Introduction
Over the past few years, a broad industry focus on improving electrical workplace safety has resulted in exciting innovations from leading global manufacturers of electrical equipment. The driving forces enabling new developments are an improved understanding of electrical shock and arc flash hazards, as well as evolving industry standards designed to create a workplace safety culture. One of the most important standards in this space is the National Fire Protection Agency (NFPA) 70E-2018 “Standard for Electrical Safety in the Workplace.” This standard, along with the harmonised Canadian Standards Association (CSA) Z462-18 “Workplace Electrical Safety, 4th Edition”, have pushed leading manufacturers to develop products, services, and solutions that address both the hazards and risks of working on or near electrical systems.

The last few iterations of these electrical workplace safety standards have evolved both in their perspective and approach to electrical hazards and risks. Earlier versions of the NFPA70E addressed electrical hazards and risks together, based on a holistic view of those factors. Today, the latest editions of these standards consider
hazard and risk as two separate issues, which need to be considered to protect personnel from the potential of electrical injury.

Just a few years ago both the NFPA and CSA standards identified the heat energy from an arc flash event to be a hazard-risk category (HRC). The standards defined the heat energy of 1.2 cal/cm\(^2\) to be the threshold at which the onset of a second degree burn may occur. One cal/cm\(^2\) of heat energy is similar to holding the tip of your finger over the flame of a lit match for one second. Further, the following five HRCs were defined:

- HRC 0 (1.2 cal/cm\(^2\)).
- HRC 1 (4 cal/cm\(^2\)).
- HRC 2 (8 cal/cm\(^2\)).
- HRC 3 (25 cal/cm\(^2\)).
- HRC 4 (40 cal/cm\(^2\)).

These hazard risk categories in effect designated the required personal protection equipment (PPE) or fire-rated clothing necessary to reduce exposure to electrical hazards.

For instance, if the incident or heat energy of a given piece of equipment in the electrical system was calculated at 7.2 cal/cm\(^2\), then this would be a HRC 2 condition and personnel would need to wear protective clothing rated at 8 cal/cm\(^2\). This would provide protection from a potential arc flash, while working on energised equipment.

Today, the hazard is the calculated heat energy at any given point of the electrical system. The hazard is either present or it is not. In the example above, if the incident energy is calculated to be 7.2 cal/cm\(^2\), then this is the defined hazard. The worker must wear suitable PPE to protect from the hazard, so in this case, fire-rated clothing rated above the 7.2 cal/cm\(^2\), including proper hand, face, and ear protection, would be necessary before performing energised work.

The evaluation of risk is task based, driven by a combination of both the likelihood and the severity of electrical injury. Consider an electrician at a manufacturing plant in one of the process industries, such as a steel mill or cement plant. If his or her task were to simply operate a circuit breaker disconnect on a 480-v low-voltage motor control centre with the enclosure door closed, what would be the risk to the electrician? First, the likelihood of a shock injury would be near zero. With the MCC door closed, the electrician would not be exposed to energised conductors. The likelihood of exposure to an arc flash event would be low, although it is possible that a change in conditions to the circuit could cause an arc flash event, since the electrician is interacting with an energised component (the circuit breaker). A tool, test cables, or misconnected wires left by a previous worker could cause such an event. That said, if the MCC were tested to one of the arc-resistant standards, such as ANSI/IEEE C37.20.7 “Guide for Testing Metal-Enclosed Switchgear Rated Up to 38kV for Internal Arcing Faults” or CSA C22.2 “Evaluation Methods for Arc Resistance Ratings of Enclosed Electrical Equipment”, then with the door closed, the equipment is designed to prevent the heat energy from escaping and harming personnel. In this example, the severity component of risk is primarily linked to the heat energy, so appropriate PPE for the task would still be required.

Consider a different task, where the electrician is performing testing or troubleshooting, using a multi-meter to test phase voltages with the enclosure door open. The hazard here would be the same calculated 7.2 cal/cm\(^2\) but the risk would be higher because the task involves exposure to energised parts. An evaluation of the likelihood and severity of this risk would need to be conducted before proceeding with energised work. The likelihood of electrical injury from shock hazard in this example is higher than in the previous example. The arc flash likelihood is also increased, since the worker is exposed to energised conductors.

Case Study
Recent initiatives at a US cement plant provide an excellent example of implementing best practices that help drive toward an improved safety culture.
In this example, the owner completed site studies using methods to quantify the arc flash hazard as defined in IEEE 1584-2002 “Guide for Performing Arc Flash Calculations”. The site had also affixed warning labels to all electrical panels which designated both the electrical shock and arc flash hazard as outlined in NFPA70E-2018.

One of the existing enclosures was a 4160-v metal enclosed assembly that feeds several medium-voltage motors at the plant. The existing line-up was a vintage assembly manufactured back in the 1970s. The main vacuum circuit breaker, which distributed power to the medium-voltage motors, was used at the site as a lockout point in the system. This meant that prior to any work being performed on the control centres, the vacuum breaker in the metal-clad switchgear needed to be at zero energy. Establishing zero energy at this device required two points of isolation: confirmation that the vacuum breaker was open and confirmation that the vacuum breaker was racked off of the energised switchgear main bus.

**Challenge**

In this class of assembly, racking a medium-voltage vacuum breaker involves an electrician standing in front of the main breaker structure, using a manual crank, which connects at the breaker cradle assembly beneath the breaker. Rotating the crank actuates a horizontal worm-gear that physically removes the vacuum breaker from the energised bus. After lockout is completed, the process is reversed, and the electrician again rotates the cranking tool to re-engage the vacuum breaker to the energised bus.

The owner analysed the hazards associated with this energised work, which were significant at 12.2 cal/cm². The risk of this activity was also considered; the risk assessment looked at both the likelihood and severity of an incident. In this case, the likelihood was a significant concern; many documented arc flash events have occurred while electricians were performing this task. All three phases of the primary and secondary finger clusters (six medium-voltage power connections) need to be disconnected and then reconnected. Should one of these connections be damaged or misaligned during breaker racking, the likelihood of an arc event is significantly increased.

Since this main breaker structure was a vintage design from the 1970s, the assembly was manufactured before the emergence of arc-resistant testing. So although the door was closed during breaker racking, an arc flash event occurring during this task would likely result in high enough pressure and heat energy to blow open the enclosure door in front of the electrician, while he or she is racking the breaker off of or on to the energised bus. Due to the high risk, the electrician performing this work would be compelled to wear the plant’s highest level of PPE used at the site, a 40 cal/cm² suit. This high level of PPE may help protect the worker, but also could introduce other risks, such as heat exhaustion and loss of dexterity.

**Solution**

In an effort to address the significant risk of this work activity, the plant owner elected to install an innovative retrofit solution that would eliminate the risk. A turn-key solution installed by field-based service engineers replaced the vacuum circuit breaker carriage/cell assembly with a new design that incorporated an integral motor operator. With this retrofit, personnel would use a remote pendant station connected at the switchgear enclosure and then stand outside of the flash protection boundary, while remotely racking the circuit breaker from the energised 4160-v bus. After the breaker was isolated from the energised bus, system lock-out was completed. Before the system was again energised, the remote breaker racking function was again used to safely rack the breaker back onto the energised bus.

The new cell assembly includes a sophisticated torque sensing controller that will cease breaker racking, should the racking mechanism or circuit breaker bind or become jammed during the racking process. The hand-held pendant station connects at the front of the switchgear, allowing the operator to open/close the circuit breaker and rack the de-energised vacuum breaker on or off the switchgear bus. The pendant is powered from the switchgear 120-v control circuit and includes three indicating lights confirming the circuit breaker position in the cell (connected-test-disconnected). The lights are controlled by cell mounted switches, assuring positive indication of the breaker position in the cell.

**Results: advancing workplace safety through an evolved approach**

“The internal remote racking device upgrade to our two VCP-W breakers onsite solved two problems for us,” noted David Fisher, an Electrical Engineer at Ash Grove Cement Co. “First and most important, it helped remove our employees from harm’s way during the engaging and disengaging of our breakers from their bus. Second, it eliminated the use of a portable remote racking device that had to be hauled up and down stairs and from substation to substation. In addition, this avoided the potential of an employee being injured during transportation of the mobile unit.”

Electrical workplace standards continue to evolve towards a better definition and understanding of both hazard and risk. This recognition is an important step forward toward advancing safety and helping to avoid or reduce
the risk of shock and arc flash events. A clear understanding of both the hazards and the risks associated with energised work needs to be discussed, and all possible scenarios need to be considered before work commences.

Many industrial facilities have performed or hired consultants to complete arc flash studies at owner sites. The deliverables from these studies include a short-circuit and coordination study, followed by an arc flash hazard analysis and labels affixed to electrical panels across the facility. Although it is useful to affix labels that define both the shock and arc flash hazard at every electrical panel, knowing just the heat energy hazard from a potential arc flash event is only part of the answer. The actual tasks or activities involved need to be considered and both the likelihood and severity of the risk needs to be understood.

About the author

David Durocher received a BSEE at Oregon State University, and serves as a Global Mining, Metals, and Minerals Industry Manager with Eaton. He has authored numerous technical papers, presented and published in the IEEE Transactions on Industry Applications and various industry publications. He serves on IEEE Standards Working Groups IEEE1584 and IEEE1458 and is an active member of the IEEE IAS Mining Industry Committee, Cement Industry Committee, and Association of Iron & Steel Technology. He served as President of IEEE Industry Applications Society between 2015 and 2016, and serves as Division II Director, IEEE Board of Directors, 2019 – 2020.

Hand-held pendant station enables remote operation and racking of the main vacuum breaker.