Allen-Bradley
by **ROCKWELL AUTOMATION**

Adding additional layers of personnel safety to UL 347 Motor Control Centers

Integrated protective maintenance grounding

An integrated protective maintenance grounding solution from Rockwell Automation for medium voltage motor control centers provides a grounding system to increase load terminal safety for personnel

Scope and background

Within the scope of UL 347 [1] compliant Medium Voltage Motor Control Centers (MV MCCs), the purpose of grounding is to reduce the risk of electrocution during operation and maintenance procedures. By placing all easily accessible medium voltage components within the controller at a ground potential for maintenance, incident voltages can be redirected to ground instead of through a person.

Today's UL 347 safety standard does not directly address the safety concerns related to the load terminal connections within a controller. Electrocutions are the third leading cause of fatalities, based on the latest U.S. OHSA "Fatal Four" listings. All workers must stay away from motor control structures before proper verification of the presence of voltage and ultimately the application of temporary equipment grounding. Anytime doors or panels are opened, there is the opportunity for energized components to be exposed, creating a risk of electrocution.

In UL 347, section 5.3 "Provisions for protective grounding," it does not specifically call out any specific details regarding provisions for the grounding of load terminals. The solution from Rockwell Automation is an integrated grounding device in the MCC to drain parasitic voltages from the load terminal connection, eliminating the need to add temporary safety devices such as utility style grounding balls.

The use of utility grade grounding balls and temporary grounding assemblies is hazardous, cumbersome and time consuming for users to apply. Plus, one large North American petroleum and chemical company determined that some grounding balls were failing (breaking) under normal use.

Some suppliers offer methods to drain residual voltages from load terminals using a special control circuit modification, see an example in Figure 1. This method requires a special control circuit modification, a separate source of control power and a test mode using a three-position selector switch (On-Off-Test).

However, medium voltage fuse elements are in the circuit path to ground. So, this method does not provide a solid or lowest path-to-ground or can it be defined as a 'safety' ground. This method injects the possibility of an open circuit on one or more phases if a fuse is cleared (open circuit). Although this method is applied by some users, it cannot be relied upon as a trusted fail-safe method for the reduction of voltage hazards at the load terminal connections. A better solution is required.
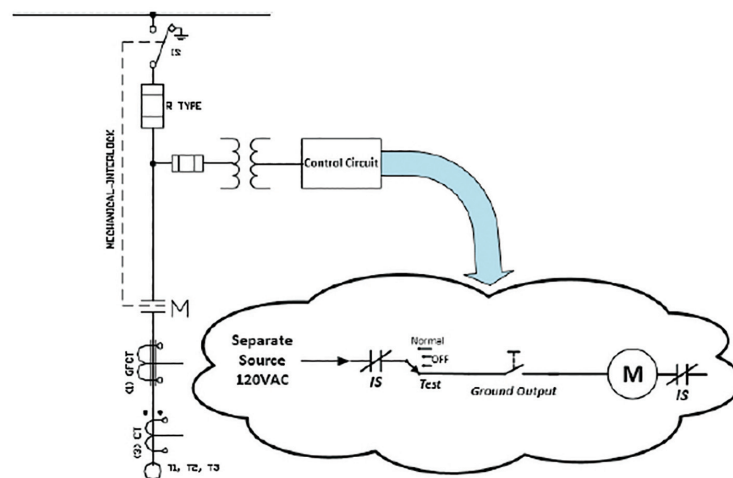
Figure 1: A current method of providing load terminal grounding

Many utility-based methods for applying temporary load cable grounding, such as grounding cable assemblies attached to grounding balls, require a detailed multi-step procedure to apply – especially when used within an MV MCC. The procedures require many steps to establish a safe work environment, are time consuming and the processes inject significant potential for human error.

Because of their inherent small cabling compartments, compared to ANSI/IEEE C37.20.2 [2] metal enclosed switchgear, the use of temporary grounding methods attached to the load terminals within medium voltage MCCs can become challenging and impractical to use due to the limited accessibility. Inappropriate use of these devices poses even more risks to maintenance personnel.

The safer solution

A recently developed solution from Rockwell Automation is an Integrated Protective Maintenance Grounding (IPMG) device for MV MCCs to remove dangerous electric potential at the load terminals. This integrated mechanism redirects harmful residual voltages from the load side of the vacuum contactor, including the connected motor and its connecting cables, to a solid low impedance ground path to the system ground. It works independent of any requirements to supply separate sources of energy and requires no control circuit modifications to support its inclusion. Plus, it does not require entry into the controller to be activated.

This new integrated grounding device removes the need to expose personnel to energized equipment by grounding current carrying elements before any panels, doors or covers are removed. The overall details and supporting technical details are described in a technical paper. [3]

This IPMG device facilitates the shorting of the load terminals and all connected cables exiting the motor controller to a ground potential before and without opening or removing doors, panels or covers. The device electrically connects to ground, all conductive load terminal parts and components on the load side of the main switching contactor of the motor controller. This system permits maintenance personnel to remove energy potential on the load side of the integral medium voltage contactor, within the motor control center.

The IPMG device offers significant benefits: simple to operate, easy to secure during lockout/tagout procedures, and added safety protection through the grounding the load cables. This is all accomplished without exposing personnel to any exposed energized parts.

This enhanced operational mode gives personnel operating and maintaining MCCs visual verification of a rigid shorting path on the load side connections without opening any compartments. With a standard viewing window, a visual position indication provides compliance with UL 347 and other safety and user site specific standard requirements.

The application of this safety device also creates an "equipotential zone," as described in OSHA 1910.269(n)(3), in which maintenance personnel may work. OHSA defines an Equipotential Zone as one where temporary protective grounds are placed at such locations and arranged in such a manner that the employer can demonstrate that it will help prevent employees from being exposed to hazardous differences in electric potential.
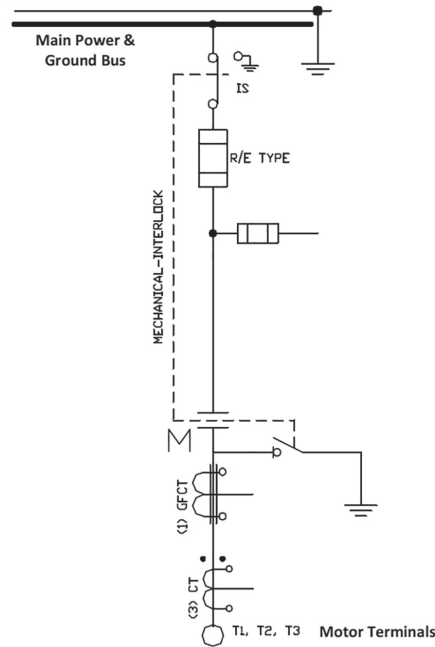
By specifying this optional IPMG device, users of UL 347 based medium voltage MCCs demonstrate to their maintenance teams they are serious about personnel safety and equipment protection.

Important considerations for implementation:

1. The IPMG device supports the rated insulation levels outlined in the 6th edition (and future editions) of UL 347. Impulse test voltage (BIL) and the power-frequency withstand tests are the same levels as the rest of the controller is expected to withstand. Levels are outlined in Table 1 of UL 347.

2. An effective mechanism is used to bond the IPMG device's blades (three) to a common grounded portion on the structure and to the main ground bus of the motor controller. All blades are mounted on a common conductive shaft that will be a common low-resistance copper conductor. This common conductor is attached to the motor controllers grounding plain using a #2 ground wire. It may also be attached at two points, for redundancy, when specified.

3. To reduce the risk of arcing, the device has a quick make action.

4. A rugged mechanical and electrical interlocking scheme is used to help prevent closing the safety device while the motor controller is under normal operation meaning the main isolation switch is closed. (See Fig. 2…5 and Table I)

5. The robust IPMG device construction withstands the mechanical forces associated with the possible level of currents that could be seen on the load terminals of the motor controller. Any current expectations at this point are very low as the motor load will have already been disconnected. Because the closure of the IPMG requires multiple steps to accomplish, and the motor speed will be well below rated speed and in most cases, the motor will have coasted to a stop. See section for expectations of load influences to this point in a medium voltage controller.

6. The IPMG device is capable to support the system voltage and any small residual fault current at its point of use in the motor controller. Unlike the use of earthing switches in switchgear applications, there is little chance of high and sustained short circuit currents since the motor will not be rotating at or above rated speed.
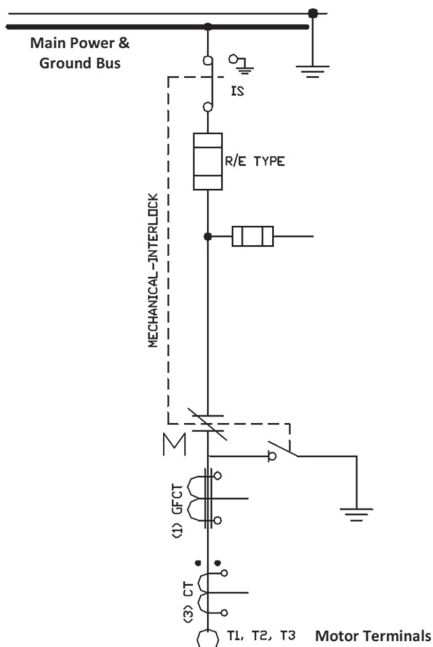
Figure 2: Motor connected and operating   **Figure 3: Main contactor opened**
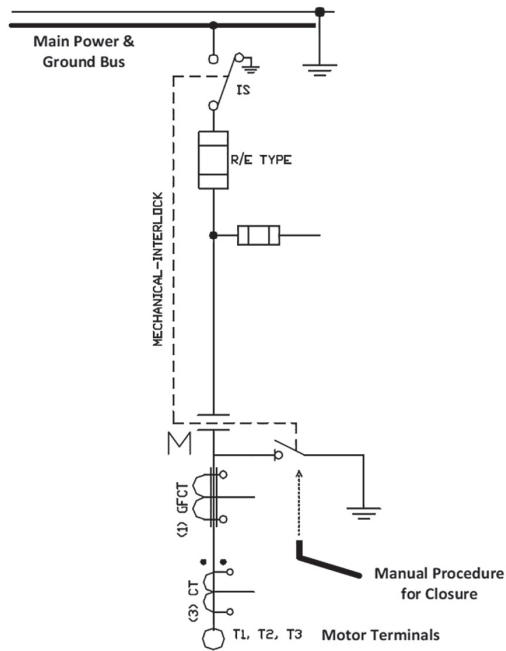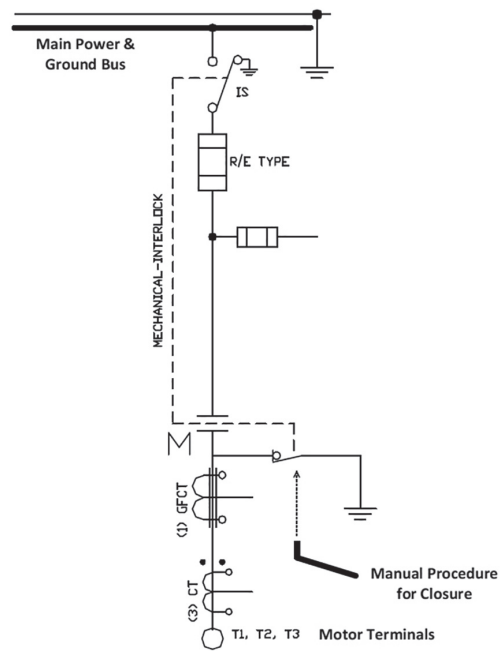
Figure 4: Isolation switch and contactor opened

Figure 5: Isolation switch and contactor opened load terminal grounding device engaged

Operational truth table

Isolation switch position	Main MV contactor position	Integrated protective maintenance grounding device position	Notes regarding operational modes
Open	Open	Open or closed	IPMG device can be closed or opened
Closed	Closed	Open	IPMG device cannot be closed
Closed	Open	Open	IPMG device cannot be closed
Open	Open/closed*	Open/closed*	IPMG device can* be moved from open to closed
Cannot be closed if IPMG is closed first	Open/closed*	Closed	When the IPMG is in the closed position, the isolation switch cannot be closed. A mechanical interlock key may also be specified optionally to lock these devices

* In some maintenance positions, meaning the isolation method (switch) is placed in the open position, the main contactor may be closed under test conditions while the IPMG device is closed, assuming the mechanical and electrical interlocking are configured to permit.

Supporting technical information / Q&A

How much voltage could be expected at the load terminals of a UL 347 listed Medium Voltage MCC?
Based on the operational methodology of the IPMG device, the terminal voltage within the controller should be very low, negligible in most cases. The expectations are the voltage levels would only be those related to parasitic voltages associated with the medium voltage cables or a portion of the system voltage as the motor decelerates or when an induction motor has the possibility of being driven to a speed more than its synchronous speed. The intent is to ensure a low path to ground and potential energy levels at the load terminals of the controller.

Load variations

Inertia – The higher inertia of the load on the motor, the more slowly the motor frequency decays during the disconnected coast-down period. This has a direct impact on how fast the phase angle changes. On low inertia loads, the phase angle changes quickly. As the frequency of the field in the motor decays quickly, the slip frequency between the motor voltage and the original source increases quickly. The induced energy levels, considering the time to properly remove power to the motor, open the main isolation device and engage the load terminal IPMG device will be low.

Motor size – The larger the motor size, the longer the time the voltage will take to decay on an induction motor. This is dictated by the motor frame size and stator style (number of poles) and ultimately the rotor material and size. However, the open circuit time constant, even of very large frame devices, is quick – in most cases, a few power cycles.

Synchronous versus induction motors – Motor voltage will tend to decay much more rapidly on induction motors versus some synchronous machines. When the power is removed from the stator of the synchronous, the rotor is typically shorted through the discharge resistor. Some synchronous motor configurations may attempt to hold up the induced voltage longer but, in general, the time constant does change much. It is mostly the inertia of the rotor that has the most impact.

Loading – The larger the load on the motors, the faster the motor frequency and voltage will decay.

The IPMG device is directly mechanically interfaced to the main isolation device and the vacuum contactor, so it can only operate (Close or Open) when the main isolation device switch is the open position. With the isolating device open, there will be no source of energy from the main power bus line. Closing the IPMG is a two-step process: 1) Opening the main isolation device switch and 2) Closing the IPMG (with a separate handle than the mechanism used to operate the main isolation device switch).

The physical time taken to accomplish normal load isolation – open the main isolation switch and the associated medium voltage contactor – would take much longer than the open circuit decay rate of almost all an induction motor spinning down in speed.

Some generalizations can be made as to the effect of motor type, size, and load characteristics on the frequency and voltage decay of the motor terminal voltage, due to the aggregate effects of the connected motor.

Larger motors generally take a longer time for the voltage to decay on an induction motor (also influenced by the number of poles). Longer in relationship to smaller frame and horsepower induction motors. This is still a relatively short time – usually less than three to five seconds. The larger the driven load, the faster the motor frequency will decay, assuming there is no chance of the load rotating the load above rate speed.

The higher the load inertia of the motor and its loads, the more slowly the frequency in the motor will decay during the coast down period. This has a direct effect on how fast the phase angle changes.

Low inertia loads will cause the phase angle to change quickly, as the frequency of motor decays quickly, and the slip frequency in the motor quickly increases (inertia-stored energy). See Figures 6, 10 and 11.

The magnitude and frequency of the voltage induced in the rotor at any speed, between the extremes of locked rotor (100% slip) and rated speed (low % of slip), are proportional to the slip of the rotor.

Synchronous motors will attempt to hold up the voltage during the initial stages of the coast down due to some residual fields left in the rotor, but this also decays quickly.

When a polyphase induction motor is open-circuited while running at rated speed, the rotor flux-linkages generate a voltage in the stator winding. Usually *after as few as 10 cycles*, the motor frequency has dropped considerably resulting in a rotating phase angle difference between the motor and the source from which it was disconnected. The associated voltage at that point also drops exponentially as the motor speed drops below near rated speed (synchronous speed X slip). Several technical papers, associated with Fast Motor Bus Transfer techniques, illustrate how quickly the motor's ability to retain voltage decays. [3][4][5][6][7][8][9][10]

This time is defined as the Open-Circuit AC Time Constant, Toc, (also called Tau). The "open circuit" time constant for a motor is the time it takes for the voltage at the motor terminals to reach 37% of the system base or rated motor voltage, when the motor is open circuited.

This time can be calculated using the formula with data from the motor characteristics:

$$T_{do} = \frac{X_m + X_2}{2\pi f r_2}$$

T_{do} = Seconds
r_1 = Stator DC resistance per phase corrected to operating temperature
r_2 = Rotor resistance per phase at rated speed and operating temperature referred to stator
X_1 = Stator leakage reactance per phase at rated current
X_2 = Rotor leakage reactance per phase at rated speed and rated current referred to stator
X_S = Total starting reactance (stator and rotor) per phase at zero speed and locked-rotor current
X_m = Magnetizing reactance per phase
LL_s = Fundamental-frequency component of stray-load loss in kW at rated current
kW1 = Stator I^2R loss in kW at rated current and operating temperature
f = Rated frequency, hertz
s = Slip in per unit of synchronous speed

These values can be derived from the motor data sheet generated by the motor vendor.

$$E_R = \sqrt{E_S{}^2 + E_M{}^2 - 2E_S E_M \cos\theta}$$

Where:

E_R = Resultant vectorial V/Hz
E_S = System equivalent V/Hz
E_M = Motor residual V/Hz (on system base)
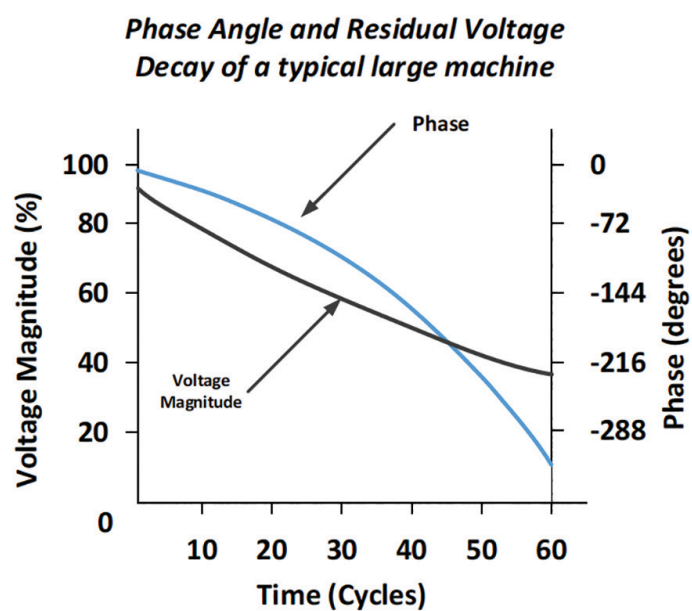θ = The varying phase angle between the motor source and the voltage at the motor terminal

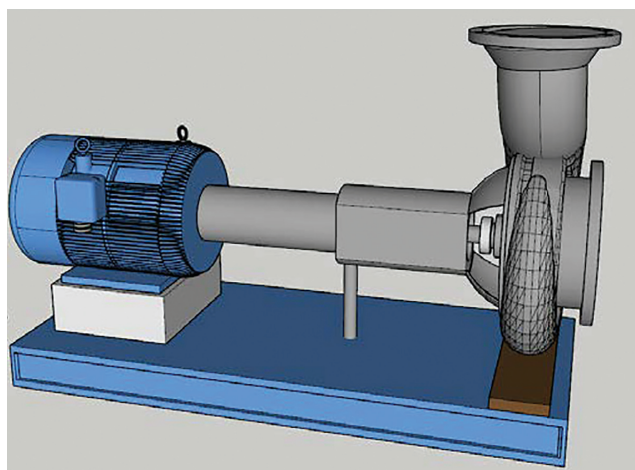Figure 6: Typical voltage decay of a large machine spinning down

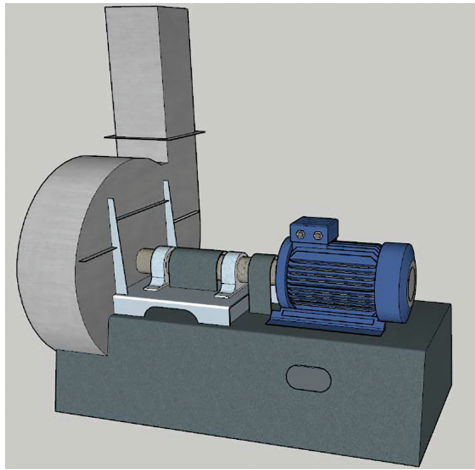Figure 7: Typical centrifugal pump on large induction motor

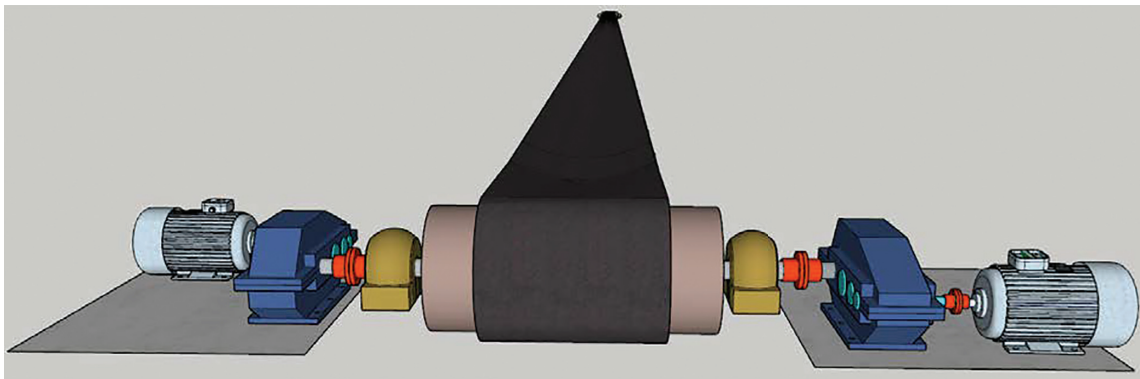**Figure 8: Typical draft fan application with a large induction motor**

Figure 9: Overland-style conveyer on a large tandem induction motor configuration
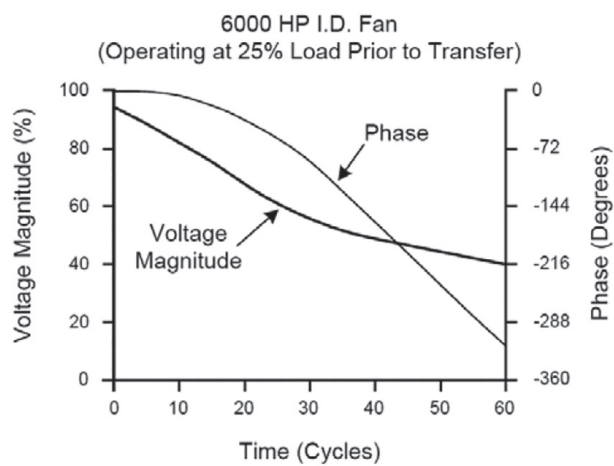

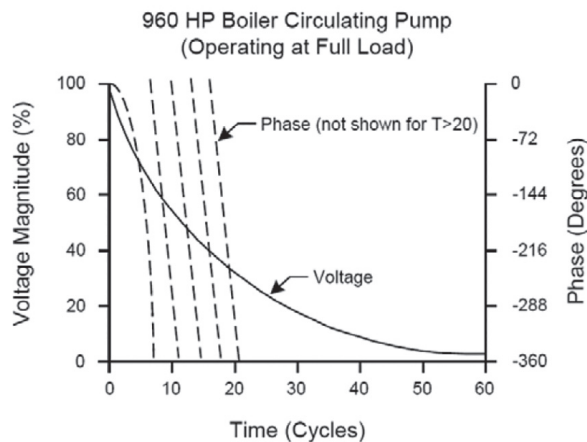**Figure 10: Typical coast-down of high inertia load on a large induction motor**

Figure 11: Coast-down of low inertia load on a typical induction motor load

Summary of use (operating procedure) for the IPMG device

In UL 347 based motor controllers, one must consider more than just the IPMG device. It is an additional part the overall safety system incorporated within the safety interlocking of the motor control center. Consideration of the application of this device is dependent on at least two methods of employment.

The application steps for these methods, using the IPMG device includes:

Step 1 - Turn off the motor with the Stop push button or via a remote stopping command. Result = contactor will open... motor now be disconnected from MV

Step 2 - Turn off the isolation switch (cannot be done until the contactor is in the Open position) - requires operator intervention and use of the appropriate PPE to accomplish, based on safety standards such as NFPA 70E. No specific purpose PPE is required if the controller is arc resistant, but many sites have a minimum PPE requirement.

The isolation switch handle must be moved from the ON to Off position. Then the user checks for visible isolation through the viewing window.

Alternative #1

Step 3 - (Implementation with a Kirk-style key used to interlock isolation switch to IPMG device.) With the isolation switch open, the mechanical interlock key located above the isolation switch handle can be released and inserted in the partner key block used with the shorting switch. Estimated time is 1.5 to 3 minutes (5400-10,800 system power cycles).

A. Key lock on shorting device is turned to release movement on the shorting device
B. Insert "L-shaped" handle onto shorting device drive shaft
C. Rotate shorting device handle to the full closed position
D. Verify position of shorting switch through viewing windows
E. Using socket wrench, remove the two MV door retaining screws and open MV door
F. Check for the presence of voltage (NFPA 70E requirement)

Alternative #2

Step 3 – (NO Kirk-style key used – direct mechanical interlock from contactor and isolation switch to IPMG device.) Estimated time is 30 seconds to 1 minute (1800-3600 system power cycles.)

A. Insert handle onto shorting device drive shaft
B. Rotate shorting device handle to the full closed position
C. Verify position of shorting switch through viewing windows
D. Using socket wrench, remove the two MV door retaining screws and open MV door
E. Check for the presence of voltage (NFPA 70E requirement)

What happened to the motor during this time? Without medium voltage applied, the motor quickly begins to decelerate. This is a chart used for basic consideration for induction motors spinning down. When a polyphase induction motor is open-circuited while running at rated speed, the rotor flux-linkages generate a voltage in the stator winding. Usually after as few as 10 cycles, the motor frequency has dropped considerably resulting in a rotating phase angle difference between the motor and the source from which it was disconnected. The associated voltage at that point also drops exponentially as the motor speed drops below near rated speed (synchronous speed X slip). This time is defined as the Open-Circuit AC Time Constant, Toc, (also called Tau). The "open circuit" time constant for a motor is the time it takes for the voltage at the motor terminals to reach 37% of the system base or rated motor voltage, when the motor is open circuited. This can be calculated with the motor data sheet.

Taking data from technical papers on fast motor bus transfers, observe and use typical supporting motor data. *Please notice the time scale.*

For almost all loads, the motor will not be generating significant voltage or current by the time the IPMG device has shorted the load terminals, even on high inertia loads. Synchronous motors behave differently as they have different open circuit time constants, but the voltage still decays rapidly.

How much current could be expected at the load terminals of a UL 347 listed Medium Voltage Motor Controller before the IPMG was closed?

Without information regarding the motor or the load, one can assume that the worst-case condition would be the generation of a current equal to the maximum full-load current of the motor. This assumes the IPMG was closed immediately after the main contactor was opened. This is not practically possible due to the sequence of operation. The motor will have been in an open circuited condition before the load grounding device is engaged. This open circuit condition will be hundreds to thousands of power cycles long (seconds to minutes) before the IPMG would be closed due to the sequence of steps required to engage it. The fields in the induction motor's rotor and stator after a few cycles (opposing angles well above their typical slip position) will decay rapidly. See fig. 6 and 11. The mechanical interlocking would help prevent the closing of the main isolation switch and/or main contactor if the IPMG was in the closed position.

The answer depends on many things related to the application, such as motor size, motor type, and load characteristics. Specific system characteristics are required for an induction motor to become a generator. This would require sustained RPM at rated or above rated RPM.

References

[1] UL 347, Medium-Voltage AC Contactors, Controllers, and Control Centers, Edition 6, 2016, Northbrook, Illinois, United States

[2] IEEE C37.20.2-1999 - IEEE Standard for Metal-Clad Switchgear

[3] TAKING MEDIUM VOLTAGE MOTOR CONTROL CENTERS TO NEW LEVELS OF SAFETY, Institute of Electrical and Electronics Engineers (IEEE), Piscataway, New Jersey, United States

[4] Effects of Momentary Voltage Dips on the Operation of Induction and Synchronous Motors, IEEE TRANSACTIONS ON INDUSTRY APPLICATIONS, VOL. 26, NO. 4, JULY/AUGUST 1990, Institute of Electrical and Electronics Engineers (IEEE), Piscataway, New Jersey, United States, 0093-9994/90/0700-0711

[5] MOTOR BUS TRANSFER, A Report Prepared by the Motor Bus Transfer Working Group of the Power System Relaying Committee, IEEE Transactions on Power Delivery, Vol. 8, No. 4, October 1993, Institute of Electrical and Electronics Engineers (IEEE), Piscataway, New Jersey, United States, 0885-8977/9

[6] FAST BUS-TRANSFER TECHNIQUES FOR MAINTAINING FULL PLANT PRODUCTION, Institute of Electrical and Electronics Engineers (IEEE), Piscataway, New Jersey, United States, 89-CH2777-1/89/0000-0229

[7] A NEW FAST BUS-TRANSFER SYSTEM, Institute of Electrical and Electronics Engineers (IEEE), Piscataway, New Jersey, United States, CH2581-7/88/0000-0105

[8] MOTOR BUS TRANSFER: CONSIDERATIONS & METHODS, I&CPS -05-7, Institute of Electrical and Electronics Engineers (IEEE), Piscataway, New Jersey, United States, 0-7803-9020-2/05

[9] Motor Bus Transfer System Performance Testing and the Search for a New Transfer Success Criterion, IEEE TRANSACTIONS ON INDUSTRY APPLICATIONS, VOL. 53, NO. 1, JANUARY/FEBRUARY 2017, Institute of Electrical and Electronics Engineers (IEEE), Piscataway, New Jersey, United States, 10.1109/TIA.2016.2602333

[10] Motor Bus Transfer: Considerations and Methods, IEEE TRANSACTIONS ON INDUSTRY APPLICATIONS, VOL. 42, NO. 2, MARCH/APRIL 2006, Institute of Electrical and Electronics Engineers (IEEE), Piscataway, New Jersey, United States, 10.1109/TIA.2005.863914

Connect with us.