabling effective management of plant power systems, which ultimately delivered improvements to the business's bottom line.

REFERENCES

[1] NFPA 70E: *Standard for Electrical Safety in the Workplace*. 2012 Edition

[2] Canadian Standards Association CSA Z462: *Workplace Electrical Safety*, 2012 Edition

[3] J.C Cawley, B.C Brenner, Occupational Electrical Injuries in the US 2003-2009, Conference Record, 2012 IEEE IAS Electrical Safety Workshop

[4] IEEE Standard 1584: *Guide for Performing Arc Flash Hazard Calculations*. 2002 Edition

[5] National Fire Protection Association, NFPA 70, National Electrical Code, 2011 Edition

[6] IEEE Standard C37.20.7: *Guide for Testing Medium-Voltage Metal-Enclosed Switchgear for Internal Arcing Faults*, 2002 Edition

[7] C.G. Walker, *"Arc Flash Energy Reduction Techniques Zone Selective Interlocking & Energy-Reducing Maintenance Switching"*, Conference Record, 2011 IEEE IAS PPIC, Pgs 42-54

[8] D.B. Durocher, *"Considerations in Unit Substation Design to Optimize Reliability and Electrical Workplace Safety"*, Conference Record, 2010 IEEE IAS/PCA CIC, Pgs 1-14

[9] IEEE Working Group P1814 *"Recommended Practice for Electrical System Design Techniques to Improve Electrical Safety"* Institute of Electrical and Electronics Engineers, IAS PCIC, 2009.