Thought leadership
White paper

Implementation of arc flash mitigating solutions at industrial manufacturing facilities

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Abstract

This paper highlights an assortment of case studies and explains how arc flash hazards were identified, measured and mitigated at various industry facilities. Case studies will include: Compliance with IEEE® 1584-2002 Guide for Performing Arc Flash Hazard Calculations along with regional workplace safety standards for a multi-site global cement manufacturer; Implementation of an Arcflash Reduction Maintenance System™ in an airlock section of a main switchroom for a minerals processing plant upgrade; Investigation of an arc flash incident at a chemical processing facility; and a "Safety by Design" upgrade for the iron ore division of a global mining business. The paper will examine the plans and processes reviewed and considered, the strategy deployed to manage/reduce arc flash hazards, and then discuss lessons learned in the implementation of new systems to improve electrical workplace safety.

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Introduction

Over the course of the past several years, industrial manufacturing facilities across the globe have learned to recognize the importance of identifying and understanding, measuring and mitigating the impact of arc flash hazards in their facilities. Although reported injuries are infrequent, the very high costs associated with these injuries make them one of the most important categories of injuries in the industrial workplace. In one U.S.-based utility, electrical injuries represented less than 2% of all accidents, but 28%–52% of injury costs. Immediate direct costs of arc flash incidents may be moderate, but these costs increase significantly over time. Coupling long-term direct costs with staggering indirect costs can bring the total U.S. cost of one incident to over $12 million. The reason: an arc flash event is effectively an explosion, involving molten copper and extreme temperatures. The human impact result is often severe burn injuries and irreparable bodily injury, which drives medical and legal costs to very high levels. The hazards are so great, although certainly persons will always be in the proximity of energized equipment, there are really few if any reasons where energized work can be justified.

In considering standards focused on electrical workplace safety, it is important to recognize that current consensus documents are country based. This is due in part to the fact that each country maintains its own installation standards that are linked to the electrical assemblies designed and tested to be applied in-country. For instance, in the U.S., the installation standard for electrical equipment is the National Fire Protection Association® NFPA 70 National Electrical Code®[1]. Article 110.16 of this standard entitled "Flash Protection" refers to the electrical workplace safety standard NFPA 70E-2012 Standard for Electrical Safety in the Workplace[2]. Most industries in the U.S. are regulated by the government's Occupational Safety and Health Administration (OSHA). OSHA regulations include language that mirrors the NFPA 70E-2012, so compliance with this consensus standard is effectively regulated. In Canada, The Canadian Standards Association CSA® Z462-12[3] Workplace Electrical Safety applies across all Canadian Provinces. This Canadian workplace safety standard is fully harmonized with the U.S. NFPA 70E-2012. Both the NFPA 70E-2012 and CSA Z462-12 mandates required safety practices for personnel working on or near energized electrical equipment. They determine the circumstances in which workers should wear specific personal protective equipment (PPE) clothing to protect them from the dangers posed by electrical arcs. One global standard focused on arc flash is IEEE Standard 1584-2002: Guide for Performing Arc Flash Hazard Calculations[4]. This standard presents methods for the calculation of arc flash incident energy (the heat energy defined in cal/cm^2) and arc flash boundaries. Because this is treated as a global standard, IEEE 1584-2002 is being used by several multi-site industrial manufacturing companies that operate facilities in many countries. The IEEE 1584-2002 offers a process to quantify the heat energy exposure at any electrical point in an industrial system, thereby defining the proper PPE necessary before performing energized work. The standard does not however define workplace safety procedures such as lockout-tagout and energized work permits that are traditionally included in workplace safety standards.

As mentioned previously, because there is a significant risk to workers in performing energized work, the author's recommendation is to find a way to turn the power off rather than take the chance of initiating an arc flash event. This said, there are some industrial users, particularly in process industries that elect to perform tasks such as troubleshooting and testing while electrical equipment is energized. This paper identifies case studies of select industrial facilities that have implemented site arc flash safety programs, highlighting the experiences of each as they worked to bring their respective sites into compliance with arc flash safety standards. In every case, the author's employer was involved in working with the respective industrial client, with first-hand knowledge of the project experience.

CASE STUDY 1

Multi-site cement processing manufacturer

The first case study for review involves a multi-site cement processing business operating 13 cement plants in the U.S. and Canada. This case study is detailed in a recent technical paper[5] that outlines details of a project to implement arc flash compliance to local standards across an enterprise. The cement producer operates globally and is one of the world's leading producers in the cement industry, but this arc flash compliance project was limited to the company's North American operations. For this project, IEEE Standard 1584-2002 was used as the tool to calculate the heat energy and both NFPA 70E-2012 Standard for Electrical Safety in the Workplace and CSA Z462-12 Workplace Electrical Safety were used as workplace safety guidelines for facilities in the U.S. and Canada respectively.

At the onset of project implementation, the cement producer engaged a global engineering services provider to perform site services and engineering studies. The services provider was chosen based on their extensive experience in the cement industry and a large and experienced team of over 100 power systems engineers, located at the company headquarters and also in field offices with both field engineering technicians and also power systems engineers across both the U.S. and Canada. To perform the arc flash hazard analysis, data needed to be collected at each site including an accurate existing state "map" of all electrical power systems. Then, the complete data package was sent to the centralized group of power systems engineers who updated the short-circuit and coordination studies and then completed a new arc flash study for each site. The starting point for collecting data was the existing plant single line drawing, along with recording of conductor lengths and protective device settings to verify that site documentation was correct. The utility serving each plant was also to be contacted for system information including the minimum and maximum fault currents that can be expected at the service entrance point of each facility. Although field service technicians were available and in close proximity to the 13 plant sites, the cement producer project team elected to deploy power systems engineers for the site work in collecting data. Their experience in performing power systems studies ensured 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.

Once the flash hazard analysis was performed, the calculated arc flash energy analysis yielded a PPE requirement for persons working on or near each energized electrical panel across each facility. Typically, the higher levels of PPE are required at the main cubicle of a 480 V unit substation and for some medium voltage systems. Because an arc flash event is generally limited to systems where bus voltage exceeds 240 V, the system model accounted for system busses only at 480 V and above.

The study results included an Arc Flash & Shock Hazard label at each electrical panel as shown in **Figure 1**. Note the label quantifies the hazard in calories per centimeter squared (cal/cm^2) at a working distance of 18 inches (about 500 centimeters). The label also identifies a Flash Protection Boundary of 21 inches. This is a distance where only "qualified persons" with appropriate PPE can safely be working while the panel is energized. PPE required while performing energized work in the panel must be rated above the 1.55 cal/cm^2 hazard.

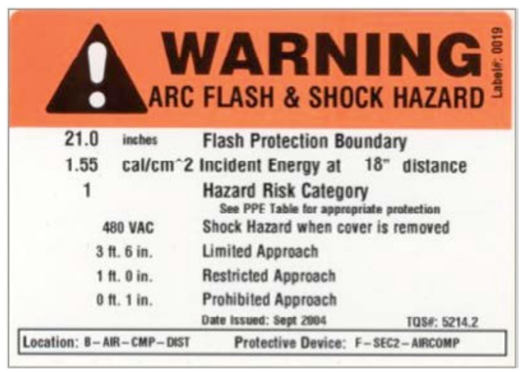

Figure 1

Typical equipment label designating arc flash in cal/cm^2 and shock hazard along with Flash Protection Boundary and PPE.

After completion of all arc flash studies, each site received a detailed report that identified the electrical hazard at every panel in the system. **Figure 2** shows a table of results from one of the plant studies. From this, note that the first bus identified as 416MCC-50/51-51G is a 4.16 kV motor control center and the calculated incident energy is 4.1 cal/cm^2. This is listed as a Hazard Risk Category, HRC #2. The second highlighted bus identified as FDR #3 SQD PNL is a 600 V motor control center with calculated incident energy of 75.8 cal/cm^2. The HRC for this panel is listed DANGER because PPE rated this high was not commercially available. In general, the unwieldy nature for PPE at the highest level comes with added risk (including loss of dexterity and heat exhaustion). Thus, the only alternative for this panel was to de-energize the system before performing work, or find a way to manage or engineer the incident energy level down. Following completion of the arc flash compliance project and posting of the labels identifying arc flash hazards at each panel, the individual cement manufacturing sites began to immediately focus on high incident areas of the plants, especially those that had historically required energized work. For these high arc flash hazard areas, the sites worked with the global services supplier to identify technologies that would allow the hazard to be managed to a lower level. The desire was to reduce the need for 40 cal/cm^2 PPE to a more manageable level closer to 8 cal/cm^2 as shown in **Figure 3**.

Device name	Bus kV	Bus bolted fault kA	Device bolted fault kA	Arcing fault kA	Trip time (s)	Breaker opening (s)	AF boundary	Working distance (inches)	Incident energy (cal/cm²)	HRC
416MCC-50/51-51G	4.16	28.82	24.03	22.9	0.083	129	129	36	4.1	#2
FDR #3 SQD PNL	0.60	25.83	25.83	17.73	1.917	0.083	402	24	75.8	DANGER
FDR #4 BULK SILO	0.58	8.53	8.53	6.55	0.028	0	12	18	0.6	#0
FDR #2 PHM CC	0.58	13.01	11.1	8.2	0.025	0	40	18	4.5	#0
FDR LCS#4 4A	0.60	35.21	31.78	22.62	0.05	0	40	18	4.5	#2
RLY U9_750	4.16	24.47	22.49	21.49	0.1	0.133	217	36	6.9	#2
FDR LCS#2 2D	0.60	20.74	19.43	14.42	0.1	0	43	18	5.1	#2
FU PUMPS1/2	0.60	6.32	6.32	4.38	0.076	0	16	18	1.0	#0
FDR LCS#4 1B	0.60	11.48	10.67	8.3	0.05	0	20	18	1.5	#1
COMP SUB MN	0.58	22.06	16.24	10.79	0.5	0	116	24	12.2	#3
RELAY COMP 50/51	0.58	22.06	16.24	10.79	1.917	0.083	287	24	46.3	DANGER
FU DIST PANEL	0.60	29.88	29.88	21.54	0.004	0	8	18	0.3	#0

Figure 2
The completed arc flash hazard study results were a table identifying each bus and the corresponding calculated incident energy based on formulas from IEEE Standard 1584-2002.

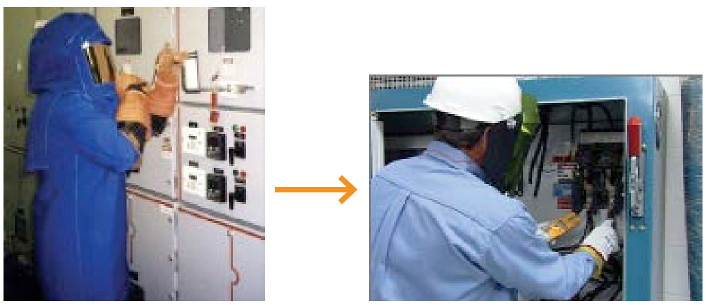

Figure 3
After the arc flash study is complete, facilities reviewed the results and identified areas where incident energy could be reduced, so workers can move from an unwieldy level of PPE (40 cal/cm² shown at left), to a more manageable level of PPE (8 cal/cm² shown at right).

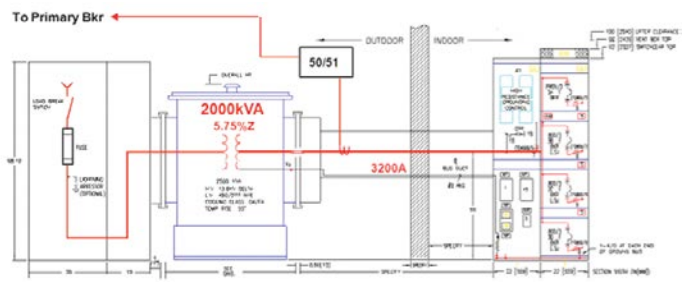

Figure 4
Typical low voltage unit substation consisting of outdoor medium voltage switch/fuse and liquid-filled transformer, bus connected to indoor low voltage equipment. Addition of CTs and an overcurrent relay to trip an upstream breaker reduces the secondary arc flash hazard.

In considering methods to reduce the arc flash incident energy at specific points of the electrical system, it is important to recognize that the heat reaching the skin of the worker is dependent primarily upon:

1. The power of the arc at the arc location.
2. The distance of the worker from the arc.
3. The time duration of the arc exposure.

System modifications that impact these would result in a reduced arc flash hazard, ensuring in some cases that workers can perform energized work in lower levels of PPE. As one example, some of the unit substations included in the existing systems included an outdoor primary fused load-break switch, close coupled a substation transformer and then bus connected to indoor low voltage switchgear or motor control centers (see **Figure 4**). Local installation standards allow this configuration when the secondary bus is less than 10 meters. The secondary bus as shown for this substation configuration is not protected—the upstream protective device is the primary fuse! The arc flash energy on the low voltage bus is calculated at over 600 cal/cm². One proposed solution to reduce arc flash energy is an added 50/51 overcurrent relay, including secondary bus current transformers at the substation transformer secondary throat. This added protective device offers secondary bus protection, sensing a fault condition should an arc flash event occur in the 480 V low voltage switchgear. If a fault occurs, the added relay will sense the overcurrent and instigate a trip of an upstream medium voltage vacuum circuit breaker. With this proposed upgrade, workers performing testing or troubleshooting at the low voltage switchgear, or racking one of the low voltage power circuit breakers from the main bus, would be exposed to a much lower heat energy should an arc flash event occur. Adding an overcurrent protective relay that includes zone selective interlocking and/or a maintenance switch[6] that is engaged when the power circuit breakers are being connected or removed from the main bus would further reduce the hazard and required PPE.

One important point regarding Case Study 1 is that the arc flash hazard compliance project was implemented for existing facilities. In this case, legacy electrical switchgear and motor control centers has been in service for perhaps 10 to 40 years. Although some of the newer power distribution assemblies include upgraded features such as arc-resistant or internal arc testing, replacing the existing infrastructure was not practical. Virtually all of the system upgrades proposed to reduce arc flash hazards were retrofit in nature. The producer was challenged to find a way to enhance facility electrical workplace safety based on modifying or upgrading existing electrical equipment.

Lessons learned

Overall, implementation of the arc flash compliance program for this multi-site cement producer was a tremendous success. Details outlining the project are included in the referenced technical paper[5] so they are not duplicated here. Overall, the success can be attributed to:

- Assurance of buy-in at all levels via early engagement with company corporate and plant site leadership through developing and issuing an Arc Flash Criteria document nearly two years in advance of project execution
- Execution of the project only after a well-developed project scope document was established and circulated
- Setting clear expectations of the plant sites and the global services provider on schedule and costs of the project
- Selecting a service provider with the appropriate scale with the needed local presence to efficiently execute to meet the project schedule
- Aligning with a supplier with capabilities both in engineering services and product technologies available to assist in “managing” the arc flash hazard down for critical plant systems
- Leveraging scale across the enterprise and driving standards for data collection, studies, reports, labels and also site safety training to ensure quality and consistency

Implementation of arc flash safety initiatives at a basalt crushing plant

The second case study reviews implementation of multiple arc flash safety initiatives as a part of a capital project and main switchroom addition in a New South Wales basalt crushing plant. The existing plant required addition of a turnkey solution that included supply and installation of a fixed basalt crushing and screening plant to support a capacity addition of 220 tonnes per hour. Included in the scope of work were design, engineering, supply, installation and commissioning of low voltage electrical switchboards and motor control centers including a new switchroom and process control system (PCS). Extensive equipment was added as a part of the project including a 2 MVA transformer, switchroom, MCC and control panels to support new crushers and screens, feeders and conveyors, luffing and radial stackers, dust extraction, lighting and plant automation. The quarrying site owner did not have permanent electrical staff onsite and oftentimes contractors who were not completely familiar with crushers on a mine site would be performing maintenance and troubleshooting services. Because of this, the design team carefully considered the primary hazard areas within the switchroom, focusing on activities such as switching and isolation of electrical devices, resetting of overloads, fault finding and testing. Specific activities in the new switchroom that would involve arc flash risk to the operators included:

1. Racking withdrawable circuit breakers on or off of an energized bus.
2. Removing or installing circuit breakers from an energized cell.
3. Working on control circuits with energized parts.
4. Low voltage testing and fault detection/troubleshooting.
5. Removing panels for visual and thermal inspections.
6. Testing for zero energy prior to lockout.

The design team considered the system design, focusing on the Hierarchy of Hazard Control as shown in **Figure 5**. The concept was to utilize PPE as a last resort, implementing more effective solutions moving toward eliminating the hazard.

Figure 5
Hierarchy of Hazard Control.

The main low voltage switchboard selected for the project was an internal arc classified system Type Tested to IEC61439-1 (and IEC 61641 criteria 1 through 7). The main switchboard also was compliant with AS3439.1. The arc fault containment features included an arc relief valve directing gases and heat away from personnel, Form 3b/4a segregation, internal penetration seals and insulation arc barriers. The collective system created an arc free zone through additional partition walls, allowing true segregation complying with the intended people-safe design.

In addition to the arc safe design, a new technology included an Arcflash Reduction Maintenance System (ARMS) that was deployed as a part of the internal trip unit of the main air circuit breakers. As is included in any low voltage air circuit breaker trip unit, the protection curve allows adjustment of long-time, short-time, instantaneous and ground (earth) fault that was necessary for selective coordination. The ARMS offers a second protection setting, a separate integral analog circuit. When enabled in the maintenance mode, ARMS overrides the standard protective settings and reverts to a trip setting based on a preset instantaneous current setting, a multiple of the trip unit rating plug. The advantage is a significant reduction in total clearing time, which in turn reduces the arc flash hazard.

Figure 6 shows the typical integral trip unit of the air circuit breaker and the ARMS or maintenance setting. Local and remote enabling and indication capabilities are provided, allowing consideration for Lock-out/Tag-out procedures from outside the arc flash hazard area.

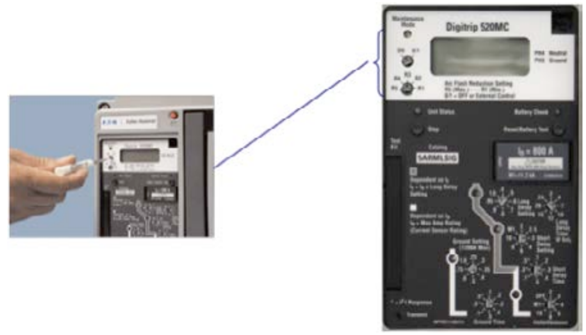

Figure 6
Air circuit breaker included an integral trip unit with Arcflash Reduction Maintenance System (ARMS) capabilities.

A part of the engineering design included the completion of a short circuit, coordination and arc flash study. The arc flash study was completed based on calculations as defined in IEEE Standard 1584[4] as discussed previously. It was discovered that the arc flash incident energy was calculated at over 36 cal/cm^2 for the incoming main breaker and also for many of the feeder sections of the main switchboard. Engaging the ARMS feature at the incoming main circuit breaker reduced the incident energy to below 4 cal/cm^2. **Figure 7** shows the calculated heat exposure for the main switchboard with the main circuit breaker trip unit set in the normal mode with selective coordination (a) and also the exposure with the main circuit breaker in the ARMS mode (b). Operating processes were established for the site maintenance personnel to set the main breaker trip unit in the maintenance mode when persons were working on or around the energized switchboard.

One noteworthy issue from the diagrams in **Figure 7** is that the panels including soft-starters to feed large low voltage motors serving the large crusher loads showed calculated arc flash heat energy at very low levels, shown in **Figure 7** at less than 1 cal/cm^2. This was due to the soft-starter units including fast acting current limiting fuses to protect the power semiconductors in these assemblies. Although these fuses were not specifically included in the design to address arc flash hazards, the positive impact was a welcome result.

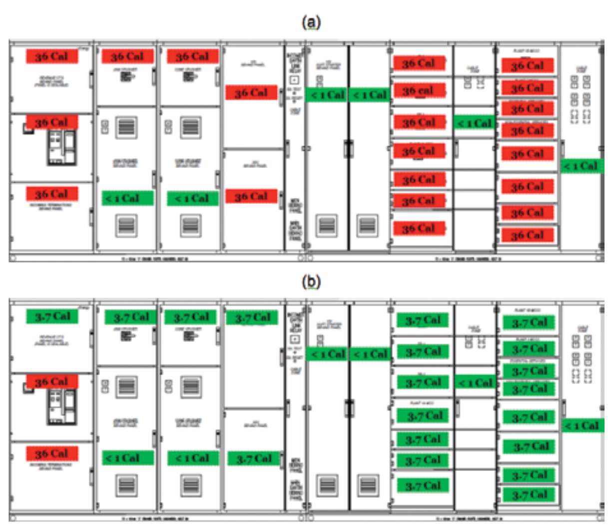

Figure 7
Heat exposure by panel for the switchboard with the main breaker set in the normal mode (a) and the exposure with the main circuit breaker in the ARMS mode (b).

To ensure an additional level of safety, the design of the main switchroom included an airlock section as shown in **Figure 8**. The airlock room is physically isolated outside of the main switchroom where the switchboard is located. An ARMS activation switch and remote maintenance mode indication light is located in the airlock room. In addition, motion detectors were installed inside the main switchroom that also engaged the maintenance mode. This was a back-up safeguard in the event the ARMS switch was mistakenly not engaged by the operators or perhaps non-qualified persons who somehow have access to this space. Indication of the ARMS mode also is connected to the SCADA system so plant operators were aware of the setting.

Figure 8
The main switchroom is designed with an airlock section where the ARMS switch and confirming indicating light are mounted. This functionality is activated prior to maintenance persons gaining access to the main switchboard area.

For an added degree of safety, Direct On Line (DOL) motor loads were equipped with electronic thermal overload protective relays. These devices included network communications allowing operators to reset motors after a trip on overload conditions. This was accomplished via the SCADA system. Magnetic trips still require an electrician to trace and manually reset this type of fault. **Figure 9** shows the thermal overload reset screen accessed from the SCADA human machine interface (HMI) and also the remote access panel included in the airlock section of the switchroom.

Figure 9
The SCADA system includes reset access to DOL motor loads so that operators can reset thermal overloads remotely (left image). Circuit breaker controls and ARMS activation is from the remote panel mounted in the airlock room adjacent to the main switchroom.

Lessons learned

This case study is an excellent example of how careful planning during design of a Greenfield industrial project can significantly reduce arc flash exposure for plant operators. Notable lessons learned from this experience:

- Use of the Hierarchy of Hazard Control (**Figure 5**) at the onset of design is a good tool to challenge system designers to push safety from a protection based approach to prevention based approach—always the better choice
- In some smaller industrial sites, outside contractors are often called upon to maintain and troubleshoot electrical systems instead of qualified and trained employees. An added level of safety should be considered in these situations
- Understanding and deploying the latest technologies both for power distribution systems and also control systems is necessary. Moving persons away from energized equipment by application of remote switching and fault reset is a best practice in designing safe electrical systems

CASE STUDY 3

Arc flash incident involving a maintenance switch

The third case study reviewed in this paper involves a chemical processing facility with a completed study and a robust electrical workplace safety process. The site experienced an actual arc flash event while energized work was being performed. Similar to Case Study 1, this event was also documented as a technical paper, presented at a recent Workshop focused on Electrical Workplace Safety[7].

A chemical processing facility in the U.S. was planning energized work for an existing 480 V low voltage switchgear assembly that was an existing piece of equipment in the plant. During a process upgrade in the facility, an energized work permit was issued to remove three abandoned load conductors from an existing 480 V low voltage switchgear assembly cable compartment. The work permit was very detailed and included tools planned for use in the project and required PPE for workers performing the task based on the incident energy defined by a recently completed arc flash hazard assessment. The defined task for the work order required the site contractor to use a nylon rope, which was typical with this type of project, disconnecting the de-energized cables and working to raise them from the top cable compartment. **Figure 10** shows a layout of the low voltage assembly involved in the work. The de-energized cables were planned for removal from Cubicle 5, whilst still energized conductors existing in Cubical 4 at the bottom of the cable wireway. The rope used was not able to grab the conductors and would slip off of the cable, so the electrical contractor elected to employ a "come along" to assist in the removal, as the come along could apply more force. The first conductor was successfully removed with this new tool. Upon removing the second conductor, a small arc flash was observed in the lower compartment. Simultaneously, the lights to the plant went out. The contractor stopped work and waited for plant electricians to arrive, not knowing what had just occurred.

The event caused the entire plant to shut down, stopping work on the project until an analysis could be completed. It was determined that the chain of the come along had drifted below where the work was being performed and into energized Cubicle 4. Fortunately, the damage to the wall of the switchgear and come along tool was minimal, which is shown in **Figure 11**. Post event analysis proved that the chain of the come along had drifted below where the work was being performed and into an energized cubicle. The chain touched an energized terminal and arced to ground, touching both phase conductor and cabinet ground metal below the non-energized cubicle where the electrician was working. After reviewing minimal damage and completing the project while de-energized, the plant switchgear was cleaned and re-energized. Fortunately, total downtime for the plant due to this event was minimal. No loss of equipment or injury to any employee was a result of this event.

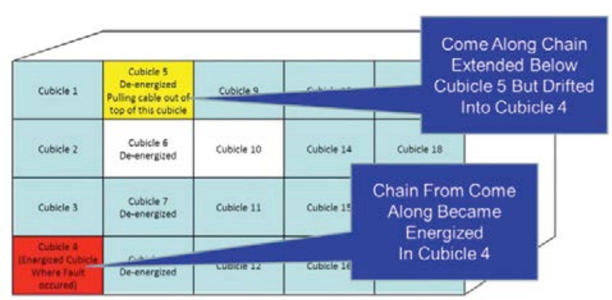

Figure 10
Low voltage assembly involved in planned energized work. The planned task included removing cables from de-energized Cubicle 5 while Cubical 4 in an adjacent section was still energized.

The important take-away here is that the arc flash study was completed before energized work was performed. The upstream low voltage power circuit breaker with the special maintenance switch setting discussed previously employed technology to clear the fault faster than the microprocessor instantaneous setting of the circuit breaker trip unit. Calculations were previously performed that quantified a reduction in incident energy from 17.7 cal/cm^2 to 2.9 cal/cm^2 using the special maintenance setting. Both workers and equipment were saved as a result of a total clearing time at 40 milliseconds as defined by the manufacturer's published trip curves[8].

Figure 11
At left, a "come along" tool used for energized work and at right, damage to panel after phase to ground arc flash event with an upstream device with maintenance setting capabilities.

Lessons learned

This case study unequivocally proves that planning for the unplanned event can save lives. Some of the key lessons learned here:

- Mistakes will happen on even the best planned projects. A change in tools is what led to this arc flash event
- Proper planning and leveraging of all accessible resources prevented what could have been a catastrophic event
- Leveraging technology can often deliver a reduction in the available energy. Using more sensitive settings can save both people and equipment should an arc flash event occur

CASE STUDY 4

Upgrade at an iron ore pellet plant in western Australia—safety by design

The fourth and final case study reviewed here describes implementation of a low voltage MCC retrofit program initiated by a global iron ore producer who operates multiple facilities across western Australia. As many existing motor control center systems have begun to reach end of life, the corporate engineering leadership responsible for improving electrical workplace safety across operations has implemented a systematic upgrade program. Many assembly safety standards including IEC61439-1[9], IEC 61641 criteria 1 through 7[10] and even AS3439.1[11] were not in existence when original equipment was first commissioned. So the replacement/upgrade program involving multiple operations includes replacement of existing assemblies with new technology based on a "Safety by Design" platform. The replacement MCCs are manufactured in compliance with the latest internal arc containment standards. These new assemblies also include a unique arc quenching device designed to protect both personnel and equipment.

Many protective relay suppliers have recently introduced overcurrent relays that include the additional arc flash safety feature of light detection. The concept is that light sensors, typically combined with measuring rate of current rise (di/dt), offers a path toward faster detection of an arc flash event. Although this is true, what a number of manufacturers do not mention here is that total clearing time is the necessary metric to measure in calculating the heat energy from an arc flash event. Of course total clearing time is a combination of the sensing time plus the interrupting time of the overcurrent protective device. Light detection systems offer very fast sensing response times, on the order of 1 to 2 milliseconds. Unfortunately, most circuit breakers responding to an external trip command via a shunt trip device operate slower than commands initiated from the internal trip actuator. So, the "enhanced performance" is often compromised by the latency of the external shunt trip. To support this assertion, note that many power systems engineers performing arc flash studies will calculate no benefit from light detecting relays. In actual practice, there is no way to reasonably determine the change in total clearing time using light detection for any given system.

Knowing this, the global iron ore producer made the decision to deploy upgraded systems that incorporated light detection plus the added functionality of an arc quenching device. This device senses light and current and then fires a voltage shunt that effectively established a three-phase bolted fault. The intent with this approach is to establish a current path via a lower impedance than the arcing current path. After sensing of an arc event, the shunt device effectively collapses voltage to zero so the arc energy cannot be sustained.

After the bolted fault is initiated by the clamping device, the next upstream overcurrent protective device is called upon to clear the fault condition. **Figure 12** shows an image of the quenching device, typically mounted at the main bus bars of the low voltage MCC. After light and current fire the device, a bolt placed in a guideway with phase insulation penetrates the insulation, creating a metallic short circuit with total clearing time of less than 2 milliseconds.

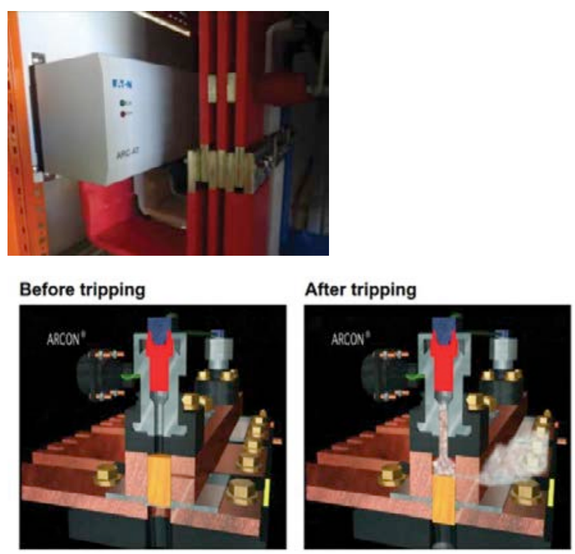

Figure 12
The unique quenching device (above) includes a bolt placed in a guideway with phase insulation before tripping (lower left). After light and overcurrent detection, the bolt penetrates the insulation creating a metallic short circuit in less than 2 milliseconds (lower right).

As mentioned previously, this low voltage MCC is an internal arc classified assembly tested to IEC61439-1and IEC 61641 criteria 1 through 7 and AS3439.1. **Figure 13** shows results from an arc test as outlined in the IEC standard. Note the damage to the ignition wire following the arc test at the primary bus. In this image, it is shown that the aftermath on an arc flash event is essentially a non-event. Using this quenching device technology is an effective way to mitigate the hazards of an arc flash event: both people and equipment are protected.

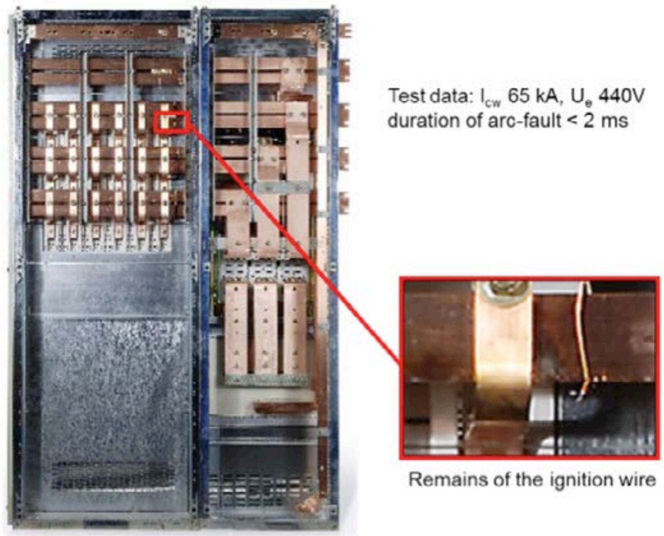

Figure 13
Internal arc classified testing as defined by IEC 61641 criteria 1 through 7 requires that an ignition wire be placed at several locations to establish an arc event. Test at the main bulbar in the image above using the quenching device yields little to no damage.

Figure 14
Replacement 415 volt switchboard with light detection and quenching device installed. The Master Control Module offers complete system controls and MMI display.

The technology deployed in the quenching device applied in the replacement low voltage MCCs is very high speed, a key factor in the arc duration lasting a total of 2 milliseconds. As discussed in previous sections, many light detecting systems rely on the overcurrent protective device clearing the fault before an arc event is extinguished. The difference using the quenching device is that voltage collapses to zero so the arc is immediately extinguished. The upstream protective device is then called upon to clear the fault, which will typically occur in the instantaneous range of a circuit breaker or the current limiting range of a fuse. The power systems engineer should consider the fault clearing time and apply protective devices/settings to assure the resulting fault is cleared as quickly as practical. In some situations, an arc event at the line side of a main incoming circuit breaker could result in very high fault currents fed through a power transformer, which could mechanically stress the transformer windings. The design in these situations should consider secondary current transformers and relay protection at the transformer secondary terminal chamber. If the system includes short time delay settings for air circuit breakers to assure selective coordination, adding zone selective interlocking[6] should be considered. This would assure the fastest possible interrupting time to clear a fault condition should the quenching device deploy. The quenching device is a one-time-use mechanically actuated component that can be easily replaced after deployed. Because arc flash events are rare, the iron ore producer planned to keep one spare quenching device per facility to support multiple installed low voltage MCCs.

Figure 14 shows one of the new low voltage MCCs on the factory assembly floor prior to witness tests. Note that the panel at the left includes an incoming power meter to record energy use. The center panel includes a master control module where the light detecting sensors are connected. In the event of an arc flash, the sensors will initiate a trip signal to the quenching device which is connected at the main bus at the load side of the incoming main circuit breaker. The master controller also captures information regarding which sensor recorded the flash so the location of the arc can easily be traced after the fault is cleared. Note that this low voltage MCC is comprised strictly on air circuit breakers, with two feeder breakers that protect downstream equipment. In this application, including the maintenance switch capability to assure faster total clearing times when personnel are working in downstream equipment would also represent a best practice in mitigating potential arc flash hazards.

Lessons learned

Unlike some of the previous case studies discussed, the site owner has a distinct advantage of design and installation of new electrical assemblies. This enabled an opportunity to apply type tested electrical assemblies and technologies to reduce the chances of an arc flash event. Some of the key lessons learned here:

- The arc quenching device offers the fastest possible means of extinguishing an arc flash event, but a careful plan in dealing with the resulting three-phase fault should the device trigger should be considered
- The most effective way to reduce arc flash hazards is by applying the latest technologies designed to address the issue. Although often not practical for legacy installations, it is important to take the opportunity to do so for any new equipment
- For both IEC and ANSI/NEMA low and medium voltage assemblies, new arc classified/tested designs should be considered, especially for Greenfield sites
- Assuring that only qualified persons have access to areas where an arc flash event might occur is a best practice for both new and existing industrial facilities

Conclusions

This paper reviews an assortment of case studies related to arc flash hazards. This review of actual problems and solutions was designed to provoke thought for the owners and system design engineers involved in decisions to initiate an arc flash study for either existing or new industrial facilities. Most certainly, understanding of this very real hazard coupled with a desire to change the current workplace safety paradigm to consider arc flash safety is the first step. Understanding the proper steps in effectively modeling electrical systems and leveraging scale to assure repeatable processes can be a key factor in a successful program. New technologies, only a few reviewed in this text, have proved effective in mitigating arc flash hazards for both existing and Greenfield sites. New construction provides a unique opportunity to design electrical systems based on a "safety by design" approach. This should be leveraged for any new project because the cost to remedy system deficiencies after the fact comes at a significantly higher cost.

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Printed in USA
Publication No. WP083015EN / Z17050
August 2015