

CASE STUDY OF HAZARDS ASSOCIATED WITH NEUTRAL CONDUCTORS

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Abstract – Establishing an electrically safe work condition, as defined in Article 120 of NFPA 70E, is a common practice in the electrical industry used to ensure a system has been and will remain de-energized during work performed on the respective equipment. The process includes steps to ensure all sources of energy have been isolated, that locks/tags have been installed, and that all voltage potential has been verified to be zero prior to work commencing. This paper will examine a scenario where a previously undetected voltage hazard manifested itself while lifting / isolating neutral conductors in an electrically safe work condition. This hazard can exist and go undetected through traditional methods used in establishing an electrically safe work condition; it can result in harmful or even fatal electrocution. This paper will examine the hazard, provide common scenarios for when this hazard could manifest itself, and will also provide methods for mitigating the hazard using engineering and administrative controls.

Index Terms — Electrically safe work condition, shock hazard, neutral conductor, voltage verification.

I. INTRODUCTION

This case study will highlight an incident which resulted in a workplace fatality. Specific details and facts will be illustrated to help outline aspects of the work related to the incident in an effort to frame the scenario to make the lessons learned transferrable to similar situations, thus avoiding further incidents due to lack of industry and regulatory solutions around neutral conductor safety. The logistics, job scope, site planning, and the activities both the day before and after the incident will be described to offer an analytical examination of the incident, thus allowing the most effective solutions to be put into place within any and all organizations performing work similar in nature to this specific event. The discussion will additionally offer one example of a response plan which contains learnings that are applicable to any incident response scenario related to a severe incident. Finally, an example procedure will be shared that has been proven as an effective countermeasure to this obscure hazard.

II. DESCRIPTION OF EVENTS

A. Job Scope

The scope of work included four (4) distinct work locations at the customer site. The discussion will focus on the location where the incident occurred, however, all have some tangential relationship, so they will also be referenced and included to a lesser degree. The work locations were Substation 7, the 5 kilovolt L1 switchgear, the central maintenance facility feed and the laboratory building feed.

- Substation 7 included two tasks; remove and replace two protective relays and one digital meter located at the 5 kilovolt L1 switchgear feeder contactor and troubleshoot the 125 volt direct current control power circuit for the feeder contactor.
- The second location, the 5 kilovolt LI switchgear, included adding fuses to three, non-fused, load interrupt switches feeding the Lab, the central maintenance facility, and a third feed not in the scope of work.
- The third location, the maintenance facility feed, would involve testing the cables that fed the maintenance facility, testing the maintenance facility incoming transformer, and testing the low voltage cables feeding the maintenance facility main switchboard.
- The fourth location was the laboratory building feed. This would include the cables from the 5 kilovolt load interrupt switch to the transformer feeding the laboratory, and the 480 volt cables feeding the Laboratory main switchboard.

The Lab feed cables ran from the 2nd location, the 5 kilovolt LI switchgear, which was approximately 150 feet away, to the Lab incoming transformer. The load cables from the Lab transformer fed the Lab's main incoming transformer, which was approximately 100 feet away. To properly test the conductors and the transformer, both needed to be disconnected from all other points of equipment contact and isolated from the system to perform the test properly. The relay replacements, control circuit troubleshooting, and the switchgear fuse installation were the primary reasons for the outage. Since the system upstream of the laboratory building was going to be de-energized, it provided an opportunity to perform routine testing and preventative maintenance on the

transformer and its primary / secondary conductors. This is noted to indicate that the transformer and associated cabling were showing no signs of malfunction and the testing to be performed was both opportunistic and for proactive examination only.

B. Planning

Roughly one month before the shutdown and subsequent work was to commence, a job walk was conducted to go through the various scopes of work, the schedule, and logistics of the project. The team which included the lead field engineer assigned to the job, as well as the customer, reviewed the single line drawings and work locations to develop a preliminary energy control plan (lockout/tagout) to isolate all impacted job locations. The teams were selected based upon familiarity with the customer, as well as skill levels necessary to complete the tasks.

C. Day of Incident

The day started with a job safety briefing to review the scope of work, PPE evaluation, site hazard analysis, mitigation plans, and energy control plan (lockout/tagout), to ensure all parties were in agreement with both plans prior to work commencing. This briefing was conducted with all parties involved in the project, including the field service team, the electrical contractor, and the customer. Part of the discussion was to inform all parties that two (2) temporary generators were installed and connected to provide temporary power at two separate locations. The first generator was installed at the central maintenance facility incoming switchboard. The second generator was installed at the Lab incoming switchboard. These generators were already in place and feeding their respective loads when all parties arrived that morning. There would be several activities going on simultaneously, and each person was to have a clear understanding of the entire job with all lockout/tagout points. The work permit was valid until 6pm that day. The energy control plan (lockout/tagout) was walked through with the customer, and all members of the team, and then reviewed and approved by the facilities electrical engineer. This plan was then used to establish and verify an electrically safe work condition using the NFPA 70E 120.5 method [1] as follows:

- (1) Determine all possible sources of electrical supply to the specific equipment. Check applicable up-to date drawings, diagrams, and identification tags.
- (2) After properly interrupting the load, open the disconnecting device(s) for each source.
- (3) Wherever possible, visually verify that all blades of the disconnecting devices are fully open or that drawout-type circuit breakers are withdrawn to the fully disconnected position.
- (4) Release stored electrical energy.
- (5) Release or block stored mechanical energy.
- (6) Apply lockout / tagout devices in accordance with a documented and established procedure.
- (7) Use an adequately rated portable test instrument to test each phase conductor or circuit part to verify it is de-energized. Test each phase conductor or circuit part both phase-to-phase and phase-to-ground. Before and after each test, determine that the test instrument is operating satisfactorily through verification on any known voltage source.

After completing these steps for each work location, the team split up into the different work areas and began work for the day. Because the work permit would expire at 6:00pm, the field service job lead wrapped up his tasks for the day at 5:30pm to perform a walk around and assess the work completed that day and to develop a plan for the following day. He moved from substation 7 to the 5 kilovolt L1 switchgear work area and talked with each team member. One individual was disconnecting cables from the low voltage secondary side of the transformer. Having the cables removed would mean that testing could start first thing the following day. All the phase conductors had been disconnected from the secondary side of the transformer, and the service technician was beginning to remove the neutral conductors. Each conductor bank had a parallel network of three 500 MCM conductors per phase on the landing pad of the transformer. The neutral bank was rated as a 300% neutral feeder and had six 500 MCM conductors on the neutral landing pad on the transformer. Each of the phase conductors is bulky and required each to be disconnected individually. Upon lifting the final neutral cable, a previously unmeasurable voltage difference appeared between the neutral cable and all areas of the equipment at ground potential including the transformer lug / paddle, which was still grounded. As a result, the individual subsequently became the path to ground between the final neutral conductor and ground when their elbow contacted the frame of the transformer housing.

D. Cause

It was discovered that the temporary generator caused the voltage potential to appear. The customer was continuing to perform lab work for the refinery that required internal power for lighting loads and miscellaneous lab equipment. It was later determined that the main switchboard had neutral loads connected to the main 480 volt switchboard. The lighting system requires a 277 voltage source. The temporary generator was rated at 480 volts and could generate up to 400 amps of capacity. The temporary cables coming from the generator to the main switchboard were connected to a 400 Amp circuit breaker on the main switchboard that was being utilized as a back-feed breaker. The main switchboard is service entrance rated equipment with ground fault protection. This is a three phase, four wire panel rated for 1200 Amps. The main circuit breaker was lockout/tagout with the customer lock attached using a lock box for all contractors. The temporary cables were connected in a three phase, three wire configuration. A neutral conductor was not installed between the temporary generator and the switchboard as the National Electric Code requires in this situation. Functionally this would have been needed because there were neutral loads on the main switchboard and a return path was needed to complete the single phase circuits. However, a ground conductor was installed from the generator to the main switchboard. It was also determined that the neutral ground jumper located inside the main distribution section was removed at some prior time, but not during the work being performed, nor when the temporary generator was connected. The neutral lighting load was subsequently left with one remaining path to ground, and that was through the neutral cable running to the pad mounted transformer where the cables were being disconnected. In summary, the neutral conductor from the main switchboard back to the generator did not exist and this is the reason for the presence of unmeasurable

potential voltage at the transformer work location.

The voltage potential appeared when the last neutral was disconnected from the landing pad on the transformer and created an open condition between the neutral return path and grounded conductor.

III. RESPONSE

There is no perfectly effective way to transfer the actions taken in the wake of such a tragedy so that others may learn and improve their own response. There are, however, transferrable processes and methodologies, and actions that were taken after the incident occurred that are valuable and worth sharing. The response / approach that was used in this scenario is outlined below.

A. Investigation and Immediate Actions

The immediate need was to perform a detailed investigation of the incident to develop a clear understanding of what happened and why this hazard went undetected. The first step was to assemble an internal investigation team that possessed a variety of skill sets, functional expertise and technical aptitude. The primary skills necessary to investigate an electrical safety incident of this magnitude included personnel proficient in safety investigations and root cause analysis, technically competent in power system design, application and testing, competent in the operation and maintenance of specific equipment that was involved, detail oriented, data driven, skilled in written and verbal communication, and team leadership. The team was quickly formed and deployed to the site the day after the incident to promptly begin the investigation. There was notable concern that access may start to become restricted, memories might fade, and critical site details might begin to change if the team wasn't timely in its response. There was also an overarching urgency to discover the causes as quickly as possible so that the lessons learned and a hazard mitigation process could be developed and shared as quickly as possible. Not all personnel on the team were directly involved in the onsite investigation, which proved to be very effective. The need to have at least one person on the team in charge of collecting notes, scheduling calls with leadership, and filtering and organizing the questions coming to the team was evident at the onset of the investigation. This person was given access to the information generated from the investigation but was not part of the site team. This allowed the core team members to focus their attention on the most critical aspect of the investigation – the identification of the root cause(s) and development of the subsequent short-term and long-term actions necessary to protect the greater organization from experiencing a similar tragedy.

Upon completion of the investigation, focus shifted to the containment action plan, which would be the primary method for ensuring there would be no other similar incidents in the future. The immediate communication was highly technical to call attention to the hazard itself and a full “stop work” was implemented with any task requiring the removal of a neutral conductor from any equipment with the potential of being fed from multiple sources.

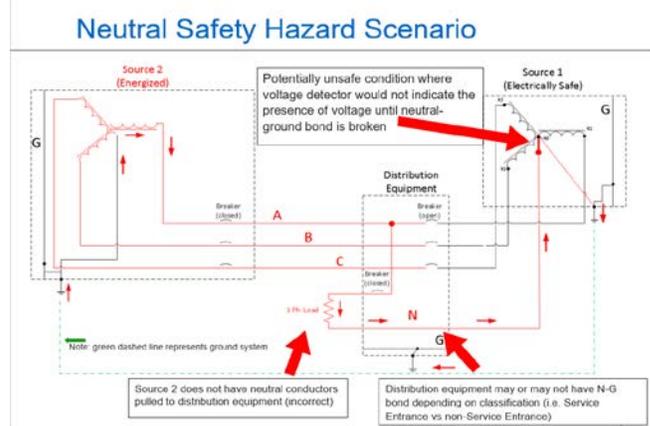


Fig. 1 Neutral Safety Hazard

Detailed schematics were created and a step-by-step process was developed to aid in the communication to the distributed workforce through a series of safety stand-down webinars. The focus of the communication was on identifying any systems that presented the potential for this hazard to exist and the mitigation steps to control it. An eight-step plan was developed focusing on how to administratively control the hazard while the search for an engineering solution continued.

The administrative control plan illustrated the following steps to be taken after an electrically safe work condition had been established and prior to lifting any neutral conductors:

- (1) Measure the current in the neutral using an ammeter. (Stop and reassess if measurable current is detected).
- (2) Create an alternate path to ground for all potential current carrying neutral conductors.
- (3) Verify the integrity of that newly created path.
- (4) Disconnect the neutral conductors from the electrical apparatus, ensuring the alternate path is maintained.
- (5) Perform the testing and/or preventative maintenance task on isolated equipment.
- (6) Maintaining the alternate path, reattach the neutral conductors.
- (7) Upon completion of terminating the final neutral conductor, remove the alternate / temporary path.
- (8) Remove the ammeter.

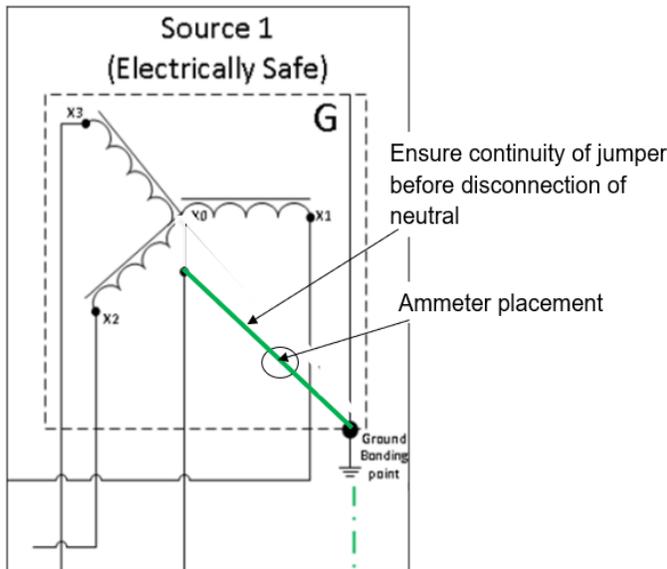


Fig. 2 Diagram of Alternate Path Creation

This approach was communicated to the entire field service organization via a series of virtual online meetings, with the initial meeting being recorded for use in future communications or as a follow-up reference. This recording was proactively shared internationally so that global teams who might perform work of a similar fashion would have an opportunity to translate, distribute and digest the information. The international teams then had an opportunity to raise questions on additional global virtual meetings with the original technical team hosting to ensure a consistent message. These meetings were also recorded for reference and future training aids.

With regard to using an ammeter to monitor current, it should be noted that this is an unreliable form of ensuring an electrical safe work condition has been created or that it is being maintained. This step is strictly to help identify if the hazard might be present in advance of performing the work. Due to limitations in the accuracy of detecting small, trace amounts of current, as well as the ability for current to “come and go” as loads are turned on/off, this should not be used as the sole prevention method. The act of ensuring the alternate path for all current carrying neutral conductors by the installation of the jumper is the portion of the solution that creates and maintains the electrical safe work condition by never allowing the neutral conductors to lose their reference to ground potential. The meter placement is also there in part to identify that there could be auxiliary issues associated with removing the neutral from an equipment standpoint and to point out potential unknown risks to the customer regarding their system design. It is also critical to note that this process is in addition to the standard method of verification that an electrically safe work condition has been created which is to follow the NFPA 70E 7 step process referenced above.

As an additional key process note, the corrective actions were communicated as they surfaced. Information and lessons were uncovered without having some of the precursor facts, but the lesson was still valid as a stand-alone learning. There were other lessons that fit into other non-technical categories, but the initial technical information was shared within 48 hours of the realization of what had gone wrong and how the hazard

manifested itself. A team built the technical slides, other members built the distribution list and scheduled calls, and others vetted the release with internal functions. It was this parallel path of each of these teams that allowed for such a quick and effective sharing. The other less technical lessons were shared over time as part of the long-term communication plan.

B. Intermediate Actions

A second team was selected for program analysis, which resulted in a deep dive of the entire field service safety program. Although nothing was learned that could have proactively prevented the situation that led to incident being shared in this paper, there were steps put into place that are actively working to predict the next failure mode, code violation or installation error. The purpose is to vet these potential gaps against the safety program and ensure the program has the proper defenses put into place to protect workers.

Having built and deployed the internal communication plan and information sharing channels, the next phase was to do the same for the next level of stake holders. A different communication was developed to help answer questions for customers and contractors that were interested in the situation and any learnings that may have been extracted from the incident. To date, the sharing of this communication has been well received and has been met with similar reactions as those reactions that were felt internally. Customers have taken the technical learnings from this incident and incorporated them into their own electrical safety programs and continued sharing with contractors and vendors as well. Awareness of this condition is a vital learning in the electrical community when working on electrical systems.

C. Long-Term Actions

The long-term actions were separated into two categories: ensuring the hazard recognition and internal solutions would be embedded into the safety training program as sustainable learnings and to expand the sharing of this event with the broader electrical community as the final communication and education step. For the first category, several training kits were created to allow a hands-on approach to the learning activity and to allow for a test to be administered to ensure knowledge transfer. These kits were used by technical trainers and safety department personnel to proctor written and hands-on examinations for all field based employees within the division. The intent and structure of the exams were also shared internationally to ensure full deployment. The second category was external communication and education, and the sharing of this event with the broader electrical community was the final step in that process. Capturing the technical description of the hazard, as well as the detailed case study of the onsite incident will allow this obscure risk to be discussed in mainstream electrical safety venues as well as incorporate it into more local programs at all levels of electrical work. For example, this concept can be expanded to commercial locations with single phase lighting loads derived from a shared neutral system. Although the incident described within this paper occurred on a 480 volt alternating current system at the secondary side of a transformer, it is of critical importance to identify that a similar neutral hazard could occur on three phase lighting circuits. The

circuit breaker can isolate one phase of the shared neutral circuit conductor, but not the neutral conductor itself. If the other two phases are sharing the same neutral conductor the returning current is still a hazard on a shared neutral conductor even though one of the A, B, or C phases has been isolated by means of lockout/tagout. It is a common practice during preventative maintenance to back-feed a lighting panel to be used as back up lighting source. Where a problem can develop is current flowing back to the main source. If the permanent neutral is not properly isolated in the subpanel, current can flow back to the main source of power and return to the grounded electrode. Another potential for a shared neutral is on three phase automatic transfer switches that have a shared neutral conductor on the line and load side of the circuit. The neutral and ground conductors are isolated and if working on the downstream system the potential current flow can exist. These examples show how this obscure hazard can manifest itself in other types of electrical systems in addition to the tragic incident reviewed within this paper, and why it is so critical to share the information with as broad an audience as possible within the electrical work arena.

IV. REFERENCES

- [1] NFPA 70E, 2018 *Standard for Electrical Safety in the Workplace*, 120.5 (1)-(7), Quincy, MA: NFPA Technical Committee on Electrical Safety in the Workplace

V. CONCLUSIONS

All electrical safety programs should be examined to ensure they have adequate defenses put in place to protect workers from the obscure hazard described in this case study. This examination should not be limited to scopes of work that involve transformer neutral connections or disconnections but should be broadened to include any work location where a shared neutral has the potential to remain a current carrying conductor even after the phase conductor(s) within the circuit in question have been properly isolated by following the industry standard approach. In this case study, it was the improper wiring of a temporary generator that caused the electrically safe work condition to be voided but this is not the only scenario that actions taken within Lockout / Tagout boundary can alter the electrically safe work condition. With that in mind, it is important to examine another aspect of safety – the electrically safe work condition itself. While there has always been a focus on creating an electrically safe work condition using industry standards, increased emphasis must be placed on maintaining that electrically safe work condition throughout the duration of the de-energized work. This emphasis of creating and maintaining an electrically safe work condition is a subtle but important distinction that calls attention to considering system changes necessary for testing, troubleshooting or maintenance of the equipment that would occur during normal execution of the job scope. It is the potential risk associated with these changes that requires the extra effort of planning and control implementation. And finally, it is how this extra effort of planning and controls should be put into all safety programs and all areas of work were the creation of an electrical safe work condition is required.

VI. VITA

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Appendix A
Neutral Safety Hazard Scenario Illustrated

Neutral Safety Hazard Scenario

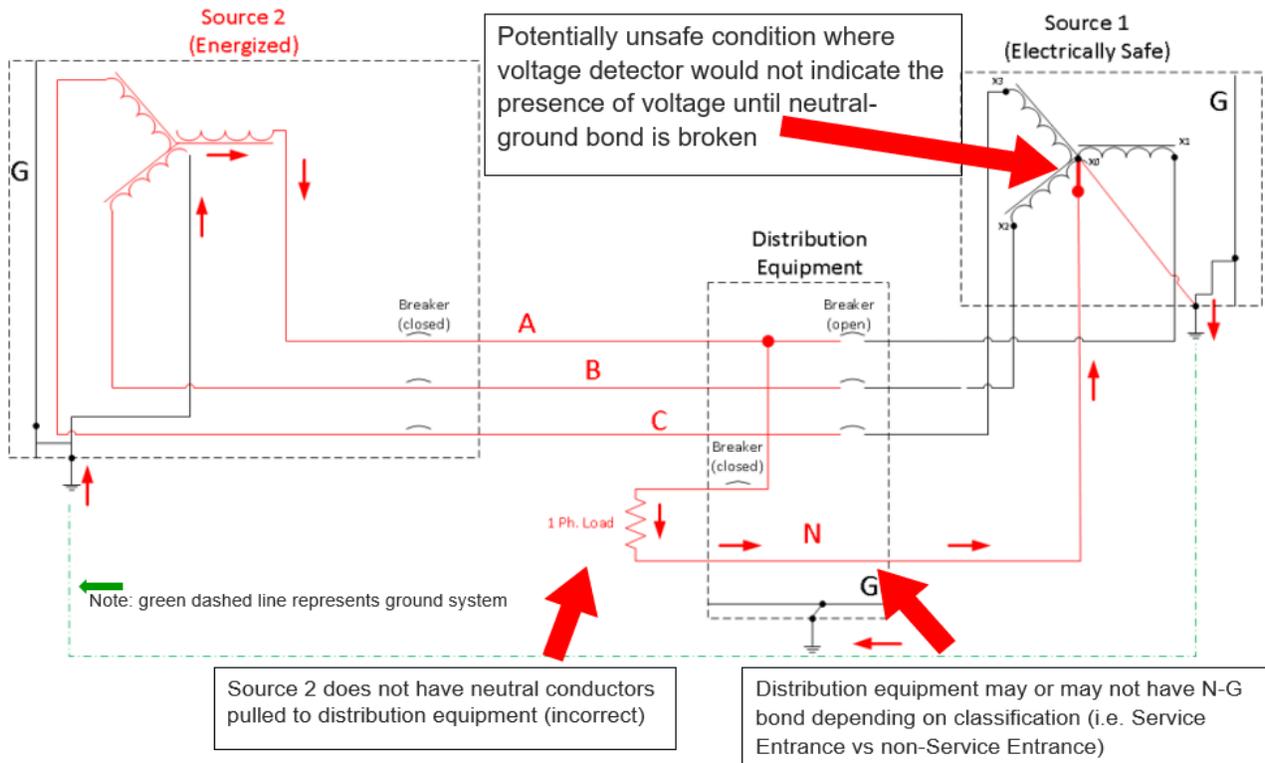


Fig. A-1 Neutral Safety Hazard