

Abstract

This paper introduces the concept of improved safety and reliability in low voltage motor control center assemblies. Improved methods for reducing the arc flash, electrical shock, and other hazards associated with the inadvertent creation of an arc flash in low voltage motor control assemblies will be discussed.

Future construction improvements and feature set will be identified. Theoretical and laboratory data, which may lead to design changes, will be shown. Testing includes arc-flash testing per IEEE 1584 and calculations per the same. The test results will demonstrate the ability to reduce hazards and arc-flash levels through improved motor control center designs. In addition to reducing the time that arc-flash energy is available, motor control center assemblies can provide features which can drastically reduce the probability for the creation of an arc flash and its propagation. Features such as a voltage test station and a unit (bucket) test position for safe access into the unit without exposure to main bus voltage will serve to reduce the Personal Protective Equipment (PPE) required to perform routine maintenance. These features will also protect the operator from other hazards that can occur during an arc-flash event.

Introduction

The Library of Construction, Occupation Safety & Health (LCOSH) describes electricity-related hazards. They include electric shock and burns, arc-flash burns, arc-blast impacts and falls.

1. **Electric shock and burns.** An electric shock occurs when electric current passes through one's body. This can happen when one touches an energized part. If the electric current passes across the chest or head, one can be killed. At high voltages, severe burns can result.
2. **Arc-flash burns.** An electric arc flash can occur if a conductive object gets too close to a high-ampere current source or by equipment failure (for instance, while opening or closing disconnects). The arc can heat the air to temperatures as high as 35,000°F, and vaporize metal in the equipment. The arc flash can cause severe skin burns by direct heat exposure and by igniting clothing.
3. **Arc-blast impacts.** The heating of the air and vaporization of metal creates a pressure wave that can damage hearing and cause memory loss (from concussion) and other injuries. Flying metal parts are also a hazard.
4. **Falls.** Electric shocks and arc blasts can cause falls, especially from ladders or unguarded scaffolding.

Motor Control Centers account for the second highest frequency of electrical accidents. [11] As a result of this finding, the industry is in need of a motor control center that addresses all of these potential hazards.

The Ultimate Design

The first hazard is electric shock and burns, which are caused either by an equipment failure or the inadvertent bridging of live electrical circuit components with a conductor, which releases heat either through the melting of metals or through direct contact to the skin. In motor control centers, this can be caused either by the grounding or short circuiting of either the main power voltage (typically 240 Vac or 480 Vac) or the control power voltage (typically 120 Vac). Some conservative approaches to minimizing the probability of electric shock burns include a prohibition to work on or in energized electrical equipment. This safety approach has also included in some cases prohibition to work on or in the vicinity of energized electrical equipment.

Unfortunately, shutting down a motor control center may in some cases be a lengthy and costly proposition. Industrial, and some commercial, customers have instituted safety procedures that have made it a very lengthy process to obtain the necessary permits to do electrical work "hot." Justifiably so, they are concerned for the well being of their employees and the liability of their company. Shutting down an entire motor control center may involve a coordinated effort to shut down a process or critical equipment. Inevitably, equipment remains shut down a long time and once shut down, troubleshooting is limited to that which can be done with the unit de-energized.

OSHA 1910.333 (a) (1) and NFPA-70E 130.1 specifies the conditions under which "hot" work is permitted. "Qualified electrical workers shall not be asked to work on equipment that is "hot" or "live" except for two demonstrable reasons:

1. *De-energizing introduces additional or increased hazard e.g., * cutting ventilation to a hazardous location* emergency alarm systems.*

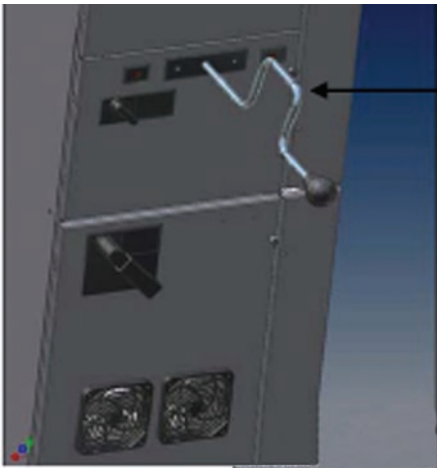
or

2. *Infeasible due to equipment design or operational limitations e.g., *voltage testing for diagnostics* start up testing".*

This is difficult, if not impractical, to do in today's MCC. During installation and commissioning, and even after the MCCs are in operation, buckets are removed then installed for a variety of reasons. This presents two separate challenges...First is the removal and installation of units on a live vertical bus. Second is the necessity to troubleshoot or make adjustments to components in the unit with control power on.

Although it has been common practice in some industries to install or remove units (buckets) manually from a live vertical bus in a motor control center, the practice is inherently unsafe. NPFA 70E Table 130.7(9)(a) general guidelines classifies that practice as a Hazard/Risk level 3 (25 cal/cm² or 104J/cm² ATPV). It should be noted that the guideline method is a conservative and alternate method for the Flash Hazard Analysis Method. Actual available fault current could result in higher available arc-flash energies. The challenge is that motor control center units (buckets) are pushed into position or pulled manually by operators at different speeds and forces. Larger or heavier units (buckets) can sometimes be awkward, especially if they need to be inserted where the operator has limited mechanical leverage.

The practice of removing devices from a live bus is not unique to MCCs. Removing and inserting switchgear breakers on a live bus presents some of the same risk. However, the biggest difference between breakers and motor control center units is that breakers have more mass and their frames are more rigid than motor control center units. Breakers are not as susceptible to deforming while being connected to the bus. Also, in typical low and medium voltage switchgear, the power breakers are advanced and retracted in their cells using a levering system, which moves the breakers on a track. This helps maintain the proper alignment through its entire travel. Lastly, medium and low voltage power breakers are inserted and removed through mechanical levering means, which helps control the speed of the insertion or removal of the breaker, thus lower the probability of damaging the power stabs. (See **Figure 1.**)



Racking Tool or Remote Operated Motor with Pendant Station

FIGURE 1. RACKING TOOL

The practical solution would be to provide a levering system for the motor control center units' stabs, or the units themselves, which would be operated locally with a tool or remotely with an electrical racking mechanism. The entire removal or insertion would need to be done with the unit door closed and tested such that the operator is in a risk Category 0 during the operation. This type of design provides the benefit of protecting the operator from some of the other results of arc-flash incidents, such as flying debris and acoustic waves. This may involve the use of arc-containment spring-loaded door latches that, when properly latched, allow internal pressure relief and help keep the doors from unlatching during an arcing fault. (See Laboratory Testing Page 3)

The second challenge (troubleshooting or making adjustments to components in the unit with control power on) can be solved by providing a "Test" position, similar to what exists today in ANSI medium voltage metal-clad switchgear or UL 1558 low voltage switchgear. The "Test" position has definite advantages, but it is predicated on proving that the risk category is below a Category 0, and that the voltages present no risk of electrocution or burn. Additionally, this "Test" position would need to have the appropriate interlocking to prevent inadvertent connection of the unit to the vertical bus.

While connected to the vertical bus, a typical motor control center would require that the main power disconnect be closed and the control power transformer energized to have control power present to do any meaningful troubleshooting. This presents a problem because the potential present at the line and load side of the disconnect and the primary of the control power transformer may deliver arc-flash energy that would require PPE. This challenge can be solved by the use of external control power, which feeds the unit (bucket). With the unit in "Test," only control power would be present. The feed from this control power transformer would not deliver arc energy above a risk Category 0. If the control power into the unit is 24 Vdc, it would be both outside the boundary, finger-safe, and free from risk of electrocution.

The second hazard identified by LCOSH is Arc-Flash Burns. NFPA-70E — Electrical Standard for Safety in the Workplace, addresses mainly the risk categories and PPE requirements to avoid hazards associated with arc-flash burns. The intent of NFPA 70E regarding arc flash is to provide guidelines which will limit injury to the onset of second-degree burns ($5\text{J}/\text{cm}^2$ ATPV or $1.2\text{cal}/\text{cm}^2$) [6]. The standard, guidelines, calculations and PPE requirements do not intend to address the other potential hazards. There are collateral benefits of the PPE and the protection they may provide for the other hazards, but they are merely coincidental. The heat reaching the skin of the worker is dependent upon three main factors:

- A. Power of the arc at the arc location
- B. Duration of the arc exposure
- C. Distance of the worker from the arc

The first two (A and B) relate to the electrical system and its design. The power of the arc is a function of the impedance of the power supply feeding the distribution system, and is measured in kilo-amperes (kA). Power feeding a motor control center; be it from a transformer or generator, has a certain maximum available current it can provide at the point of the fault. Resistance or impedance to that current forms a relationship that equals the arc energy that can be delivered at the arc location.

(B) Duration of the arc exposure. This is dependent upon the opening time and clearing time of the upstream overcurrent protective devices. Protective devices in motor control centers (primarily circuit breakers and fuses) are selected to interrupt the maximum available fault currents present at the motor control center. Additionally, these devices operate the quickest at higher values of current. In past years, engineers designed systems such that the trip time for the overcurrent device feeding the motor control center was between the maximum allowable withstand rating of the motor control center and the trip time of the breaker directly upstream of the fault. This allows the upstream breakers to interrupt the fault and maintains the breaker feeding the MCC closed. This conservative approach to system coordination has the adverse effect of slowing the response time of the breaker feeding the motor control center.

Conservative system coordination is diametrically contrary to arc-flash energy mitigation. That is not to say that both system coordination and minimizing arc flash cannot be accomplished. Also, it should be noted that a conservative fault current value might not provide the "worst case" arc-flash condition. In many cases, calculations of arc-flash hazard based upon conservatively high available fault current values can underestimate the actual flash hazard at circuit locations.

The advent of electronic trip units, high-speed grounding circuits, zone selective interlocking, and more sophisticated selective coordination software tools provide today's engineer with improved methods to arrive at the best available design. Another recent development, which offers both system coordination and the ability to lower the available arc-flash current, is an "Arc-Flash Reduction Maintenance System™" (ARMS). When properly applied, the maintenance system reduces the trip time of a power circuit breaker and can reduce the risk category in an MCC dramatically. In some cases the ARMS can reduce the arc flash risk category from a Category 3 to a Category 0 without nuisance tripping. [10]

The final factor (C) Distance of the worker from the arc...NFPA-70E has defined the arc-flash boundaries as follows.

TABLE 1. ARC-FLASH BOUNDARIES

BOUNDARY	DESCRIPTION
Prohibited Approach Boundary	A shock protection boundary only to be crossed by qualified persons. When crossed, the same protection is required as if direct contact is made with the live part.
Restricted Approach Boundary	A shock protection boundary to be crossed by only qualified persons. When crossed, the use of shock protection techniques and equipment is required.
Limited Approach Boundary	A shock protection boundary not to be crossed by unqualified persons unless escorted by a qualified person.
Flash Protection Boundary	Distance at which the incident energy level equals 1.2 cal/cm ² for faulting clearing time greater than 0.1 seconds. Use 1.5 cal/cm ² for clearing times that are 0.1 seconds or faster.

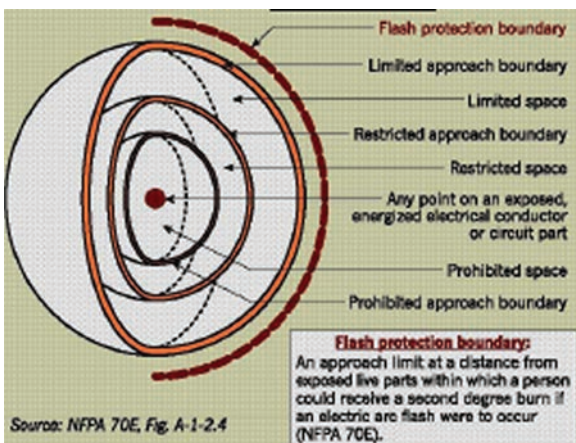


FIGURE 2.

The last two hazards, Arc-Blast Impacts and Falls, are typically the most overlooked aspects of total electrical safety, and not directly addressed by NFPA- 70E. Some describe the resultant ejection of molten metal or shrapnel traveling at a very high rate of speed to be as dangerous as a hand grenade blast. The approved PPE for arc flash will not protect the person standing in close proximity to the blast from these hazards. It would be impractical to require operators to don impact-resistant equipment in addition to the flame-resistant clothing. The best method of protection is either distance or a protective barrier, such as the unit door.

One possible solution in use in medium and low voltage switchgear is a remote racking mechanism. A device, typically a slow speed motor, connected through a shaft to the racking mechanism of the breaker. Utilizing this technology would keep an operator at a safe distance from the motor control center. The engineering challenge becomes the racking mechanisms, which require some sort of feedback to prevent overtorquing and damaging the racking mechanism.

A motor control center needs to offer solutions to address all of the electrical related hazards. Motor control center design features, when used in conjunction with sound engineering safety practices, can not only drastically reduce the probability of an incident and injuries, but also reduce costly downtime.

Arc-Resistant Design

In an attempt to address arc-flash hazards, the industry developed ANSI C3720.7, which provides testing standards for "Arc Resistant Switchgear." The standard addresses internal arcing faults on metal-enclosed switchgear rated up to 38 kV. The equipment tested to this standard has proven to protect against the effect of abnormal internal pressure or "arc-flash," as long as all the doors and access areas are properly secured [4]. However, motor control centers, more than distribution switchgear, are routinely accessed for a variety of reasons; such as adjusting trip settings, replacing fuses, adding motor loads or troubleshooting. Unlike much distribution equipment, access to the interior of the unit buckets is required to make such adjustments. Constructing a motor control center to pass the aforementioned ANSI standard does not address all of the electrical hazards, and does not provide the highest level of personnel protection. When covers are removed or breaker doors are open is exactly when most accidents occur. Most likely the arc will be created in the vicinity of where the person is working. Maintaining a deadfront barrier, i.e., the unit door closed whenever possible, and removing voltages and potential arc energy outside the unit with the door open, is a more sound and practical solution.

Laboratory Testing



FIGURE 3. DOOR OPEN

- Per IEEE P1584: Test conducted at Beaver, PA laboratory 9/20/06.
- Location of source: Shorted vertical bus behind the unit.
- Duration: 3 cycles, 60 Hz.
- Available current: 100 kA.
- Results: Risk Category 1 with door open.

The calorimeter is placed at a distance of 18 inches from the door opening.



FIGURE 4. DOOR CLOSED

- Per IEEE P1584: Test conducted at Beaver, PA laboratory 9/20/06.
- Location of source: Shorted vertical bus behind the unit.
- Duration: 3 cycles, 60 Hz.
- Available current: 100 kA.
- Results: Risk Category 0 with door closed.

TABLE 2. RESULTS OF MCC ARC-FLASH TESTS — 100 KA, 480 V, 3-PHASE FOR 3 CYCLES, 60 HZ

TEST	MCC STATUS	INCIDENT ENERGY (CAL/CM2)	ARC CURRENT (KA PEAK)
1a	MCC Door Closed	0.1	25.1
2a	MCC Door Open	0.7	29.64
3	No Bucket, Door Open	3.3	31.44
1b	MCC Door Closed	0.3	36.4
2b	MCC Door Open	0.8	38.22

Conclusion

Comprehensive electrical safety as it relates to electrical distribution gear, and low voltage motor control centers that incorporate the additional design features identified in this paper, provide a product that more than satisfies NFPA-70E and provides more user features than simple "Arc Resistant" design. There are more hazards to the electrical worker than thermal energy. NFPA-70 Article 340.7 states that an employer is responsible for providing training and supervision by qualified personnel to:

- Explain the nature of the hazard.
- Develop strategies to minimize the hazard.
- Provide methods to avoid and protect against the hazard.
- Convey the necessity of reporting any hazardous incident.

Future motor control center designs and safety features need to address all the potential hazards. The features should address both prevention and mitigation of electrical hazards and at a minimum should include the following:

1. Insulated vertical and horizontal bus.
2. Shrouded unit (bucket) stabs.
3. Positive ground connection.
4. Touch-safe voltage test station (unit door closed).

5. Visual means to detect if units are disconnected from vertical bus.
6. Door closed unit (bucket) racking mechanism and indicators.
7. Testing to certify risk Category 0 with door closed.
8. Testing to certify doors remain closed on maximum fault.
9. Mechanism to eliminate the need or ability to manual insert units on to a live vertical bus.
10. Unit "Test" position — control power only. No electrocution or arc-flash voltage potential present inside the unit (bucket).

Most of these features exist today in various products throughout the electrical industry and have proven to be reliable and effective means of providing enhanced electrical safety.

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