NFPA 70E: Reducing and Eliminating Electrical Hazards through Electrical Equipment Design Considerations

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Abstract - This paper uses the National Fire Protection Association 70E Standard for Electrical Safety in the Workplace (NFPA 70E) as a guide for designing safer and smarter electrical equipment, in particular large horsepower motor starters under 600 volts. In the United States, the Occupational Safety and Health Act (OSHA) and NFPA 70E continuously raise the standard for electrical safety in the workplace; as such, fundamentally changing how employers keep their employees safe and how employees interact with their electrical equipment. It is the employer's responsibility to abide by these safety standards; however, these standards should inspire better electrical designs that ease the employer's burden by reducing or eliminating employee exposure to electrical hazards – the latter should be the main goal of any electrical design. We can accomplish much of this goal by providing employees with maintenance and troubleshooting tools on the outside of energized equipment by using Human Machine Interface touch screens that communicate with internal intelligent components, by isolating power and control components, using permanent electrical safety devices (PESDs) and electric door interlocks. This allows employees to troubleshoot, collect data, and configure motor starter components while it is energized and also eliminates and/or minimizes their exposure to electrical hazards.

Index Terms — arc flash hazards, electrical accidents, electrical design, electrical hazards, equipment manufacturers, motor starter, National Fire Protection Association 70E Standard for Electrical Safety in the Workplace

I. INTRODUCTION

The human tragedy, its effects, and total costs of an electrical accident, especially arc flash hazards and electric shock, are well documented [1]. In the United States, OSHA and NFPA 70E are making great strides to improve electrical safety in the workplace and to promote awareness across all industries [2]. In spite of these efforts, electrical accidents continue to occur on a regular basis [3]. Furthermore, there are still companies that are not aware of or do not understand their legal OSHA obligations to provide employees with an electrically safe workplace.

The NFPA 70E is a company's roadmap to comply with OSHA requirements but it is not a building or design standard for electrical original equipment manufacturers (OEM). Employers and employees must abide by OSHA and NFPA 70E in the workplace – though NFPA 70E advocates for electrical equipment design considerations that will enhance the standard, electrical equipment manufacturers do not share the same obligation. Electrical OEMs follow a different set of standards when building their equipment; for example, NFPA 70 National Electric Code; Underwriter’s Laboratory 508A Standard for Safety: Industrial Control Panels; NFPA 79 Electrical Standard for Industrial Machinery; International Standards IEC 60204 Safety of Machinery; IEC 60364 Electrical Installations for Buildings are common standards. These codes are to protect us when equipment is energized and working under normal circumstances when components and conductors are behind enclosure doors. On the other hand, NFPA 70E is to protect us under abnormal circumstances when we need to work on de-energized as well as troubleshooting energized equipment [4].

As such, most electrical OEMs are building and shipping their equipment everyday to companies that then have to adapt to the equipment they receive. In electrical equipment under 600V, electrical OEMs pay little regard to their customer's NFPA 70E burden or how they will troubleshoot energized equipment. However, there are a few companies that are actually demanding that electrical OEMs consider the safety content of their equipment such when employees need to maintain and/or troubleshoot the equipment when it is deenergized or energized. Companies are asking for help to keep their employees safer, to help them work smarter and to help them with their NFPA 70E requirements.

We will review a few simple design changes to an industrial refrigeration compressor motor starter that is rated under 600V that helps solve many of the safety concerns when working on deenergized and energized equipment. We will contrast the redesigned motor starter to a traditional motor starter and parallel that comparison with a brief review of NFPA 70E requirements. These design change considerations can be easily expounded on and advanced across an array of electrical equipment.

II. ELECTRICAL DESIGN CHANGE CONSIDERATIONS

Much of our electrical equipment is static in nature that once it is energized there is relatively nothing more to its operation than to conduct electricity, protect conductors and distribute power to other equipment. There is little operator interface with this equipment and maintenance is typically performed on an annual basis during planned shut downs;
therefore, any maintenance is performed when the equipment is deenergized in an electrically safe work condition [5]. Any operator interface with energized distribution equipment is normally accomplished through a power metering device mounted through the equipment enclosure; therefore, energized components and conductors are safely behind enclosure doors and panels.

On the other hand, the electrical equipment that we are concerned about, the controllers and motor starters that drive our processes can be very dynamic devices. Unlike panelboards that simply distribute power and provide overcurrent protection, controllers and motor starters need set-up on initial start up, adjustments after start-up and at times troubleshooting on faults or alarms. These activities could expose an operator to electrical hazards and put them at risk of an electrical injury if it is required to enter the equipment while energized [6].

The following recommended design changes are for motor starters in particular and other 480VAC equipment. Many of the motors in the United States operate at 480VAC — this is a common voltage in the United States. Controllers, in contrast, either programmable logic controls or micro controllers, often operate at 120VAC or 24VDC. These lower voltages, though potentially dangerous, are easier to manage safely through the NFPA 70E than is 480VAC. At 480VAC, there are more requirements that must be adhered to and is inherently more dangerous to handle [7].

A. Isolating Power and Control Voltages in Separate Enclosures

In traditional motor starters the main disconnect (or main overcurrent protection device) and starter components are all mounted in the same enclosure. When the main disconnect is in the off position there is still line voltage (normally 480VAC) on the line side disconnect terminals – as such the motor starter is considered, and must be treated as, an electrical hazard per NFPA 70E [8]. Even when the line voltage is removed by disconnecting, locking out and tagging the upstream feeder in the off position it is still considered an electrical hazard until the motor starter is placed in an electrically safe work condition [9]. If it is feasible, the six step process of putting equipment into an electrically safe work condition can be complex and a potentially dangerous task for the employee and employer.

A simple solution is to remove the line side voltage out of the main motor starter enclosure by placing the main disconnect in a separate enclosure adjacent to the main motor starter enclosure. Now when the main disconnect is in the off position the line side voltage is in a separate enclosure and out of the main enclosure.

There are a number of ways this can be accomplished. A practical solution is to mount the main disconnect enclosure onto the main motor starter enclosure. This would increase the width of a traditional motor starter but it would be easier for a contractor to install as they would only need to bring the feeder cables into the main disconnect. The interconnect wiring from the load side of the main disconnect would be done at the factory.

Although the line side voltage is removed from the main motor starter enclosure we still must verify that the load side conductors entering the main starter enclosure are deenergized while also following the proper lock out tag out procedures. Verifying whether voltage is present or not without exposing employees to energized components and conductors will be discussed in the following section.

At times it is necessary to access the motor starter control circuit and components while troubleshooting or monitoring system anomalies. We often need to do this while the motor starter is energized. Again, in a traditional motor starter the control circuit and components are located in the same enclosure with the power circuit and other motor starter components. Accessing the control circuit and components under these conditions exposes the employee to the 480VAC power circuit. To prevent exposure to 480VAC, we can remove the control circuit and components out of the main motor starter enclosure and away from the 480VAC power circuit. This can be accomplished in the same manner as our main breaker solution. We can simply put the control circuit and components in a separate enclosure and have it mounted to the side of the main motor starter enclosure. This greatly reduces an operator’s exposure to higher voltages and significantly lowers the risk of an arc flash event when they need to access the control circuit or components.

Many controls operate at 120VAC or 24VDC. Per NFPA 70E, at 120VAC, the employee is subject to a Hazard/Risk Category 0 [10]. This category greatly reduces the risk of injury and required personal protection equipment that employees must wear. The following clothing and equipment is required for a Hazard/Risk Category 0: a long sleeve shirt

The following design change considerations can be used individually or collectively — though we advocate for using them collectively and migrate toward smarter and safer motor starter solutions.

We will address the following topics:

- Isolating power and control voltages in separate enclosures
- Ease of verifying energized motor starters
- Interlocks to prevent accidental entry into energized equipment
- Provide tools for troubleshooting and set-up outside of motor starters
(non-melting, for example cotton), long pants, safety glasses or goggles, hearing protection (ear canal inserts) and rubber gloves with leather protectors [11]. This type of clothing is likely what operators, maintenance and electricians would normally wear or have readily accessible. This category of personal protection equipment is less expensive, easier to work in and allows the operator to check components quicker as they do not need to suit up in higher arc rated clothing. Once the electrical hazard exceeds the Hazard/Risk Category 0 and enters categories 1-4 the requirements become more burdensome and the electrical hazards more dangerous.

Voltages less than 50 have fewer NFPA 70E requirements and are inherently safer to handle. It would be sensible if we designed all control circuits at 50 volts or less. Our counterparts in Europe use 24VDC on many of their control circuits. At 24VDC there are some drawbacks with voltage drop on high amp loads over long distances but most controls are local to the machines and motor starters – often less than 200 feet (61 m) from the controller [12].

B. Ease of Verifying that Equipment is Deenergized

We have taken the first step of creating a safer motor starter by removing the main disconnect and control circuit and components from the main starter enclosure and placing them in their separate enclosures. The next step is to verify that there isn’t any voltage in the main starter enclosure once the main disconnect is in the off position and locked out. According to the NFPA 70E we still need to follow the six steps to establish an electrically safe work condition – one of the steps is to verify that the equipment is deenergized by testing each phase conductor phase to phase and phase to ground to verify the absence of voltage [13]. In our new solution, with the main disconnect in a separate enclosure, this is normally done by opening the main disconnect enclosure and physically testing each terminal with an adequately rated voltage tester on the load side of the main disconnect for voltage. However, the employee is still exposed to 480VAC on the line side of the main disconnect if the feeder circuit is not deenergized – this is still considered a Hazard/Risk Category 2 and defeating the reason for removing the breaker from the main starter cabinet. To make this effective we need to verify that the load side of the breaker is deenergized while preventing exposure to 480VAC.

The “test before touch” method, that is, the testing of electrical conductors and components with the appropriately rated voltage meter to ensure they are deenergized before work begins is essential in electrical workplace safety [14]. The “test before touch” method has prevented many injuries and will continue to be a foundation for safety in our industry; however, depending on the complexity of the electrical equipment or machines, especially if the equipment is unfamiliar, this can be a difficult and dangerous task. This task becomes more difficult because the equipment must be treated as if it is energized, thus, the qualified person conducting the tests must use the appropriate personal protection equipment [15]. Furthermore, the qualified person may be exposed to electrical hazards during the testing if they did not open all possible sources of power to the equipment. Although the qualified person is using the appropriate personal protection equipment, testing equipment is still inherently dangerous because they are physically touching electrical conductors and components with their meter – they are essentially face to face with an electrical shock and/or an arc flash event. This seems to be a safety gap that should be improved upon.

There are a few companies that specialize in permanent electrical safety device (PESD) technology [16]. This technology allows the qualified person to verify the absence and presence of voltage without exposure to electrical hazards. When properly and strategically installed, at all possible sources of an equipment’s electrical supply, a PESD can continuously monitor (continuously touch and test) voltage between each phase (L1-L2; L1-L3; L2-L3) and phase to ground (L1-GND; L2-GND; L3-GND) displaying the interaction with bright red LEDs. Additionally, another PESD can test each phase (L1, L2 & L3) and is hardwired out to a voltage portal. Via capacitive coupling, a proximity tester illuminates and/or beeps when voltage is present at the voltage portal. Using a proximity tester also allows a qualified person to ensure the tester is operating properly by using it on a separate known voltage source. The proximity tester could be used on the PESD itself to ensure they are both working properly and then observe that the red LEDs are blinking properly before deenergizing the equipment. However, the proximity tester should still be used on a separately known voltage source to ensure it is working properly.

PESDs are typically mounted on the motor starter enclosure door, away from any electrical hazards, and are hardwired directly to the line or load side of the main disconnect. Because the PESDs are directly hardwired to the
source of electrical supply they are continuously monitoring for voltage and monitoring itself that it is working properly. Operators and maintenance employees often carry proximity testers and can easily, both visually and physically, access the PESDs on the enclosure door. When using PESDs, it is possible for an operator to visually and physically verify the presence of voltage, open all the possible sources of electrical supply, lock out and tag the main disconnect operator and then verify the absence of voltage in the main motor starter enclosure without exposure to any electrical hazards. If our goal is to eliminate any exposure, or potential exposure, to electrical hazards, PESDs should be considered and studied as a viable option to the “test and touch” method of ensuring equipment is deenergized.

The PESDs are also useful if there are multiple circuits from different sources feeding a piece of equipment [17]. Although it is not a recommended practice, at times there is a separate power circuit for the motor starter that drives the motor and a separate control circuit for controlling the motor starter from different sources in the same enclosure. Placing PESDs on each circuit that enters the equipment is a way to verify that each circuit to the equipment is deenergized before beginning work on that equipment. PESDs for each circuit can also warn unaware employees that there are multiple voltage sources in the equipment. This can save someone from accidentally entering energized equipment when they believe it is deenergized [18].

The NFPA 70E also discusses the problem of “Look-Alike Equipment” where there are more than one piece of equipment that has a similar size, shape and construction [19]. The fear is that an employee will enter the wrong piece of equipment thinking that it is deenergized and in an electrically safe work condition. The NFPA 70E requires that safety signs or tags, barricades or attendants alert employees to prevent them from entering the wrong equipment [20].

With multiple machines of similar sizes, motor starter enclosures are often the same frame size. So there is a neat row of motor starters that essentially look the same (motor control centers have the same issue when all the buckets look the same). Motor starters are often labeled to differentiate them but labeling can be inadequate, especially if the motor starter is fed from multiple sources; however, adding a PESD would alert an employee of voltage being present and possibly preventing them from entering the wrong motor starter.

Another problem with labeling and differentiating equipment is that of the power distribution switch gear that is feeding the motor starters and drawings that are not up to date. Though the motor starters might be labeled correctly it is possible that the distribution switch gear is labeled incorrectly causing the employee to turn off the wrong feeder switch to the motor starter. Older distribution gear especially may have multiple labels because over time it was used for different purposes and fed different loads. A feeder switch that was once feeding machine C1 is now actually feeding C10 – now this switch might be labeled C1 and C10. The employee looks to turn off C1 and encounters a switch labeled C1 and C10, or they might just focus on the C1 markings and ignore the C10, and turns off the switch. Now the employee just turned off the wrong equipment and the equipment they want off is still energized. This is not uncommon across all market segments – electrical drawings are not updated when upgrades or changes are made to the system and then we fail to properly label equipment [21]. To eliminate some of this confusion a PESD would at least alert the employee that equipment is energized before beginning work. Turning off the assumed switch and finding the PESDs still blinking and energized would alert the employee that something is wrong.

C. Interlocks to Prevent Entry into Energized Equipment

Another method of alerting employees and preventing them from entering energized equipment is to install an electrical interlock on the enclosure door [22]. When the motor starter is energized the interlock engages preventing employees from opening the enclosure door.

On a motor starter the electrical interlock can be energized from either the line or load sides of the main disconnect. If the interlock is energized from the load side of the main disconnect the enclosure door will remain locked until the main disconnect is turned off – once turned off, the employee will be able to open the enclosure door. If the interlock is energized from the line side of the main disconnect then the enclosure door will remain locked until the feeder switch that is feeding the motor starter is turned off. In this case, turning off the main disconnect will not unlock the enclosure door.

We could assume that the motor starter is deenergized if the interlock is not engaged and the enclosure door opens. Our assumption would be wrong because interlocks are typically fed from a fused single phase circuit. It is possible that the fuses could blow releasing the interlock. Therefore, having an electrical interlock does not eliminate the need to verify that the equipment is deenergized – it is simply a part of the broader safety system.

D. Troubleshooting, Diagnostics and Set- up Outside of the Motor Starter

It is often required to have the motor starter energized when troubleshooting and during set up (solid state/soft start (SS) devices and variable frequency (speed) drive (VFD) starter packages often need set up). Traditionally, this requires that the operator enter an energized motor starter to access the starter components. We now know that if an operator needs to enter an energized motor starter they will be exposed to
electrical hazards and must follow the NFPA 70E requirements. The goal, as mentioned before, is to keep employees outside of energized equipment and away from dangerous voltages. This design change would transfer these functions from inside the energized motor starter to the outside of the motor starter enclosure. This would keep employees safer and also reduce many of the NFPA 70E requirements.

We can use a human machine interface (HMI or touch screen) on the outside of the motor starter to perform this function. HMIs are widely used in the electrical industry on the controllers for our machines and processes. The HMI on a motor starter will take data created by individual starter devices and display them for the operator.

The challenge is finding intelligent components that can create data and send it to the HMI via an industrial network protocol. Most SS and VFD devices have built in intelligence that captures motor data and have native communication ports that allow information to transfer to a HMI or a controller. Some manufacturers produce intelligent across-the-line full voltage motor starters that are often used on smaller motor loads. In addition to data acquisition, these devices provide good fault information giving operators valuable troubleshooting tools. Communication to the devices works both ways so we can use the HMI to configure devices during start-up as well. HMI configurations and available data are mainly limited to the devices they are interacting with.

Again, the goal is to provide the operator with the tools to configure the motor starter during set-up, troubleshooting when the system is down and data acquisition while the system is running without exposure to any electrical hazards. The added benefit with these tools is the operator better understands their system and is able to continuously monitor motor and starter performance. Furthermore, this data can be integrated into a network that is operating and monitoring a larger system. This data can be used to monitor for process drift as well as for scheduling predictive and preventive maintenance to prevent unwanted shut downs.

The following is a sampling of data that can be displayed on the HMI for the operator’s use:

- Motor Parameter Configuration
- Motor Parameter Settings
- Phase Voltage – L1-L2; L1-L3; L2-L3
- Average Voltage
- Phase Current – L1; L2; L3
- Average Current
- Kilowatts
- Kilowatt Hours
- Motor Starts
- Motor Operating Time
- Motor FLA %
- Motor Thermal State %
- Starter Hours
- Starter Temperature %
- Analog Input Signal
- Motor Frequency
- Motor Voltage and Current Trending – Historical Data
- Fault and Event Logs
- Fault Codes and Fault Reset Buttons
- Motor Starter Device Specification Sheets
- Motor Starter Layout Drawings

As components become more technically advanced, more information will be available to the operator via the HMI further enhancing their safety and understanding of their equipment [25].

III. CONCLUSION

The NFPA 70E standard provides stringent requirements for employers that are meant to keep employees safe in their workplace from electrical hazards. Electrical shocks and arc flash hazards can severely injure, even kill, employees and costing companies millions of dollars. However, we can minimize these risks and prevent injuries by implementing design changes to electrical equipment that will keep employees safer and more productive. We should have a common goal when designing electrical equipment – to keep employees out of energized equipment while enabling them to excel at their job. Codes, standards and especially end-users are demanding and advocating for safe, robust and intelligent electrical equipment. The next step is to take the initiative to implement new technologies and strategies into our equipment designs that will make our industry safer and smarter.

The brevity of this paper is not a substitute for NFPA 70E. The standard, in contrast, is rich in substantive information for employers to develop safe working standards for their employees.

IV. REFERENCES


VI. VITA

Dennis W. Doody is a Project Manager for Vilter Mfg’s engineered motor starters. He has worked in the electrical industry for 22 years receiving his formal training through IBEW Local Union 134 Joint Apprentice Training. He worked on many large industrial projects such as the Inland Steel-Indiana Harbor Coke Battery, Dresden Nuclear Power Plant and Chicago Mercantile Exchange. Dennis also worked in technical sales focusing on automation and controls in the MRO and OEM market. He graduated from Washington University in St. Louis studying economics, political science, anthropology, environmental studies and history. Dennis has been with Vilter Manufacturing since April 2010.