White Paper

Arc-Flash Resistant Low Voltage Motor Control Center Designs

Recently, the benefits of arc-flash resistant designs for Low Voltage Motor Control Centers (LV MCCs) have become a much recognized topic. This notoriety has been driven by new requirements in the National Electrical Code NFPA 70-2002 (NEC), Standard for Electrical Safety Requirements for Employee Workplaces NFPA 70E-2004 (NFPA 70E) and the IEEE. The intent of these arc-flash resistant designs is as follows:

1. Should an abnormality occur causing an arc-fault within a LV MCC, it becomes necessary that the equipment's enclosure contain the majority of the arc energy.

2. There would be a lowering of the arc energy to minimize the potential for injury to personnel standing near the equipment.

As background, arc-flash resistant designs originated some years ago in the IEC world for medium voltage (MV) equipment because the arc-flash energy and the resulting hazard is more substantial, due to the higher voltage potential in MV gear (1000V or higher). This work resulted in the development of MV arc-flash standards [1-Re IEC 298]. However, recent arc flash resistance research is also being carried out as a result of "ongoing improvements in safety;" work by technical societies such as the IEEE; work by working groups for NFPA 70E and work by manufacturers. The result of this effort has recognized there can be improvements in the arc flash protection for personnel required to work on LV MCCs. The following safety improvements have been incorporated:

1. Today's safety standards now stipulate:

   - Proper training of qualified personnel.
   - Requirements for arc-flash energy calculations in order to determine the arc-flash hazard/risk potential.
   - Marking of electrical equipment to specify the Protective Clothing and Personal Protective Equipment (PPE) that must be worn to protect the worker from the hazard, e.g. double-layer-switching hood, heavy flash suit, etc.

2. The introduction of arc-flash resistant designs for LV MCCs, which improves the arc-flash containment and may also allow the equipment to carry a lower Hazard/Risk Category Classification. This in turn allows a reduction in the requirement of wearing some of the cumbersome/restricting PPE.

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The following "Failure-Tree Analysis" has been developed to better understand the arc-flash hazard/risk potential for LV MCCs. The LV MCC operating condition, postulated failure scenario, risk assessment and the potential hazard to personnel are defined in the following analysis. The postulated failures are listed in order of most likely to occur to least likely to occur. Risk assessment and hazard to personnel are defined as: extremely high, very high, high, medium, low, very low and extremely low with extremely high being the highest risk/hazard and extremely low being the lowest risk/hazard.

Operating Condition I - Passive

Personnel Activity:	LV MCC units are operating; carrying load; no manual switching by personnel; all doors are closed and latched.
Postulated Failure:	Field-cable connection failure; component reaching end of life; short-circuit protective device failure.
Risk Assessment:	Extremely low. Chance of arc-flash occurrence is extremely low. If the equipment has been type-tested and meets all the necessary requirements, an arc-fault would be most unlikely. Additionally, with preventive maintenance, risk is reduced further, e.g. infra-red imaging and service inspections, etc.
Potential Hazard to Personnel:	Extremely low, due to the extremely low risk assessment. Also, the arc-flash hazard risk is further reduced as the proximity of personnel to the equipment may be limited due to the passive LV MCC operating condition. In many instances, in the case of an arc-fault, the arc energy would be limited by the unit short-circuit protective device.

Operating Condition II - Active, Normal Operation

Personnel Activity:	LV MCC units are operating; carrying load; manual switching by personnel (opening or closing of the disconnecting means) is occurring at the unit, all doors are closed and latched.
Postulated Failure:	During operation of the disconnecting means or contactor, a failure occurs, a part breaks loose and contacts an energized part; field-cable connection failure; component reaching end of life; short-circuit protective device failure
Risk Assessment:	Very low. Chance of arc-flash occurrence is very low. If the components and mechanisms have been type-tested and meet the minimum life requirements in the safety standards, (UL, CSA), an abnormality should not occur. If a switch is used beyond its normal life, a mechanism failure may occur. Additionally, with preventive maintenance, risk is reduced further, e.g. infra-red imaging and service inspections, etc.
Potential Hazard to Personnel:	Very low, due to the very low risk assessment. However, there is a greater hazard when closing a disconnecting device as compared to opening a disconnecting device. The arc-flash hazard risk is increased because of the proximity of personnel to the equipment during LV MCC operation. In many instances, in the case of an arc-fault, the arc energy would be limited by the unit short-circuit protective device.

Operating Condition III - Active, Normal Operation after Unit Maintenance

Personnel Activity:	Maintenance has been performed on the unit and manual switching by personnel (closing of the disconnecting means) is occurring at the recently maintained unit. Other LV MCC units are operating, carrying load, all doors are closed and latched.
Postulated Failure:	Maintenance personnel inadvertently leaves a wire or tool in the unit which contacts an energized part; during operation of the disconnecting means or contactor, a failure occurs, a part breaks loose and contacts an energized part; field-cable connection failure; component reaching end of life; short-circuit protective device failure.
Risk Assessment:	Chance of an arc-flash occurrence is very low, but more likely than Operating Condition II. If the maintenance personnel are qualified, properly trained and use care, this should not occur. If the components and mechanisms have been type-tested and meet the minimum life requirements in the safety standards (UL, CSA) an abnormality should not occur. If a switch is used beyond its normal life a mechanism failure may occur. Additionally, with preventive maintenance, risk is reduced further, e.g. infra-red imaging and service inspections, etc.
Potential Hazard to Personnel:	Very low, due to the very low risk assessment. The arc-flash hazard risk is increased over Operating Condition II because of the proximity of personnel to the equipment during LV MCC operation. In many instances, in the case of an arc-fault, the arc energy would be limited by the unit short-circuit protective device.

Operating Condition IV - Active, Maintaining a De-energized Unit while plugged into the LV MCC

Personnel Activity:	Maintenance is being performed on the unit by qualified maintenance personnel with the unit disconnecting means open and the unit door open. Other LV MCC units are operating, carrying load, all other doors are closed and latched.
Postulated Failure:	The maintenance person inadvertently comes in contact with an energized part on the line side of the disconnecting means, possibly while checking voltage with a probe.
Risk Assessment:	If the disconnecting means is equipped with a line terminal guard, the chance of an arc-flash occurrence is very low, but more likely than Operating Conditions II and III. If the disconnecting means is off and the line side of the disconnecting means is guarded, it should be very difficult to cause an arc-fault. If the disconnecting means is not equipped with a line terminal guard or the line terminal guard has been removed for the purpose of checking voltage then the chance of an arc-flash occurrence is low because it is more likely that an energized part may be contacted. However, if the maintenance personnel have been properly trained and use care, this should not occur.
Potential Hazard to Personnel:	High due to the proximity of the personnel working on the equipment with the door open. Although the risk assessment is very low, if an arc-fault does occur under this condition, the hazard would be very high. The wearing of proper PPE is imperative.

Operating Condition V - Active, Maintaining an Energized Unit while Plugged into the LV MCC

Personnel Activity:	Maintenance is being performed on the unit by qualified maintenance personnel with the unit disconnecting means closed and the unit door open. Other LV MCC units are operating, carrying load, all other doors are closed and latched.
Postulated Failure:	The maintenance person inadvertently comes in contact with an energized part in the unit, possibly while checking voltage with a probe or changing fuses.
Risk Assessment:	Chance of an arc-flash occurrence is medium, more likely than all other previously listed Operating Conditions. Working on a LV MCC unit live is not good practice. If the disconnecting means is on, there will be numerous energized parts that the maintenance personnel might accidentally come in contact with and cause an arc-fault. However, if the maintenance personnel have been properly trained and use care this should not occur.
Potential Hazard to Personnel:	Very high due to the proximity of the personnel working on the equipment with the door open and the unit energized. The risk assessment is medium and if an arc-fault does occur under this condition the hazard would be very high. The wearing of proper PPE is imperative. In many instances, in the case of an arc-fault, the arc energy would be limited by the unit short-circuit protective device.

Common Arc-Flash Questions

How can arc-faults be avoided?

The best way to avoid arc-faults is to only service equipment when all power has been removed. If an LV MCC unit must be worked on while still plugged into energized bus, it is important to have the disconnecting means open and locked out. The disconnecting means should have an effective line terminal guard to prevent any accidental contact with a live part. If at all possible, the unit should be un-plugged for servicing. Some LV MCCs have a provision for a service position where the unit can be un-plugged from the bus and locked out in the service position while still being located in the LV MCC. Before putting the equipment back in service make sure that all foreign objects have been removed from the equipment.

It is also important to maintain the disconnecting means and the associated operating mechanism. The disconnecting means and the associated operating mechanism should be inspected periodically and replaced if excessive wear is present. Disconnects and operating mechanisms may need to be lubricated periodically. Follow manufacturer's instructions for lubrication guidelines. Applications considered to have a high number of electrical/mechanical operations require the user to be aware of the estimated life of the disconnecting means and the number of operations the disconnecting means has seen. The minimum required life varies by rating but can be found in UL 98

which applies to disconnect switches and UL 489 which applies to circuit breakers.

When an arc-fault does occur, what is the desired outcome?

If an arc-fault should occur, it is of the utmost importance to protect personnel in the immediate area of the fault. Secondly, it is desirable to keep equipment damage to a minimum. The best way to accomplish both of these goals is to interrupt the fault as quickly as possible. Generally, if the fault is interrupted in less than two cycles, the damage to the equipment is not extensive.

Based on the NFPA 70E Flash Protection Boundary formula (B-2-3.2) the following will better explain the importance of a short interruption time:

$$D_c = (2.65 \times \dot{MVA}_{bf} \times t)^{1/2}$$

D_c = distance in feet from arc source

MVA_{bf} = bolted fault at the point involved (i.e. the RMS available short circuit current in amperes (A), the system voltage (V) in mega units (M).

t = time exposure to the arc

D_c is basically a type of measurement of the "flash/burn energy." It can be seen that the flash energy is directly proportioned to voltage, current and time. The system voltage "V" would be fixed for the application. However, the current and time values can be affected by the application design and the selection of the protective devices. These devices can substantially reduce the time "t" as well as reduce the let-through current and thus, reducing current "A."

If the fault occurs on the load side of the LV MCCs unit short-circuit protective device, the arc-fault should be interrupted relatively quickly. Normally, within a LV MCC unit, the protective device will have a relatively low current rating. Therefore, it will interrupt the fault relatively quick less than a half-cycle. Certainly, this is dependent upon the size and speed of protective device, e.g., with current limitation both the current "A" as well as the time "t" is reduced. For example, a 200A fuse will interrupt (clear the fault) much faster (lower i^2t) than a 2000A fuse.

If the fault occurs on the line side of the unit short-circuit protective device, the upstream short-circuit protective device should interrupt the fault. Tests have shown to be able to quickly and effectively interrupt an arc-fault, the protective device should be no larger than 1200A, as

devices larger than 1200A may take up to 6 cycles to interrupt the fault, i.e., long interruption time for "t." This recommendation is based on 65,000A available fault current (MVA_{bf}) with the actual arc-fault current drawing approximately 30,000A, i.e., the available fault current is reduced by the impedance from the arc and the actual arc-fault current is reduced. It is also important to avoid adding time-delay to the protective device. The longer the arc-fault lasts the greater the chance of injury to personnel and damage to equipment, i.e., "t" is increased.

What is the best way to protect personnel from injury during an arc-fault?

It is imperative when servicing equipment to always use the proper PPE in accordance with NFPA 70E and the marking on the equipment.

The disconnecting means handle should only be operated with the door closed and latched. When operating a disconnecting means, it is recommended that the operator not stand directly in front of the equipment. Rather, the disconnecting means handle should be operated from the side, usually with the left hand, if the handle is located near the right hand side of the equipment. If possible the operator should stand at a distance of at least 18 inches from the LV MCC.

Finally, to reduce the chance of injury, in case an arc-flash does occur while manually operating the disconnecting means, it is advisable to use an arc-flash resistant LV MCC. An arc-flash resistant LV MCC would be equipped with features designed to limit or contain the arc-flash energy, such as, arc-flash resistant latches on the doors.

Obviously, if the equipment is being worked on with the door open, arc-flash resistant latches provide no value. If an arc-fault occurs with the door open the only protection would come from interrupting the fault as quickly as possible and the use of proper PPE in accordance with NFPA 70E. To emphasize the point, protective devices no larger than 1200A will offer better protection than larger protective devices, obviously an 800A protective device would be better than a 1200A protective device. Also, these protective devices should be fast acting, for example when specifying fuses, the faster acting fuses will offer better protection than slower fuses. Finally, time delays should be avoided if at all possible.

What is the benefit of LV MCC arc-flash resistant enclosures?

There is some benefit to using arc-flash resistant enclosures on LV MCCs. Although arc-faults are relatively rare, they can occur. An arc-flash resistant enclosure would help protect personnel in the vicinity of the equipment if the arc-fault occurs when the doors are closed and latched. Arc-faults caused by personnel working within the equipment are much more common, and in these cases the arc-flash resistant enclosure would be of no benefit.

Arc-Flash Enclosure Rating

One other arc-flash topic worth discussing is the actual rating of the arc-flash resistant enclosure. There can be different ratings for arc-flash resistant enclosures based on energy levels and time. For example, an arc-flash resistant enclosure may be rated to withstand an arc-fault with 65,000A available at 480V for 200ms. In this example where there is quite a long time specified, 200ms, the enclosure will have to be built to withstand the pressures and may have to incorporate means for venting the gases. Obviously, the longer the arc-fault must be contained, the more robust the equipment will have to be, and this will affect the design and cost. Also, if the arcing would actually last 200ms, damage to the equipment would be extensive and the equipment would likely have to be replaced.

A long time withstand requirement would only be necessary if there is a large protective device, no protective device or a time-delay associated with the protective device. An arc-flash resistant enclosure may also be rated to withstand an arc-fault with 65,000A available at 480V when protected by a specified protective device, e.g., 1200A maximum Class L fuse or circuit breaker. If the protective device is chosen and sized with arc-flash protection in mind, the arcing could be interrupted in less than 2 cycles. If this was the case, the arc-flash resistant enclosure may not need to be as robust and probably would not require special features. Also, if an arc-fault would actually occur, the damage to the equipment may not be too extensive and the equipment might not have to be replaced. The method of using a specified protective device also has the advantage of reducing the arc-flash hazard for those cases where the equipment is serviced live.

Summary

An arc-flash resistant enclosure is only effective for arc-faults that happen with the door closed and latched. When the equipment is properly maintained and serviced by trained electricians, an arc-fault occurring with the door closed should be very rare. However, if an arc-fault occurs, the sooner it can be interrupted (shortest clearing time) the better (reduced flash hazard). There will be less chance of injury to personnel and damage to the equipment can be minimized. The large majority of arc-faults happen with the enclosure door open, when someone inadvertently causes a phase-to-phase or phase-to-ground fault with a tool or a probe. In this instance, the arc-flash resistant enclosure is of no value and interrupting the fault as quickly as possible and using the proper PPE are imperative.

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