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Causes of Electrical Safety Incidents

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Abstract

We often become short sighted; we forget that PPE is not the solution to all of our electrical safety worries; electrical safety is more than just Lock-out/Tag-out; and Arc Flash is not the only electrical hazard industrial employees will encounter. Each year the engineers and technicians working for the Industrial Services Business Unit of Siemens Energy & Automation, Inc. perform approximately 1 million man-hours of electrical service work at industrial sites. Our employees work on circuit panels energized from 120V all the way to electrical sub-stations powered at several hundred-thousand volts. We work on equipment made by all major manufacturers—even direct competitors to Siemens. As such, we see a much wider variety of electrical problems, equipment failures, and maintenance issues than would be typical for a single industrial site. This presentation will discuss some common sources electrical safety incidents we have encountered in our work. It also addresses recommended work practices that can be implemented to prevent these problems from turning into an injury or resulting in equipment damage.

Introduction

We often become short sighted; we forget that PPE is not the solution to all of our electrical safety worries; electrical safety is more than just Lock-out/Tag-out; and Arc Flash is not the only electrical hazard industrial employees will encounter. This paper will discuss the common sources electrical safety incidents that Siemens has encountered in our work. It also addresses recommended work practices to prevent these problems from turning into an injury or result in equipment damage. Later in the paper, I will be citing specific examples we have encountered to illustrate the various points and recommendations.
Our experience has led us to conclude that the majority of electrical safety incidents result from one or more of the following four problems. Often the cause is multiple failures, not a single cause.

1. Failure to de-energize equipment
2. Failures associated with Lock-out/Tag-out procedures
3. Inadequate personnel training and qualifications
4. Improper maintenance and/or operation

De-Energize Equipment

This is, without a doubt, the single most important causal factor in electrical safety incidents. We simply cannot stress this issue enough. Failing to de-energize or correctly verify that a circuit is de-energized is the single most common factor we see in electrical injury and near miss situations. There are a number of ways in which this might come about:

- simply failing check,
- checking, but checking the wrong circuit,
- checking, but failing to check correctly or completely
- equipment backfeeds which are not discovered;
- equipment failures which lead to improperly or incompletely de-energized circuits
- miscommunications among co-workers ("I though Bob was checking")
- honest mistakes, opening or locking-out the wrong circuit
- incomplete or inaccurate lock-out procedures

There are hundreds of other possibilities, most of which are the result of honest errors or simple ignorance. Unfortunately, the situations which lead to improperly de-energized equipment occur at a frequency that makes verification an imperative step in a good lock-out/tag-out program.

The final reason to work on properly de-energized equipment is that it is an inherently better safety solution. OSHA[1] refers to this concept as the Hierarchy of Controls. In order of preference the controls are:

1. <u>Engineering Controls</u> – Eliminate specific safety hazards altogether
2. <u>Administrative Controls</u> – Reduce the chance that a hazardous event will happen
3. <u>Protective Equipment</u> – Mitigate consequences after the hazardous event has occurred

One of the best examples of an engineering control applicable to electrical work would be to only work on de-energized equipment. Equipment that is verified de-energized cannot be the cause of an arc-flash event or electrocution. The National Fire Protection Agency (NFPA)[2] goes even further in their electrical safety standard (NFPA 70E – *Standard for Electrical Safety in the Workplace,* 2004 Edition). Section 130.1 of this standard requires employers to implement an electrical work permit system. As part of their permit system they require employers to justify, in writing, why work must be performed on energized equipment. The permit system and the

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1 Occupational Safety and Health Administration

2 The NFPA is the agency in the U.S. who has responsibility for publishing the National Electrical Code or NEC. The National Electrical Code is contained in section 70 of the NFPA consensus standards. This section is the basis for all local electrical codes, as well as OSHA's electrical safety work rules.

justification requirement would be examples of an Administrative Control that reinforces the Engineering Control of working only on de-energized equipment.

This is also a good place to discuss a formal definition of de-energized equipment. Siemens applies to the following policy to our field work. We consider that equipment is not truly de-energized until it is:

1. Isolated with a visibly open switch or circuit breaker
2. Locked-out following a written, and verified procedure
3. Tested to confirm that the equipment is truly de-energized
4. Grounded, to prevent injury in the event that the equipment becomes inadvertently re-energized during work.

Validate Lock-out/Tag-out Procedures

We see many incidents where the Lock-Out/Tag-Out (LOTO) procedures were either inadequate or simply not verified. We also see instances where the procedures have not been reviewed recently. We recommend to our customers that they get an up-to-date set of one-line diagrams for their electrical infrastructure. If they have not been maintaining their drawings all along, this can be a moderately expensive proposition (depending on the facility size). However, you simply cannot have a safe and accurate LOTO program if you don’t know how your systems are put together.

We see many client sites with informal electrical LOTO systems. Procedures should be in writing and should be device specific. OSHA addresses general in-plant electrical safety in Subpart S to 29 CFR 1910 (1910.300-399). In section 1910.333(b)(2)(i), OSHA requires a <u>written</u> electrical LOTO plan:

> The employer shall maintain a written copy of the procedures [for electrical Lock-out/Tag-out], and shall make it available for inspection by employees and by the Assistant Secretary of Labor and his or her authorized representative.

The recommended best-practice is to have a written procedure for each and every machine, device, circuit breaker, etc. in your facility.

We also see facilities that have not validated their LOTO procedures. Our experience has been that equipment failures, undocumented modifications and outright errors are common enough to warrant significant concern. One important aspect of a validation process is to verify that the circuit you open actually de-energizes the intended device—this means using test devices like meters or non-contact voltage detectors to prove that circuits are dead.
Lastly OSHA says in 1910.333(b)(2)(ii)(B) that:

> Control circuit devices, such as push buttons, selector switches, and interlocks, may not be used as the sole means for deenergizing circuits or equipment. Interlocks for electric equipment may not be used as a substitute for lockout and tagging procedure.

These devices are unreliable as the sole source of electrical disconnects—especially if they are tied to computer control systems. Automated controls are only as good as the programmer who wrote the software for the controller. We have seen incidents where odd or extraordinary circumstances have bypassed software controls because the programmer did not anticipate a particular combination of circumstances. We also see situations where operators have purposely taken advantage of bypass opportunities to defeat interlocks. The only acceptable means of electrical LOTO should be a physical break in the supply circuit—preferably one that can be visually inspected.

Trained, Qualified Employees

OSHA requires employees who will be working on electrical equipment (whether it is 120V or 34,000V) to be “Qualified”. They define a “Qualified” employee[3] as someone who is

1. Trained in and familiar with safety-related work practices;
2. Able to distinguish exposed live parts;
3. Able to determine the nominal voltage of exposed live parts;
4. Knowledgeable of minimum approach distances; and
5. Familiar with the construction and operation of the equipment

While it doesn’t strictly apply to an industrial environment, you would be well served to add one more requirement (this one from 1910.269 OSHA’s electrical generation, transmission, and distribution standard)

- Knowledgeable of the precautionary techniques, personal protective equipment, insulating and shielding materials, and insulated tools.

Finally, OSHA also states in the definition of a “Qualified Person” found in 1910.399 that:

> Whether an employee is considered to be a "qualified person" will depend upon various circumstances in the workplace. It is possible and, in fact, likely for an individual to be considered “qualified" with regard to certain equipment in the workplace, but "unqualified" as to other equipment.

Training should not be one time activity. The employee you gave electrical safety training to 10 years ago probably remembers little content from that class. OSHA does not prescribe a specific regimen o for electrical safety training—instead they provide a hodge-podge of vague recommendations. In Subpart R or 1910.269, they suggest re-training may be required, but do not specify the frequency. Under 1910.269, OSHA requires annual evaluations and additional training if the employer cannot verify that employees are complying with required safety precautions. They also suggest additional training when new equipment is put in place, or when changes are made to work rules or OSHA rules. Finally they suggest refresher training to cover out-of-the-ordinary work practices—those that an employee would not normally use on a frequent

[3] Items 1-4 of this list are found in 1910.332 and item 5 is from 1910.399 in the definition of a “Qualified Person”.

or reoccurring basis. Unfortunately all of this is very nebulous, and we still see many industrial sites where little or no electrical safety training has been completed. Siemens has chosen to require 4-8 hours of refresher training covering electrical safety every year.

In this category, we also include supervision and management personnel who may not be aware of the currently accepted standards for electrical safety. We still see a large number of clients who do not require or enforce employee use electrical protective equipment. This is not just FR clothing. We still see plant electricians working on live equipment without insulating gloves. Often, other safety equipment like blankets, hot sticks, non-contact voltage detectors or properly rated handheld meters are missing. I routinely hear anecdotes from our engineers of customer practices that make them shudder. If management does not understand the need for training and does not recognize safe work practices, then employees certainly will not.

Equipment Maintenance and Operation

We see a lot of equipment that has not been properly maintained, or is not being operated in a safe manner. The four most common maintenance safety problems we see are:

1. Undetected equipment failures (due to lack of inspections and/or maintenance)
2. Lack of cleaning;
3. Improper equipment settings or poor operating procedures
4. Code-violating modifications (especially Rube-Goldberg modifications)

Problems with the condition of your electrical equipment can eventually lead to catastrophic failure of the equipment. Undetected failures can cause employees to become confused or lulled into false security. Examples of undetected problems might be switches or breakers which fail to open on all three phases.

Industrial environments are dirty. Dust, debris and critters can accumulate in electrical equipment enclosures. This material to become airborne when enclosures are opened, bumped or otherwise disturbed. It is possible for sufficient airborne junk to result in a flashover between adjacent conductors.

We often see customers who set extraordinarily high trip delays on the circuit breakers. These can result in otherwise small arc-flash events to become longer and larger than might normally be expected. We also see customers who use circuit breakers as a means of turning off equipment. Circuit breakers are designed to open under load on an infrequent emergency basis. Using them in this manner repeatedly will lead to premature failure of the breaker—with potential catastrophic consequences.

Electrical code and manufacturer's recommended maintenance practices are ultimately there for safety reasons. We see a lot of duct-tape and chewing-gum type repairs or modifications to equipment. Temporary fixes have a way of becoming permanent solutions. Customers may occasionally be tempted to delay needed repairs, hoping to get by for another month without having to shut down production.

Common Electrical Safety Problems

I want to conclude this discussion with some specific examples. These are anecdotes of some things we have encountered in our service work. These are examples that we see multiple times during the course of a year and are in our opinion areas where our customers could most easily address.

Energized Equipment

As we have said before…the single best practice you can implement in regards to electrical safety is to work only on de-energized equipment. We simply cannot stress this point enough. All manner of problems disappear when this practice is followed. Working on energized equipment will eventually bite you—hard!

Exhibit 1.

Example 1. An electrician working at a client site was attempting to replace a door on a piece of equipment purchased from Siemens. He needed to drill out the old rivets which secured the door hinge. As he was drilling out the last rivet, he struck a live 480V cable inside the enclosure. The drill was destroyed, and the drill bit vaporized. Fortunately the cabinet contained the arc-flash and the electrician was unhurt. Had the electrician de-energized this piece of equipment, the short triggered by the drill nicking the cable insulation could not have occurred. Further he could have worked on the equipment with the door open. He would have been able to see what he was doing and not nicked the cable insulation in the first place. In either case, the entire event could have been prevented.

Causes:

1. Failure to de-energize equipment
2. Inadequate personnel training and qualifications

Verification that Equipment is De-Energized

We see repeated problems when workers fail to verify that equipment is de-energized. As safety manager for the field service engineers, I literally get several reports a month about how one of our engineers found a circuit was still energized after it was supposedly isolated and locked-out. The reasons vary from site to site but it is a relatively common occurrence. You simply should not take this step for granted.

Exhibit 2.

Example 2. This enclosure should look bright, shiny and freshly painted. An electrician working on this Siemens equipment thought it was de-energized. He had access to a non-contact voltage detector, but used it incorrectly. The electrician needed to run additional control wiring in this enclosure. He was using a metal wire-fish. When the wire-fish contacted the energized bus there was an arc-flash event. The electrician was only wearing a short sleeve shirt. He received 2nd degree burns over his face, hands, arms and neck—everywhere not covered by clothing. A coworker described him as having weeping blisters over all the exposed skin areas for several days after the incident.

Causes:

1. Failures associated with Lock-out/Tag-out procedures
2. Inadequate personnel training and qualifications

Trip-Delay Settings on Breakers

Industrial circuit breakers have the ability to open slower than normal depending on settings that are "user" controlled. A 15kV breaker will typically trip (open) within 6-cycles or 100 mSec if the factory instantaneous setting has not been changed. 480V breakers will open even faster. Longer trip delays are sometimes used as a poor-mans substitute to handle coordination problems with subsidiary equipment startups (especially large motors). Adding a few tenths of a second to a trip delay can greatly increase the energy available in an arc-flash event…the total energy is directly dependent on this value. Values in the range of several seconds are ill-advised. If a trip-delay of several seconds is needed in order to keep a circuit breaker from opening under start-up or peak loads you have a problem with your load management. There are several options to fix the problem. They include adding an automation solution to sequence the start-up of multiple loads, or adding additional circuits to better distribute the load.

Exhibit 3.

Example 3. Siemens recently completed an arc-flash study for a client. We found a particular device supplied by a 34kV breaker with a trip delay set to 6.8 seconds (versus an instantaneous trip of 100 mSec.) The arc-flash energy was calculated to be in excess of 11,500 cal/cm^2. The best flash suit only goes to 100 cal/cm^2.

Our power study revealed a potential fault current at this location of 19,000 amps. Adding this value to the energy calculation below:

$$34{,}000\,volts \times 19{,}000\,amps \times 6.8\,\sec onds \Rightarrow 4.39 \times 10^{9}\ joules$$

This is roughly equivalent to an explosion of **2,000 lbs of TNT**[4].

4 According to www.megaconverter.com/mega2/ an explosion of 1 ton of TNT equals 4.18x10^9 joules.

This equipment cannot be safety worked on while energized regardless of what type of protective equipment is used. We were able to modify the equipment after the study with an automation solution to eliminate the need for the long trip-delay and therefore reduce the hazard to a manageable level.

Causes:

1. Inadequate personnel training and qualifications
2. Improper maintenance and/or operation

Keep Track of Tools

When your maintenance personnel examine or service your equipment they should perform careful counts of tools and parts before you re-energize the equipment. We get to fix or replace several pieces of equipment every year after a tool, wire, or part got left behind.

Exhibit 4a. BEFORE.

Siemens sold this 15kV circuit breaker to a client for use in their manufacturing facility. The racking handle can bee seen sitting across the upper fingers. The breaker fingers mate with electrical contacts in the back of the breaker enclosure to make the electrical connection.

Exhibit 4b. AFTER…

The client had their electrical contractor install the breaker for them. The racking handle (or what remains of it) is in the same location as before. The contractor failed to notice that they left it in place before energizing the breaker. A simple check would have revealed the short-circuit before the energizing.

Causes:

1. Inadequate personnel training and qualifications
2. Improper maintenance and/or operation

Cleaning and Maintenance

Factory and industrial environments are often dirty. Your equipment must be cleaned and maintained periodically. We recommend annual service inspections. Many companies put off routine cleaning of their electrical equipment assuming that if it is currently working they doesn't have any problems. Build up of dust or debris can cause electrical problems, fires, and even equipment explosions. Electrical equipment is also warm—and warm dark areas invite critters. We have found customer equipment with dead (and live) birds, bugs, reptiles, rodents, and all other manner of crawly (or formerly crawly) things inside.

Exhibit 5.

Example 5. This bird's nest (with dead birds) was found in a 480V transformer at a customer site. The factory cover was missing and the customer's electricians had replaced it with a home-made one which allowed the birds to get inside. The nest was obviously several years old.

Causes:

- Improper maintenance and/or operation

Equipment Modifications

We have seen many home-made modifications to equipment over the years. We often see customers resort to home-made replacement parts on older equipment when standard spare parts are no longer available. Make-do parts may be used to save money. We often see customers who have make modifications to their electrical infrastructure without updating their one-line diagrams. After many years of this practice it becomes very difficult to determine what is actually connected where. In this case we often find unexpected back-feeds (like the one in the example below). We also see a lot of equipment that is fed from multiple sources. We see switches and breakers that have been bypassed or hardwired with a fair amount of regularity. There are some very creative (Rube-Goldberg) solutions out there to electrical equipment problems.

Exhibit 6.

Example 6. This was a spare (out of service) transformer at a customer's site. When our engineer came to the site it was standing alone, in a small containment area, well separated from other units and sources of power. No obvious electrical service was connected. Our scope of project was to regasket the low voltage bushings on this unit as well as seven other units. When our employees opened the bushing throats they noticed the wiring (see inset photo) and stopped work.

The customer forgot he had added a 480V back-feed to the low voltage side in order to keep this unit warm in the winter.

Not only was this a potentially dangerous practice but it actually damaged the transformer. We had to complete many thousands of dollars worth of additional repairs to the transformer to fix the damage. A more appropriate method to keep the unit warm in cold weather would have been to purchase the standard heater made by the transformer's manufacturer.

Causes:

- Improper maintenance and/or operation