Electrical Safety, the NFPA and PLC Safety

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Abstract:

As a professor responsible for teaching the principles of PLC programming, the presenter has always considered it a responsibility to train students to be aware of the general rules for constructing an electrical control panel. Both general practice and rules that have become part of the OSHA requirements have been taught. The present state of electrical control has outdistanced what was considered acceptable practice as little as 10 to 15 years ago. New initiatives such as ArcFlash, NFPA 70E and the European initiatives for safety in the manufacturing environment have significantly changed what is accepted or legal.

The purpose of this paper is to distinguish what areas should be discussed and the depth of that discussion. It is not enough to just introduce students to these concepts but in the case of the PLC courses and electrical safety, a more thorough discussion is required.

Students may be introduced to the real world as employees of large companies with committed safety programs in place. These new employees will quickly be introduced to the newest rules and changing practices of electrical safety. Smaller companies may be as committed to safety but many lack the resources to keep up with the rapidly changing environment of electrical and process safety. Students should be armed with enough information so that no matter which environment they are employed, they will have the tools to thrive.

Introduction:

In recent years, it has become evident that electrical practice has changed. Terms such as “Arc Flash” have been discussed more frequently than before. This term has a technical meaning to educators. An alternate meaning was discovered, however, when a YouTube video was being used to discuss arc flash and inadvertently a substitute video was shown which showed two electricians exposed to a violent arc flash which probably killed or severely injured the two. The results were sobering to the students who were used to an environment of 5 and 24 V.

In years past, arc flash was a common hazard of industry. It was accepted and planned for (hopefully). Most engineers opened panel doors and started equipment of varying potential energy and thought nothing of it. While this has been the practice that most were introduced to, it was a dangerous environment and one that had the potential for injury at any time.

New initiatives have changed this environment and educators must follow these changes with curriculum changes that properly prepare students for the new workplace.

To begin the process of teaching the changes, a number of outside personnel were queried as to the state of safety training at their company. These people were from large companies with large corporate staffs as well as private consultants who regularly deal with issues of safety in the design of electrical equipment including the electrical control panel.

Some of the areas of interest from these sources have been listed below:

1. Arc Flash Safety Practices (Short Circuit Safety Calculations)
2. NFPA 70E Compliance
3. UL Guidelines
4. US Panels to CE Compliance (European Design)
5. Risk Assessment
6. PLC Open Safety Embedded Software
7. Achieving Reliability in Safety PLCs
8. Functional Safety from a European Perspective (BGIA Report)
9. Inclusion of Safety PLC Programming Requirements

This list serves as a starting point for the major points of this paper. The subject is dynamic and any list must be reviewed often to properly address the subject of safety for electrical personnel. The paper will discuss some of the more pertinent topics since a thorough review of all these topics would be beyond the bounds of any one paper.

The Control Panel:

Students enrolled in an Electrical Engineering Technology curriculum should be taught the basic design of how to construct an electrical panel. Their experience should be included in a PLC course or other automation course and should include practical information pertaining to the design and construction of the panel. While students are usually interested in programming the PLC and solving the logic associated with control of devices, the work of designing the panel for housing the PLC and the other equipment necessary to run the process may be considered an after-thought. It should be stressed that this is not the case. Care must be taken to properly lay out the panel for maximum use of the interior of the enclosure while giving enough room inside for the equipment and wiring. Panel builders are experts at layout of a panel and should be given some latitude in the construction of panels. The student should be given the basic ground rules used by panel builders for construction of a panel. A field trip to the local panel builder should be considered. Appendix 1 contains a number of general rules for panel construction. Appendix 3 [1] contains an article identifying additional considerations in the proper design of a panel.

The NEC:

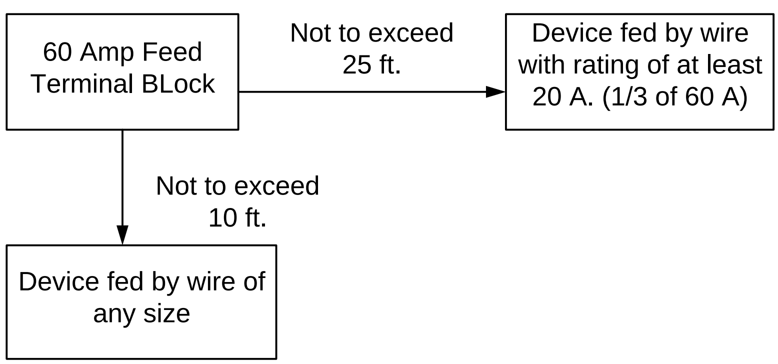
The NEC or National Electric Code will continue to be discussed with students in the PLC classes. Concepts such as the tap rules have been in place for many years but should be understood and serve as a discussion point for students.

Determination of wire size in a panel as well as to field devices must be considered. Wire size is determined in general by the current load of the wire and the insulation rating of the wire. The NEC includes tables for determining the proper size of wire for all electrical applications.

An example of use of the NEC Code in a practical way when stressing panel design is the tap rule. Usually, #14 AWG (American Wire Gage) or #16 AWG wire is sufficient for panel control wiring. Number 18 AWG cable wiring is also used from time to time. Wiring to motors and other control devices must be sized for the application. For most applications, a power feed is brought into the panel and fuses or circuit breakers are used to distribute the load to each of several circuits in the panel.

The NEC also permits feeder taps that comply with the 10 and 25 foot tap rules. These two rules are common to electric installations and provide convenience for electrical installations using terminals to distribute electric power to a number of devices. These two rules allow the tap feeding a device to not be rated at the current rating of the tap but at the rating of the device being fed.

The 10 foot tap rule allows any size wire to be used to tap from the source while the 25 foot tap rule allows for wire to be used to tap from a source that is rated 1/3 or more of the rating of the tap. These two rules are summarized in Article 240-21 (b) Feeder Taps in the 2011 NEC. Other sections amplify the tap rule for taps supplying transformers and for conductors outside the control panel. The rules should be read carefully and applied for all electrical installations. The tap rules allow for distribution of electrical power in a control panel in a practical yet safe manner. An example is shown in the figure below:



Changes in Panel Design Necessitated by OSHA

A number of major changes have occurred in the past 10 to 15 years that make the traditional panel design obsolete as safety of the person troubleshooting the panel has taken on a new importance. For instance, the OSHA warning and fine for the Maine steel fabricator listed in Appendix 4 [2] would not have been discussed prior to a few years ago without an accident having actually occurred. A review of the fine shows new techniques that must be used. These new topics have not been part of the curriculum in the past but must now be introduced into

present coursework in order to provide students with adequate training to thrive in the present market.
In this case, while these fines may seem extreme, the federal government has given sufficient warning as evidenced by the news release found in Appendix 6. The government warning is new in that it cites arc flash hazard as a potential fine from inspectors in the production facility prior to any accident having happened.

Arc Flash

The study of Arc Flash must be integrated into the EET curriculum. Arc Flash is due to the rapid release of energy caused by an arcing fault between two phases or from a phase to ground of an AC power circuit. The discharge of energy may be massive and vaporize copper causing an arc blast devastating everything in its path. This may be more easily described in the following figure or from the YouTube video inadvertently shown in the EET class a year ago. The results are devastating.

Why the focus on Arc Flash?

The study of arc flash dates to the early 1980's paper "The Other Electrical Hazard: Electric Arc Blast Burns" by Ralph Lee which was published in the IEEE Transactions on Industrial Applications. The standards based on this paper have been available for quite a long time but have only recently been taken seriously. They focused on prevention of arc flash incidents and included the following:

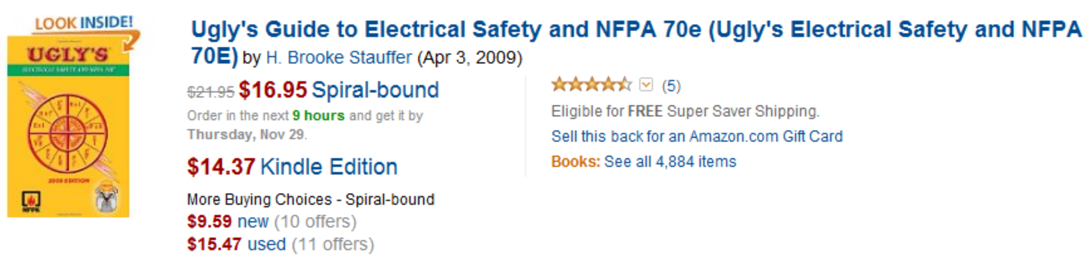
- OSHA 29 Code of Federal Regulations (CFR) Part 1910 Subpart S.
- NFPA 70-2002 National Electrical Code.
- NFPA 70E-2000 Standard for Electrical Safety Requirements for Employee Workplaces.
- IEEE Standard 1584-2002 Guide for Performing Arc Flash Hazard Calculations.

Today, the expansion of NFPA 70E version 2012 has moved the compliance to the category of law. OSHA requires adherence to a six-point plan including:

- "A facility must provide, and be able to demonstrate, a safety program with defined responsibilities.
- Calculations for the degree of arc flash hazard.
- Correct personal protective equipment (PPE) for workers.
- Training for workers on the hazards of arc flash.
- Appropriate tools for safe working.
- Warning labels on equipment. Note that the labels are provided by the equipment owners, not the manufacturers. It is expected that the next revision of the National Electric Code will require that the labels contain the equipment's flash protection boundary, its incident energy level, and the required personal protective equipment (PPE)." [3]

How to Teach Arc Flash Concepts

How does one begin to adequately teach these concepts? One approach is to purchase the NFPA 70E book for each student and require a passage be read and a report be submitted. Another would be to look for an abridged version of the NFPA book. This seems to be a better approach as the pocket text discussed below fits that category. The only objection is the date of the Ugly's book references an earlier version of NFPA 70E, not the 2012 version. This reference is by far the least expensive product that provides extensive commentary on NFPA 70E. Inclusion of a number of these small booklets in the classroom with an assignment to answer a number of survey questions from the books is being added to the course in PLCs at present.



The above text is "a quick on-the-job reference covering the key requirements for electrical safety in an easy-to-read format". While it is not to be considered a replacement for NFPA 70E, it will enhance any instruction on the topic of electrical safety in the technical electrical courses, especially with regard to the requirements of NFPA 70E.

Some key points to be aware of is that the guide does not cover electrical systems below 50 volts or over 600 volts AC, and is not applicable to any work related to utility systems. The guide contains basic information regarding "qualified persons" (those legally permitted to do certain kinds of electrical work), basic safety and energy control procedures, arc flash hazards and arc ratings, personal protective equipment (PPE) and fire retardant clothing, first aid, and NFPA 70E definitions.

Clearly, design of electrical panels is changing as a result of arc flash and will continue to cause panel design, selection of electrical controls and coordination of electrical equipment to change in the future.

Safety Standards for the Factory

Another topic for discussion from the "list" is that of Risk Assessment and machine safety. NFPA 79 has been a standard used by industry to define safety standards in machine control in the past. It is included in Appendix 4 for review. It has been eclipsed by other standards that continue to evolve.

Standards for use in Risk Assessment include those by ANSI (American National Standards Institute) and RIA (RIA – Robotic Industries Association). The European standards have tended to dominate in risk assessment and should be included in any discussion. The BGIA website and publication should also be part of the work in this area.

To design any system, a plan has to be generated to identify what it is that the system is supposed to do. The objective of the safety system function is to reduce risk. Hazards need to be defined for each mode of operation of the machine to meet the objective. Functional requirements will be defined by sequencing of the machine, the requirements of the risk assessment, the types of components and subsystems within the system and the standards requirements.

A Safety system is designed to protect (in the following order):

- People
- Environment
- Machinery/Equipment
- A Safe Application is defined as a situation where the residual risk is **at or less than** the accepted risk.

This also means that **absolute** safety cannot be achieved. Each safety product must be applied as a whole to effectively reduce risk. Safety is the sum of its parts and safety is only as good as its weakest link. The complexity of the inputs (sensors) and outputs (actuators) and the flexibility of the control will determine the type of logic solver. The type may be stand-alone relay, modular relay or safety PLC.

What is Functional Safety?

The following two figures give a description of the two major types of functional safety:

Functional safety can be described in the above as what is safe or unsafe. On the left, a machine is running and safe is a machine with enough guards with sensors in place to determine if the machine is indeed safe to run and capable of stopping if not safe. On the right a continuous process is determined to be fault-tolerant based on a set of criteria. It may be unsafe to stop the process (process may blow up, etc) and the safe mode is to maintain a safe control environment. If this means slowly ramp down a temperature, the control system must guarantee that this will happen in a predictable manner. Stopping in a continuous process is not always safe and may be very unsafe.

How does one teach these concepts and make the student more aware of their responsibility to provide a "safe" system to the process. The best source for this study is the BGIA Report 2/2008 – Functional Safety for Machine Controls. This on-line manual from the German Insurance industry outlines rules for design of safe design. Since the European safety designs are law in the EU, the design of a machine for Europe must contain the content of this text. The inclusion of safe design in the US is increasing and in many aspects a copy of the European concepts. The rating for acceptable safety and how to achieve these ratings appears to be coming mainly from the European and specifically German publications. The BGIA guide should be introduced and discussed. Its inclusion should be a part of the PLC course.

While the study of functional safety does not directly contribute to the design of a panel, the purchase of the PLC directly relates to the safety designation as well as the double wiring to redundant switches, etc.

Other Considerations:

Siemens' PLCs may be designed to not include panels at all. This novel concept is not just a niche but accounts for over 20% of the sale of PLC product by this German PLC maker. Gone are the requirements for finger safety due to the insulation at the terminal and the low voltage.

The design of panels below the 50V threshold for arc flash inclusion has led to the design of panels with 24V only controls. This design is gaining rapid acceptance in the US as well as elsewhere. Providing dead-front enclosures for other equipment has become commonplace and is growing in acceptance.

Conclusion:

Looking at the design of an electrical control panel brings up several new requirements not considered only a few years ago. Arc Flash has become a topic to be studied and understood in order to design and commission a control panel today. The inclusion of the Ugly's pocket reference manual may be of some assistance in the study of NFPA 70E. The topics of Risk Assessment and Functional Safety from a European Perspective (BGIA Report) may be included in a combined study. The BGIA text is online and may furnish some insights into the design of a machine for safe operation. These topics serve as a beginning to understand the state of electrical panel design and troubleshooting for today.

REFERENCES

[1] Condensed Guide to Automation Control System Specification,Design and Installation Part 1: System Identification and Safety by Tom Elavsky, AutomationDirect (Appendix 3)

[2] OSHA Regional News Release, U.S. Department of Labor, Office of Public Affairs,Region 1 News Release: 12-1356-BOS, July 9, 2012, Leni Fortson Joanna Hawkins (Appendix 4)

[3] Arc Flash, John C. Pfeiffer, P.E., president, Pfeiffer Engineering Co., Inc., Louisville, Kentucky

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Appendix 1

Commonly Accepted Practice in Panel Design

1. Enough room should be allowed in the panel for a terminal strip along one side.
2. Panduit or wire-way should be laid out on both sides of the terminal strip. One side should be left empty so the field wiring has sufficient room for entry into the panel through this wire-way. The other side should be wired to the terminal strip from the PLC or other devices as needed.
3. Circuit breakers and other devices in the panel should be properly labeled corresponding to their name on the electrical schematic.
4. AC wiring should be separated from DC wiring.
5. Analog wiring should be run in separate wire-ways and away from AC and discrete signal DC wiring.
6. When analog wiring must cross other wiring, it should cross at 90 degree angles.
7. Analog wiring should, in general, not be terminated except at the PLC. Do not use terminal blocks for intermediate terminals for analog.
8. Vendor specifications should be thoroughly reviewed for heat and cold limitations. If the panel is to be located outside or in a non-heated building, the panel may need to be heated with a small heater under thermostat control.

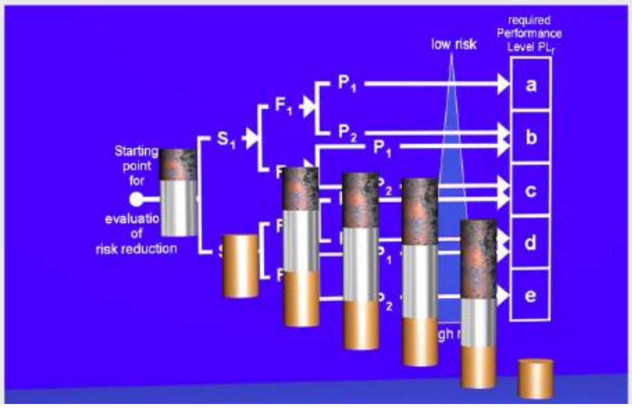
Appendix 2

BGIA

Institut für Arbeitsschutz der
Deutschen Gesetzlichen Unfallversicherung

BGIA Report 2/2008e

Functional safety of machine controls
– Application of EN ISO 13849 –



As a sub-organization of the IFA, the Institute for Occupational Health and Safety of the German Social Accident Insurance, the BGIA or German Institute for Occupational Safety is responsible for testing and certification according to European guidelines and national laws. In this way the BGIA gives manufacturers the security that their products meet all requirements concerning occupational safety at European level. The U-Tech GSG202 system has also been subjected to all safety tests and was granted certification according to European norm EN954 in 2003. Our cooperation goes far beyond this, however, and also includes joint product and further development projects, particularly with regard to the application of the system in other industries. On 29 December 2009 a new European machine directive was introduced, the 2006/42/EG, which states that machines introduced in the European Economic Area must fulfill basic health and safety requirements. The first certificates based on the new legal stipulations began being issued to companies in February 2010. New certification for U-Tech's safety systems has already been applied for and is expected to be granted shortly.

Appendix 3

Condensed Guide to Automation Control System Specification, Design and Installation Part 1: System Identification and Safety
by Tom Elavsky, AutomationDirect

If you have not been directly involved in the world of factory automation, data acquisition, process instrumentation or electrical controls in general, then the above words and acronyms may be somewhat overwhelming. But these words, and many others, are part of the language that's used in the industrial automation world. (For "A Guide to Common Automation Terms" refer to http://support.automationdirect.com/docs/glossary.html.)

The following is Part 1 of a four-part series of articles on Control System Design that can act as a general guide to the specification, design and installation of automated control systems. The information and references are presented in a logical order that will take you from the skills required to recognize an operation or process suited for automating, to tips on setting up a program, to maintaining the control system. Whether you are an expert or a novice at electrical control devices and systems, the information presented should give you a check list to use in the steps to implementing an automated control system. Electrical control systems are used on everything from simple pump controls to car washes, to complex chemical processing plants. Automation of machine tools, material handling/conveyor systems, mixing processes, assembly machines, metal processing, textile processing and more has increased productivity and reliability in all areas of manufacturing, utilities and material processing.

You may have come to realize that an operation or process used to produce your end product is very laborious, time consuming, and produces inconsistent results. You may have also visualized ways that would allow you to automate the operation. Automating the process will reduce the amount of manual labor, improve throughput and produce consistent results. You may have the skills to develop the mechanical means and select the appropriate equipment to make this happen, and although you have a basic understanding of electrical control devices, you may not have the experience to put it all together. Your first option may be to enlist the help of a qualified System Integrator. If you do decide to use a System Integrator, it would be beneficial to understand as much as possible about automation control system devices and their terminology so that your communications with the System Integrator go faster and more smoothly.

In most cases, special expertise is required to design and install industrial automation control systems. Persons without such expertise or guidance should not design and install automation control systems because they can fail and cause serious injury to personnel or damage to equipment. The information provided in this series of articles is provided "as is" without a guarantee of any kind. We do not guarantee that the information is suitable for your particular application, nor do we assume any responsibility for its use in your application.

It is our intent to produce this series of articles as a usable guide, with additional information, including a typical "real world" application that can be followed from concept to completion. It is not our intent for the guide to cover every possible topic dealing with automation control systems or to even suggest that the topics being covered are fully detailed. Instead, the topics are

aimed at giving the reader a good starting reference for automated control systems. In Part 1, we will cover the topics of Safety and Identifying an operation or process that could benefit from automation. In upcoming issues we will cover control device specification, control system design and construction, control system installation, and finally control system maintenance.
Safety:

The first and most important item to consider before attempting an automated control system, or even a simple on/off control for a pump, is safety, both for personnel who may be working with or near the automated equipment, as well as to prevent damage to the equipment.

To minimize the risk of potential safety problems, you should follow all applicable local, state and national codes that regulate the installation and operation of your control system, along with the equipment or process it is designed to control. These codes vary by area and usually change over time. It will be your responsibility to determine which codes should be followed and to verify that the equipment, installation, and operation is in compliance with the latest revision of these codes. Most likely your control system will be dealing with electrical energy, so your first goal will be to eliminate the risk of fire and electrical shock to personnel. The top organizations that provide applicable standards and codes are listed below, but even before you get to this area of safety, it would be wise to educate yourself as much as possible about electricity and electrical equipment in general. A good understanding of basic electricity, including DC and AC theory and practice, Ohm's Law, etc. will go a long way in helping you understand the various codes and standards. There are many good publications and articles on the subject of basic electricity and some local technical colleges offer courses covering subjects dealing with basic electricity. Some even offer courses in Programmable Logic Controllers (PLCs), which can be very useful when dealing with automated control systems. Also, many Web sites offer free tutorials covering basic electricity and PLCs. It would be beneficial to have some understanding of electronic devices, such as the operation of a transistor and other solid state devices, as well as understanding of the use and operation of electrical test and measurement instruments, such as voltmeters, current loop meters, clamp-on amp meters, etc.

At a minimum, you should follow all applicable sections of the National Fire Protection Association (NFPA) fire code, and the codes of the National Electrical Manufacturer's Association (NEMA). There may also be local regulatory or government offices that can help determine which codes and standards are necessary for the safe installation and operation of electrical control equipment and systems.

Please keep in mind that if the automated control system you are developing needs to be accepted in the international market, the National Electrical Code (NEC), as a publication of NFPA, is being harmonized with the International Electrotechnical Commission (IEC) (Web site: www.iec.ch/) and the European Hazardous Location Ratings. For more information, check the Instrument Society of America's (ISA) Web site at www.isa.org. Additional resources on the subject can be found at www.ul.com/hazloc/. Another area of safety that needs to be considered for automated control systems is lockout/tagout procedures as specified by Occupational Safety and Health Administration (OSHA). "Lockout/tagout" refers to specific practices and procedures to safeguard operators and maintenance personnel from the unexpected energization or startup of machinery and equipment, or the release of hazardous energy during service or maintenance activities. In order to have your control system make use of a lockout/tagout procedure, the design should include the ability to shut off, neutralize, or isolate any energy source, such as the main electrical feed, but also any pneumatic, hydraulic or mechanical energy storage device. The means to do this should be considered in the initial design of the automated control system. Additional information can be found on OSHA's Web site at:

http://www.osha.gov/SLTC/controlhazardousenergy/

There are many reasons why the electrical devices that you will use in the design of your automated control system should be listed, approved or registered with a testing laboratory. One reason is to ensure that the device meets standards that will prevent failure that could lead to catastrophic results. Another reason might be for insurance or compliance purposes. One of the most specified and premier safety testing laboratories is Underwriters Laboratories (UL). The most applicable area of interest for control systems is UL's Standard for Safety 508A. If your control system panel requires being built to UL508A, then you will need to contract directly with UL to become a UL508A panel builder or use an existing UL508A panel builder. Additional information can be found at: http://www.ul.com/controlequipment/devices.html

The following are other safety points to consider in the design of your automated control system:
- Emergency Stop - The control system must provide a quick manual method of disconnecting all system power to the machinery, equipment or process. The disconnect device or switch must be clearly labeled "Emergency Stop". After an Emergency shutdown or any other type of power interruption, there may be requirements that must be met before the control system or PLC control program can be restarted.

For example, there may be specific register values in the PLC memory that must be established (or maintained from the state prior to the shutdown) before operations can resume. There may also be mechanical positions of equipment that have to be moved or jogged to the proper position.

- Accidental Powering of Outputs - Do not rely on the automation control system alone to provide a safe operating environment. You should use external electromechanical devices, such as relays or limit switches that are independent of any electronic controlling device, such as a solid state relay or a PLC output module, to provide protection for any part of the system that may cause personal injury or damage. These devices should be installed in a manner that prevents any machine operations from occurring unexpectedly. For example, if the machine has a jammed part, the controlling system or PLC program can turn off the motor rotating a saw blade. However, since the operator must open a guard to remove the part, you should also include a bypass switch that disconnects all system power any time the guard is opened.

- Orderly Equipment Shutdown - Whether using a control system designed around relays and timers or a PLC, an orderly system shutdown sequence should be included in your design. If a fault is detected, then any mechanical motion, valve position, etc., needs to be returned to its fail-safe position and the equipment/process stopped. These types of problems are usually things such as jammed parts, broken cutting tools, bin full, etc. that do not pose a risk of personal injury or equipment damage. If a detected problem would result in risk of personal injury or equipment damage, then use other means to deal with it, such as applying a brake to rotating equipment to stop it before personnel can come in contact with it.

- Grounding - To prevent electrical shock, incorporate good grounding practices in the design, construction and installation of your system. Use protective devices for faulted conductors to prevent fire, and also realize that good grounding practices can reduce electromagnetic and radiated noise interference to sensitive electronic devices.

- Control Power Distribution - Develop a power distribution scheme in the control system circuitry, according to code, that ensures all circuits are protected with fusing, circuit breakers or other interrupting means coordinated such that only the faulted circuit will be opened (de-energized), allowing other powered equipment and devices to continue to operate.

- Unauthorized Access - Make sure all enclosures and cabinets that have energized circuits are secured to prevent unauthorized personnel from gaining access without the proper tool, key or other authorized means.

- Finger-Safe and Dead Fronts - Another safety area to consider is the use of devices that have finger-safe terminal connections, which are surrounded by insulated guarding. The use of protective guards over live circuits should also be considered, even on control panels that have limited access, so it is safer for maintenance electricians and authorized personnel to troubleshoot or make adjustments to electrical control devices. Dead fronts should be used on control system enclosures where the operator needs to make adjustments to devices, such as selector switches, thumbwheels, potentiometers, etc., and the controls need to be inside the enclosure so as to protect them from outside weather conditions. The dead front is normally an interior door that is mounted in front of the main control panel. The outside enclosure door may still require key entry by the operator, but the dead front interior door with adjustable devices is interlocked so that it requires a switch to open it, disconnecting power to the electrical devices mounted on the main control panel.

- Closed-loop Control - It is your responsibility in any type of closed-loop control system to ensure that if the feedback signal is lost, the system shuts down so as not to cause injury to personnel or damage to the equipment. Identifying Process for Automation:

The first step in configuring an automated control system is to identify what can be automated. You need to have a good understanding of basic electricity and safety. It is also important that you have an understanding of basic hydraulics, pneumatics, mechanical operating mechanisms, electronics, control sequences, etc. and a solid knowledge of the operation or process that you are going to automate. You should understand how to control motion and movement, regulate the flow of fluids, dispense granular materials, orient parts, sense product in position, detect when an operation is complete, etc. As a simple example, let's say we have a conveyor that moves our product from point A to point B. The conveyor is powered by a 3-phase AC motor, which is turned off and on by a manually controlled motor starter and includes, for fire protection, both short circuit and overload protection. The system requires an operator standing at the motor starter to watch as the product reaches the entrance to the conveyor, and to turn the conveyor on to move the product. The operator must also turn the conveyor off once the product has reached the discharge end. To automate the conveyor, we will need to replace the manually controlled motor starter with an electrically controlled motor starter, including short circuit and overload protection. We will need to size the motor starter to work with the existing conveyor motor.

We will also need to identify where to locate sensors such as limit switches, photoelectric sensors, proximity sensors, etc. that will indicate when an operation is completed. This is required so our control system knows when to proceed to the next step in our operation. As an example, we usually need a limit switch to detect when a cylinder is fully extended, as in the case when the cylinder is used to push our product onto a conveyor. The cylinder "fully extended" signal is used to de-energize the solenoid valve that provided the air pressure to the pneumatic cylinder. We also need a limit switch to indicate when the cylinder has fully retracted, and provide a signal to the start/stop control of the conveyor that the product push cylinder is out of the way for the next product. Another application for a sensor is to indicate when the product has reached the conveyor. The sensor can be a limit switch with a roller arm that comes in contact with the product or a photoelectric sensor that can detect the product by using an infrared beam of light. The photoelectric approach may be the better choice because the position of the product on the conveyor belt may vary.

We would continue with this analysis, looking at each piece of equipment or component in our system, and select a device that could control or sense it. Some examples include an electrical solenoid valve to control water used to wash residue from a product, or a pneumatic valve to control air pressure to a cylinder operating a gate that diverts product on a conveyor, or energizing a control relay to signal that a product is in position on a scale.

In some instances we may need to vary the speed, rate or position of our controlling device, such as varying the speed of a conveyor, changing the amount a valve opens to control a flow rate, or remotely changing the setpoint level for a tank. This could be accomplished by using an analog output signal. An analog output signal is a varying signal that corresponds to the real value we have determined and calibrated into the device. For example, a 0 to 10 VDC signal could represent a conveyor speed of 0 to 500 feet per minute. An analog signal to the speed controlling device for the conveyor motor of 5 VDC would result in a conveyor speed of 250 feet per minute. Identifying devices to control motion, flow, events, etc. and sensing completion is basically identifying the I/O (inputs and outputs) of our control system. Once these devices are identified, they can be used as the field devices in a PLC-based system, or they can be “hard-wired” for simpler applications. You will also want to determine if your automated control system will benefit from the use of an operator interface, also referred to as a Human Machine Interface (HMI). If your process requires making changes to setpoint values, process time, flow rates, etc., then the use of an HMI is the best way to proceed. In these situations, you will most likely need a PLC that can easily communicate with the HMI device. If your application requires keeping data records for reference, traceability, history, trending, meeting regulations, etc., then you should look at using a control system that would fall into the category of a "Supervisory Control And Data Acquisition" (SCADA) system. Most of these control systems would be comprised of PLC-type I/O that interface to a PC with appropriate software.

Appendix 4

OSHA Regional News Release

U.S. Department of Labor

Office of Public Affairs

Region 1 News Release: 12-1356-BOS
July 9, 2012
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US Labor Department's OSHA proposes $132,000 in fines against Maine steel fabricator for electrical, crushing and laceration hazards at Augusta, Maine, plant

AUGUSTA, Maine – The U.S. Department of Labor's Occupational Safety and Health Administration has cited Cives Steel Co. for alleged willful, repeat and serious violations of workplace safety standards at its Augusta production facility. The steel products fabricator faces a total of $132,000 in proposed fines for electrical, crushing, laceration and other hazards identified during an inspection by OSHA's Augusta Area Office begun in January.

"The sizable fines proposed in this case reflect the severity and recurring nature of a number of these hazards," said William Coffin, OSHA's area director for Maine. "For the safety of its workers, this employer must take effective and expeditious action to eliminate these conditions and prevent their recurrence."

OSHA found that maintenance employees were not supplied with and did not use personal protective equipment to protect themselves against the hazards of electric shock, arc flash and arc blast while performing diagnostic work on electrical equipment. This situation resulted in OSHA issuing the plant one willful citation, with a $70,000 fine. A willful violation is one committed with intentional knowing or voluntary disregard for the law's requirements, or with plain indifference to worker safety and health.

Another electrical hazard cited is the use of extension cords as a substitute for fixed wiring, a condition similar to one for which OSHA had cited Cives Steel's Gouverneur, N.Y., plant in 2010. This situation resulted in the issuance of one repeat citation, with a $22,000 fine. A repeat violation exists when an employer previously has been cited for the same or a similar violation of a standard, regulation, rule or order at any other facility in federal enforcement states within the last five years.

Nine serious citations, with $40,000 in fines, have been issued for crushing hazards stemming from the plant's failure to label and test the weight capacity of an in-house fabricated lifting device used to lift metal plates weighing up to 900 pounds; laceration hazards from the unsafe practice of drop staring a chain saw; a lack of leg protection while using chain saws; falls from standing on raw and fabricated steel products; an incomplete confined space entry program; inadequate egress from a mezzanine and additional electrical hazards. A serious violation occurs when there is substantial probability that death or serious physical harm could result from a hazard about which the employer knew or should have known.

The inspection was conducted under OSHA's Site-Specific Targeting Program, which directs inspections toward workplaces with a rate of workdays lost due to injuries and illnesses that is higher than the industry average.

The citations can be viewed at
http://www.osha.gov/ooc/citations/CivesSteelCompany_316216969_0706_12.pdf*.

Cives Steel Co. has15 business days from receipt of its citations and proposed penalties to comply, meet with OSHA's area director or contest the findings to the independent Occupational Safety and Health Review Commission. To ask questions, obtain compliance assistance, file a complaint, or report workplace hospitalizations, fatalities or situations posing imminent danger to workers, the public should call OSHA's toll-free hotline at 800-321-OSHA (6742) or the agency's Augusta office at 207-626-9160.

Under the Occupational Safety and Health Act of 1970, employers are responsible for providing safe and healthful workplaces for their employees. OSHA's role is to ensure these conditions for America's working men and women by setting and enforcing standards, and providing training, education and assistance. For more information, visit http://www.osha.gov/index.html.

Appendix 5

Arc Flash

Arc Flash is the result of a rapid release of energy due to an arcing fault between a phase bus bar and another phase bus bar, neutral or a ground. During an arc fault the air is the conductor. Arc faults are generally limited to systems where the bus voltage is in excess of 120 volts. Lower voltage levels normally will not sustain an arc. An arc fault is similar to the arc obtained during electric welding and the fault has to be manually started by something creating the path of conduction or a failure such as a breakdown in insulation.

The cause of the short normally burns away during the initial flash and the arc fault is then sustained by the establishment of a highly-conductive plasma. The plasma will conduct as much energy as is available and is only limited by the impedance of the arc. This massive energy discharge burns the bus bars, vaporizing the copper and thus causing an explosive volumetric increase, the arc blast, conservatively estimated, as an expansion of 40,000 to 1. This fiery explosion devastates everything in its path, creating deadly shrapnel as it dissipates.

The arc fault current is usually much less than the available bolted fault current and below the rating of circuit breakers. Unless these devices have been selected to handle the arc fault condition, they will not trip and the full force of an arc flash will occur. The electrical equation for energy is volts x current x time. The transition from arc fault to arc flash takes a finite time, increasing in intensity as the pressure wave develops. The challenge is to sense the arc fault current and shut off the voltage in a timely manner before it develops into a serious arc flash condition.

Fig. 9-26 More Examples of Arc Flash

Why the focus on Arc Flash?

In the early 1980's a paper "The Other Electrical Hazard: Electric Arc Blast Burns" by Ralph Lee was published in the IEEE Transactions on Industrial Applications. The effect of this paper was to realize the need to protect people from the hazards of arc flash. Four separate industry standards concern the prevention of arc flash incidents:

- OSHA 29 Code of Federal Regulations (CFR) Part 1910 Subpart S.
- NFPA 70-2002 National Electrical Code.
- NFPA 70E-2000 Standard for Electrical Safety Requirements for Employee Workplaces.
- IEEE Standard 1584-2002 Guide for Performing Arc Flash Hazard Calculations.
-

Compliance with OSHA involves adherence to a six-point plan:

- A facility must provide, and be able to demonstrate, a safety program with defined responsibilities.
- Calculations for the degree of arc flash hazard.
- Correct personal protective equipment (PPE) for workers.
- Training for workers on the hazards of arc flash.
- Appropriate tools for safe working.
- Warning labels on equipment. Note that the labels are provided by the equipment owners, not the manufacturers. It is expected that the next revision of the National Electric Code will require that the labels contain the equipment's flash protection boundary, its incident energy level, and the required personal protective equipment (PPE).

Companies will be cited and fined for not complying with these standards.
Personal Protective Equipment (PPE)
Categories of PPE as described in NFPA 70E are:

Category	Cal/cm^2	Clothing
0	1.2	Untreated Cotton
1	5	Flame retardant (FR) shirt and FR pants
2	8	Cotton underwear FR shirt and FR pants
3	25	Cotton underwear FR shirt, FR pants and FR coveralls
4	40	Cotton underwear FR shirt, FR pants and double layer switching coat and pants

Cal/cm2 are the units of incident energy that the PPE can withstand. Note that a hard hat with full-face shield and the appropriate gloves are required also.

Steps required for a flash hazard analysis:

To perform an arc flash hazard analysis, data is collected about the facility's power distribution system. The data includes the arrangement of components on a one-line drawing with nameplate specifications of every device. Also required are details of the lengths and cross section area of all cables. The utility should be contacted for information including the minimum and maximum fault currents that can be expected at the entrance to the facility. Once the data has been collected, a short circuit analysis followed by a coordination study should be performed. The resultant data can then be fed into the equations described by either NFPA 70E-2000 or IEEE Standard 1584-2002. These equations will produce the necessary flash protection boundary distances and incident energy to determine the minimum PPE requirement.

Flash hazard analysis - a new approach

Once the data is prepared and a flash hazard analysis has been performed, most likely it will be discovered that category 4 PPE will be required in most places. This is most unfortunate as this type of PPE is very unwieldy and could be costly in terms of time taken to perform work and the potential for mistakes. Prior to the new arc flash regulations, coordination studies were targeted at reliability with all settings adjusted towards the high side. Compliance with the new arc flash regulations means that not only does the coordination study need to be more accurate but it also needs to take into account the fact that the arc fault current is less than the bolted fault current.

The data can be used to perform a sensitivity study to adjust breaker/fuse characteristics to lower the PPE requirement. To achieve this goal, the existing breakers may need to be replaced, generally by more modern counterparts. Old breakers have relatively slow reaction times and will trip at too high a current. To limit the flash hazard the breakers are adjusted to trip earlier than before. It is expected that the outcome of this sensitivity study, when implemented, will result in most category 4 PPE requirements being decreased to category 1 or 2.
Short-Circuit Study

The short-circuit study is based on a review of one-line drawings. The drawings must be created if they do not exist, and field-verified if they do. Maximum available fault current is calculated at each significant point in system. Each interrupting protective device is then analyzed to determine whether it is appropriately designed and sized to interrupt the circuit in the event of a bolted type of short circuit. Next, the associated equipment must be reviewed to insure that the bus bar is adequately braced to handle the available fault current. Finally, the bolted fault currents are converted into arc fault currents for additional analysis.

Coordination Study

A coordination study is the examination of the electrical system and available documentation with the goal of ensuring that over-current protection devices are properly designed and coordinated. Over-current protective devices are rated, selected and adjusted so only the fault current carrying device nearest the fault opens to isolate a faulted circuit from the system. This permits the rest of the system to remain in operation, providing maximum service continuity. The study consists of time-current coordination curves that illustrate coordination among the devices shown on the one-line diagram. Note that protective devices are set or adjusted so that pickup currents and operating times are short but sufficient to override system transient overloads such as inrush currents experienced when energizing transformers or starting motors.

The Problems

Now that the hazards associated with arc flash have been brought to our attention, we face the problem of trying to eliminate or at least reduce those hazards. The following discusses some of these problems and the subtleties in implementing corrective actions.

There are several problems in dealing with Arc Flash Analysis:

1. Being overly conservative in your short circuit analysis may result in the required PPE protection category being set at a level higher than necessary.

Fig. 9-27 Category 4 PPE

The above figure is a person in a full Category 4 suit. This suit will provide the necessary protection, but it is cumbersome to work in, it is hot, and it provides poor visibility. The suits will make many tasks very difficult, if not impossible, to perform. Because of their restrictions to vision and movement, they may even make some tasks more dangerous. There are definitely times when this type of protection is both necessary and required, but being overly conservative will result in excessive stress to workers and unacceptable time to make repairs or adjustments.

2. Relying upon quick analysis methods can expose you to unexpected liabilities. There are a number of shortcuts being offered by individuals and companies that can have disastrous results. Be sure that your methods will stand up to analysis and peer review. Cure-all solutions are being promoted, such as the installation of current-limiting fuses. Pfeiffer Engineering is a firm believer in the use of fuses, particularly current-limiting types, but as will be shown below, they are not always the answer. They are definitely not a quick fix solution.

3. Being overly conservative when performing a short circuit analysis results in the misapplication of circuit protection equipment, which in turn has the consequence of calculated Arc Flash levels being higher than they actually are.

4. The calculated bolted fault or short circuit current is a worst-case calculation that assumes very low short circuit impedance. It is a short circuit connection based upon two conductors being bolted together to form the short. In reality, most short circuits are less than ideal resulting in fault currents that are less than the calculated bolted short circuit condition.
5. On the other hand, the Arc Fault should be a more predictable occurrence. The arc fault calculations assume that there is a physical gap between conductors that was bridged by something resulting in the formation of an arc. Once the arc is formed and plasma is produced, the arc current should closely approximate the calculated fault levels. The Arc Fault calculations are an approximation based upon research and testing similar to the short circuit analysis methods. They are not exact and therefore one needs to be careful when using the results.

Solution

The solution is to first perform, as accurately as practical, a short circuit analysis. The goal for most people performing a short circuit analysis has always been to error toward the conservative. For example, when a cable length was needed, it is the practice to always use the shortest practical value, which would result in higher calculated short circuit current values. When the public utility is contacted, it is the practice to only ask for the worse case short circuit value.

The overall result is that the short circuit values are always calculated on the high side. When doing a short circuit analysis for sizing the interrupting capability of protection equipment, this is the best practice. But, it is not the best practice when evaluating equipment for Arc Faults and establishing PPE requirements. This is extremely significant, and quite non-intuitive, situation.

Arc Fault current (Ifc) is derived from the available bolted short circuit or fault current (Isc) and is always substantially less than its corresponding short circuit current. The IEEE has established formula for calculating (estimating) the I_{fc} and they provide a spreadsheet. The following are example results from using their formula:

Bolted Fault Current	Arc Fault Current
@ 480 V	
10 kA	= 6.56 kA
20 kA	= 11.85 kA
30 kA	= 16.76 kA
40 kA	= 21.43 kA

What is now important is to obtain:

1. The expected maximum (worse case) bolted short circuit current.
2. The minimum and maximum voltage to the facility.
3. The minimum expected short circuit current.

Also needed are definitions of the operating modes of the facility such as:

1. What are the minimum and maximum motor loads expected during normal operation and off-hour operation.
2. Variation in the sources of supply to the plant, such as alternate feeders or co-generation.

The data from the public utility and the determination of the facility's modes of operation should be converted into the maximum and minimum Arc Fault current at various locations in the plant. These results are applied to protective device coordination studies, where the protective devices are evaluated, and adjusted, if necessary, allowing the proper PPE categories to be determined.

The following coordination curve illustrates the point:

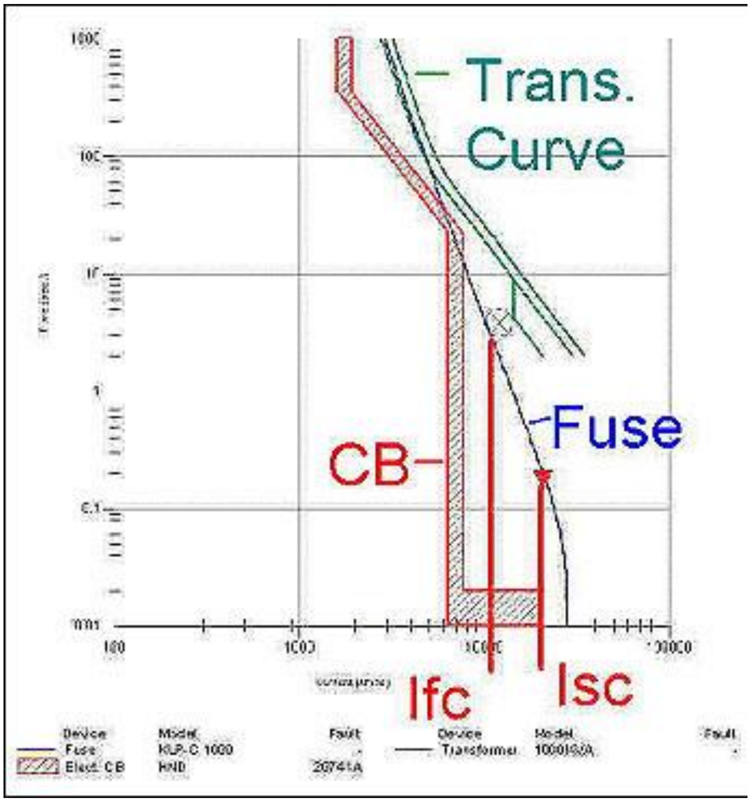

Fig. 9-28 Fuse Coordination Curve

The figure above shows the coordination curve for the secondary of a 1000 kVA 480 V transformer. The curve shows two types of secondary protection, a fuse and a circuit breaker, each selected based upon the National Electrical Code requirements. The fuse is a KLP-C 1600A and the circuit breaker is a Westinghouse HND breaker with a Digitrip.

All transformers limit the amount of fault current that can pass through the transformer. This is a function of the transformer's impedance. The coordination curve shows a line for the Isc, the maximum short circuit current that can pass through this transformer (20,741 amps). The Isc value used assumes that there actually is sufficient current available at the primary to provide 20,741 amps on the secondary.

Based upon the IEEE formula, the calculated Arc Fault current Ifc is 12,230 amps. Using these two currents and the coordination curve one can estimate the time the circuit breaker and the fuse will take to clear the fault.

Bolted Fault Condition:

- Fuse clears in 0.22 seconds
- Circuit Breaker clears in 0.02 seconds

Arc Fault Condition

- Fuse clears in 1.80 seconds
- Circuit Breaker clears in 0.02 seconds

From these current levels and clearing times the PPE category can be determined.
Emb (Maximum in cubic box incident energy)

- Fuse 74 cal/cm2 Category 4 PPE
- Circuit Breaker 0.8 cal/cm2 Category 0 PPE

Clearly, in this example the circuit breaker outperforms the current-limiting fuse resulting in a minimal "worker friendly" PPE requirement.

In the above example both the Arc Fault current and the Bolted Fault current are less than the current-limiting point for the fuse, which is approximately 28,000 amps. Thus, there is no current-limit effect from using the fuse. Current-limiting fuses often do provide additional protection and they are very good devices but they must be applied properly. In this example, the circuit breaker provides the best protection.

Studying this example further, let us assume that the fuse and the circuit breaker are at the main of a facility and the facility is served by a much larger transformer where the worse-case bolted short circuit current as reported by the utility is 60,000 amps. Under this condition the arc fault current would be 30,300 amps. In this case, the fuse would open in 1/4 cycle and would limit the fault current.

The Emb would equal 1.15 cal/cm2, which falls under a category 0 PPE.

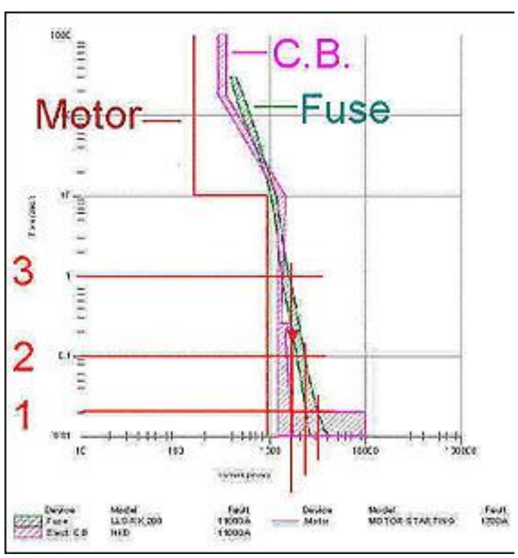

Fig. 9-29 Fuse and Circuit Breaker Coordination Curve

In the next example we have a fuse and a circuit breaker protecting a 125 Hp motor. The fuse is a LLS-RK 200 A and the circuit breaker is a Westinghouse HKD with a Digitrip. There are three Arc Fault currents analyzed.

Point 1

- Arc Fault Current 3100 Amps
- Bolted Fault Current 4200 Amps
  Point 2
- Arc Fault Current 2200 Amps
- Bolted Fault Current 2800 Amps
  Point 3
- Arc Fault Current 1800 Amps
- Bolted Fault Current 2200 Amps
- Results:
  Point 1
- Circuit Breaker clears in .02 seconds 1.42 cal/cm2 PPE Cat. 1
- Fuse clears in .02 seconds 1.42 cal/cm2 PPE Cat. 1
  Point 2
- Circuit Breaker clears in .02 seconds 1.42 cal/cm2 PPE Cat. 1
- Fuse clears in .1 seconds 7.7 cal/cm2 PPE Cat. 2
  Point 3
- Circuit Breaker clears in .02 seconds 1.42 cal/cm2 PPE Cat. 1
- Fuse clears in 1.0seconds 78.8 cal/cm2 PPE Cat. 4

At an Arc Fault current of 4000 amps the fuse will begin to current limit and will open the circuit in ¼ cycle reducing the PPE category to 0.

The three points analyzed show that a relatively small change in calculated bolted fault current has a major effect on the calculated arc fault current. This situation could easily lead to the misapplication of circuit protection equipment or inappropriate adjustment of same. It should also be noted that as the calculated arc fault current is reduced, the clearing time increases, resulting in the incident energy level increasing and thus, the PPE requirement increases.
In reality, the arc current is primarily effected by facility operating conditions, i.e. motor contribution and changes in the fault current coming from the utility. The examples illustrate that the accuracy required when calculating short currents has to be improved over traditional methods. Both reliability and arc fault conditions must now be considered when performing coordination studies.

The Risk

In a study of 33 plants with 4892 busses or switch points under 600 volts, the median incident energy was only 2.1 cal/cm2, however many busses had quite high incident energy levels1:

- 24% of busses over 8 cal/ cm2 PPE 2
- 12% of busses over 40 cal/ cm2 PPE 4
- 5% of busses over 85 cal/ cm2 Deadly - no protection
- 1% of busses over 205 cal/ cm2 Deadly - no protection

Risks to personnel include2:

- Burns
- Damaging sound levels
- High pressure - 720 lbs/ft2 eardrums rupture, 1728 to 2160 lbs/ft2 lung damage

Conclusions

1. Arc Fault Analysis is in actually Risk Management. There are basically three choices:
   - Be very conservative and require PPE 4 in most cases resulting in higher maintenance cost.
   - Do nothing and suffer the consequences (pay later). Perform the necessary analysis and make adjustments to reduce the arc fault conditions resulting in reduced PPE requirements.

2. A reduction in bolted fault current and thus a reduction in arc fault current can actually result in a worse situation. In the motor example above an arc fault current reduction from 4000 amps to 1800 amps resulted in an increase in arc fault energy from 0.6 cal/cm2 to 78.8 cal/cm2. Exactly the opposite one would expect before doing the math. In terms of the above example coordination curves, this occurs because the arc fault current moves from the instantaneous portion at the bottom of the coordination curve to a point higher up, incurring a the time delay before the device trips.

3. Overly conservative short circuit analysis will result in bolted short circuit numbers that may well result in the misapplication of circuit protection equipment.

4. It is very important to obtain the minimum available short circuit current as well as the maximum short circuit current from the electric utility. Voltage fluctuations in the plant supply should be considered when developing the short circuit calculations. The arc fault calculations need to be evaluated at more than just the worse case and the minimum case conditions. In the example above, a reduction in the arc fault current actually resulted in worse conditions. This represents a subtle, but extremely significant, change in the methodology of short circuit analysis.

5. Apart from the fines, nominal compliance with the regulations will cause workers to have to wear cumbersome PPE. This will result in little or no high voltage maintenance being performed, eventually compromising safety, equipment operation, and ultimately productivity. Arc flash is a risk management issue.

6. Have a registered professional engineering firm perform the calculations for arc flash hazards for the devices in your facility and have them recommend any necessary plans that when executed would result in the lowest category of PPE being required.

Note:

Short circuit analysis is based upon a number of assumptions; any or all may change over time;

1. Available short circuit current from the utility may vary, particularly in areas where there has been a significant expansion of, or change to, the electrical systems.
2. The number of motors running at the time of a fault affects the amount of short circuit current and arc fault current available (motor contribution).
3. The facility voltage often varies as a function of time of day. The utility is often more loaded during the day.

Similarly, the arc fault may also be affected by variations in any of the following:

1. The available short circuit current.
2. Dirt buildup in the equipment that may affect the conductive path.
3. Moisture (humidity).
4. Circuit supply voltage.
5. Amount of motor contribution during a fault

Definitions

Bolted Fault - Short circuit current resulting from conductors at different potentials becoming solidly connected together.

Arc Fault - Short circuit current resulting from conductors at different potentials making a less than solid contact. This results in a relatively high resistant connection with respect to a bolted fault.

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