

Making My Paper Mill Safer: An Arc-Flash Energy Reduction Story

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MAKING MY PAPER MILL SAFER: AN ARC-FLASH ENERGY REDUCTION STORY

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Abstract - A Midwestern pulp and paper mill had arc-flash values around 100 cal/cm² on fifty 480 V unit substations. New relays were installed to replace existing protection and add light detection to improve arc-flash detection times. During a couple of one-day outages, sample installations took place. During the cold mill outage, 44 installations were completed over 12 days by working around the clock. Old relays were removed, new plates were mounted and wired in, and fiber sensors were routed through the buswork and into the breaker cubicles. Updated arc-flash studies show an average arc-flash rating reduction of 90 percent.

Index Terms - Arc-flash reduction, paper mill, outage plan, 480 V switchgear, close-coupled transformer and switchgear

I. INTRODUCTION

In 2016, an arc-flash study was conducted at a Midwestern pulp and paper mill. The study determined that a significant amount of equipment was categorized as exceeding 40 cal/cm², increasing the potential severity of an incident during operation and significantly elevating the level of precautions and protection needed to service the equipment. Upon further analysis, it was discovered that the areas with high incident energy throughout the mill—the 13.8 kV/480 V unit substations—contained similar types of equipment.

The low-voltage unit substations are fed with a primary load interrupter switch with fuses to protect the transformer. The transformer is close-coupled with the switchgear (see Fig. 1). Four to six 480 V feeder circuit breakers, selected based on the needs of the operating area, are installed in the switchgear (see Fig. 2). On the 480 V secondary side there is no main circuit breaker. With this design, the area of concern encompasses the 480 V feeder circuit breakers and all the 480 V switchgear compartments.

Due to the high incident energy, mill personnel were unable to operate these 480 V feeder circuit breakers in an energized state. This forced the mill to take additional downtime to install local disconnects to perform maintenance. Maintenance was not completed at scheduled times because that equipment could not be de-energized safely. In some cases, a transformer with up to six feeder circuit breakers had to be de-energized to work on a single feeder circuit breaker, which had a major impact on mill operations.



Fig. 1 Close-Coupled Transformer and Switchgear

The next step for the mill was to find potential solutions for the problem. It was a lengthy process to find a solution that would take minimal downtime to install, be cost-effective, and reduce high incident energy to less than 40 cal/cm² on all 480 V unit substations.

Most of the potential solutions required new equipment at some point in the system. Following are the solutions that were considered:

1. Replacement of the fused load interrupter switches on the primary side of the transformer to provide a controllable device upstream, in conjunction with a relay upgrade.
2. Upgrading the low-voltage switchgear to a design that included a main circuit breaker.
3. Several different relaying options, including maintenance switches, transformer differential, and dedicated arc-flash protection.

After careful consideration, it was determined that an arc-flash relay with optical light detection would be the correct solution for the mill because it met all the primary goals.

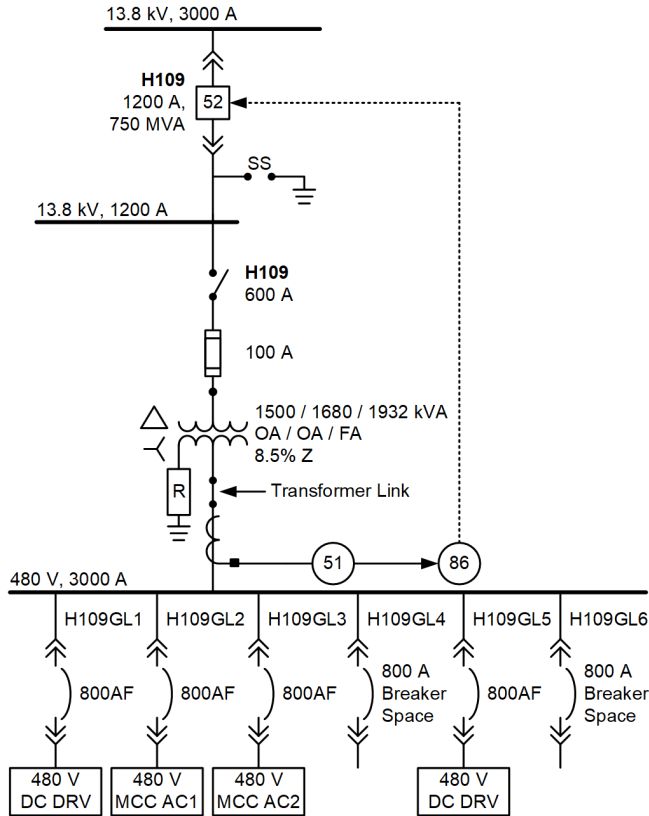


Fig. 2 One-Line of Example Unit Substation

II. DESIGN

Upgrades to the fifty 480 V unit substation installations with unacceptable arc-flash ratings began with an evaluation of the existing equipment. Following the evaluation, a retrofit design was created. The primary intent of the design was arc-flash mitigation. The secondary concern was ensuring that the design was robust and able to be quickly installed in the limited outage window.

A. Existing Design Investigation

The drawings available for the existing equipment were gathered to identify equipment vintages. This investigation identified two manufacturers. All the Manufacturer A equipment (see Fig. 3) was of the same design, except that some had a ground overcurrent and some only had phase overcurrent protection. Manufacturer B equipment (see Fig. 4) is similar, except for one recent installation. The physical location of the relaying and associated equipment varies in the Manufacturer B equipment. With this information, it was decided that four standard templates and a fifth unique design for the recent installation would allow for the best economy in design time and installation of equipment.



Fig. 3 Manufacturer A Switchgear



Fig. 4 Manufacturer B Switchgear

Manufacturer A equipment consists of two rear bus compartments and five feeder breaker compartments. All breaker compartments in Manufacturer A equipment are fully equipped with bus connections regardless of whether they have a breaker installed.

Manufacturer B equipment consists of two rear bus compartments, one transformer bus linkage compartment, and five breaker compartments, where one to five are equipped based on the number of feeder breakers installed.

The existing equipment does not have a dedicated high- or low-side breaker for the 13.8 kV/480 V transformers serving each remote switchgear installation. The overcurrent elements trip an 86 lockout relay, which trips the incoming 13.8 kV feed, taking out about 15 percent of the mill for each section. Installation of a dedicated breaker was not an option for this upgrade due to space, budget, and time considerations. Therefore, the overcurrent and arc-flash protection will continue to operate the 86 lockout relay and trip the main feed.

B. Retrofit Design Decision

Selecting the proper microprocessor-based relay for the replacement required consideration of the required protective functions, form factor, and arc-flash sensor installation. Each switchgear installation required one microprocessor-based relay for all its associated 480 V circuit breakers. It was decided that a feeder protective relay would suit the needs, as the protective functions are basic and require only inverse-time overcurrent elements. A relay would need a form factor like that of the existing electromechanical relays so that the relay could fit into the door with only minor modifications. Finally, the relay needed to support up to eight arc-flash light sensors for the worst-case Manufacturer B equipment. This equipment contains five breakers and three bus compartments; each breaker and each bus compartment requires its own sensor (see Fig. 5).

To increase efficiencies in installation, the design included prewired relays with a ten-foot whip with origin and destination labels. These were designed for the five different designs of existing equipment and shipped in boxes labeled A, B, C, D, and E, respectively. These prewired relays were paired with updated design prints for each of the 50 remote switchgear installations for efficiency in the field. Using the prewired relays was intended to reduce demolition time by eliminating the need to reuse existing wiring to the door. Steel plates were also cut to mount the relay and cover holes left by the electromechanical relays. Prior to installation, the relays were mounted in the plates to provide a finished installation with no holes in the doors that might allow debris or rodents to enter.

Correct mounting for the arc-flash sensors was critical to ensuring that the arc-flash mitigation functions properly. The bus sections and transformer link section on each manufacturer’s equipment were designated for bare-fiber loop sensors. For the bare fiber to detect light, it needs to be located no more than 2 meters from the light source and must have no less than half a meter of fiber exposed to the light. To accomplish this, the fiber was looped through the compartment, with all the bare fiber in the protected compartment (see Fig. 6).

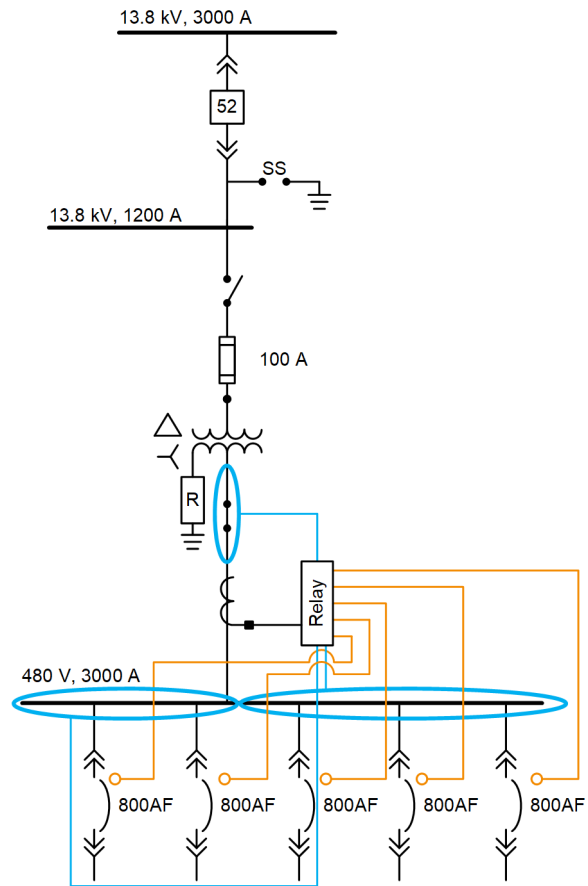


Fig. 5 Light Sensor Locations

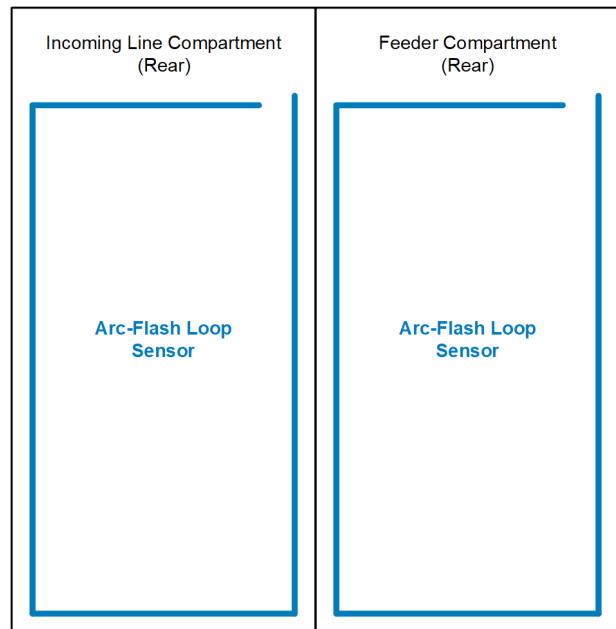


Fig. 6 Loop Sensor Routing Detail

The circuit breaker compartments are equipped with point sensors to better protect the enclosed breaker space. They were mounted on the ceiling of each compartment directly over the breaker stabs to detect arc-flash events as quickly as possible (see Fig. 7).



Fig. 7 Point Sensor Mounting Detail

C. Settings

The final portion of the design included creating settings files for the new microprocessor-based relays. The overcurrent set points were created using the existing electromechanical relay settings. The existing curves, pickups, and time dials were loaded into power system modeling software, and an appropriate curve and set point were selected and mapped in the software for the new relay to ensure a match.

Fast and secure arc-flash settings were also developed. Because a trip will take out a large portion of the mill, it is important to only trip when there is a true arc-flash event. To this end, the arc-flash trip initiates when one of the sensors sees light and the relay senses at least two times the expected full load amperes. This ensures that a startup will not trip on an arc flash even if the current spikes above twice the transformer full load because there will be no light sensed. The relay can still pick up early in the fault as the current just begins to spike.

The 480 V circuit breakers are air-magnetic devices that create significant light when interrupting high fault current as a result of the interrupting arc. This adds an additional challenge to arc-flash protection because if the circuit breakers operate for a downstream overcurrent, the relay will see both high current (from the fault occurring) and light (from the circuit breaker functioning properly to clear the fault). The circuit breakers did not have position contacts available to bring into the relays. Thus, to prevent a false trip, the light sensors in the breaker compartments are programmed with a five-cycle delay to allow the circuit breaker to clear a downstream fault while still operating quickly for an arc-flash event (see Fig. 8).

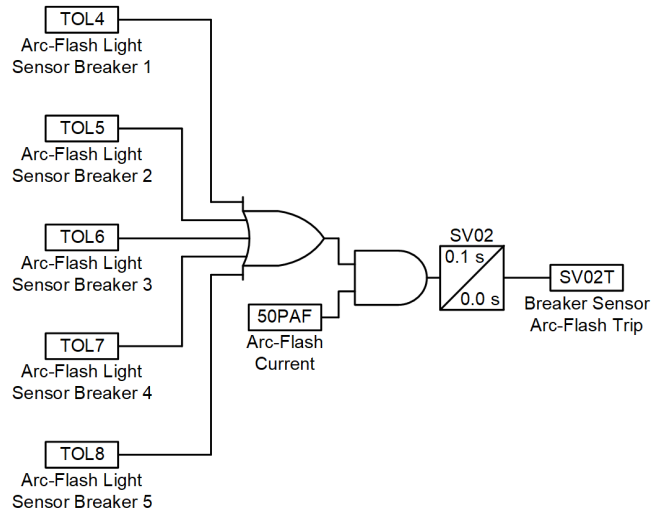


Fig. 8 Delay Logic for Arc-Flash Trip on Breakers

III. INSTALLATION

The biggest challenge in completing the arc-flash protection upgrade was the installation. In a mill, there are few opportunities for the outages required to upgrade power systems. The mill was scheduled for a cold mill outage for 14.5 days in April of 2018. Because the plan required the upgrade of 50 unit substations located throughout the mill, scheduling was critical. To better understand the needs and process for installation, a few non-critical systems, which were already scheduled for shorter outages at the end of 2017 and the beginning of 2018, were selected as pilots.

A. Pilot Installations

The first two pilot installations took place over two days in November of 2017. One Manufacturer A and one Manufacturer B switchgear installation were selected to give a sampling of what would be encountered in the remaining 48 installations. With the end goal of an 8-hour installation time per switchgear unit, 12 hours were allotted for each of the first two installations. The Manufacturer A equipment was the first to be retrofitted. The lockout-tagout process to properly isolate the gear and apply grounding cables (see Fig. 9) took nearly two hours. To save time, one electrician began removing the old electromechanical overcurrent relays and associated wiring while another began routing the bare-fiber cable into the back of the gear. The demolition took an hour to complete, and about half of this time was spent verifying that the correct wires were being removed.

Following the removal of the electromechanical relays, a punch was used to enlarge the hole in the door to allow the slightly larger microprocessor-based relay to fit. The hydraulic punch worked well, but some trial and error were required to find the correct size, and the hole needed some filing to remove sharp edges. Enlarging the hole took about half an hour.

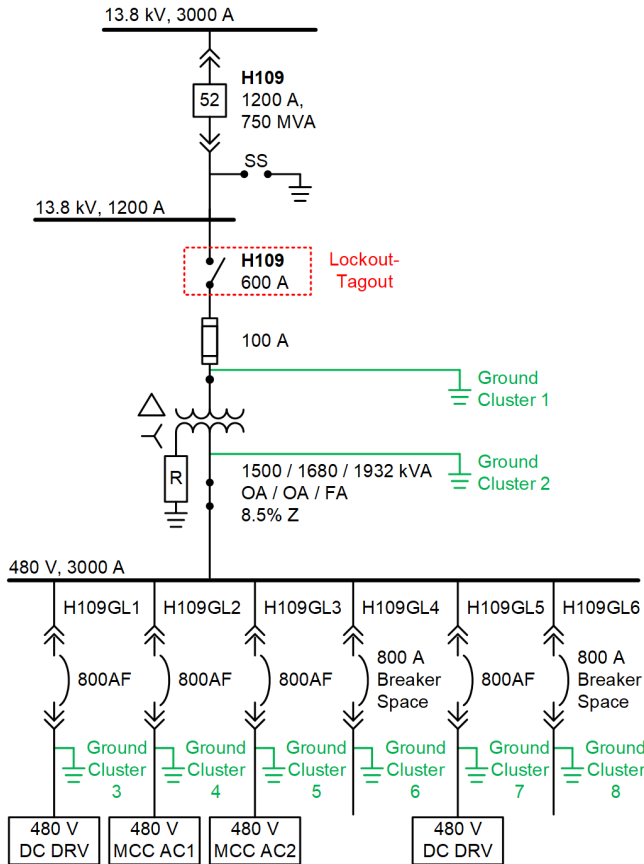


Fig. 9 Isolation and Lockout Detail

The relay, already mounted on a prefabricated steel plate sized to cover the holes from the removed relays, was mounted to the door. Then, the whip of wires pre-attached to the relay rear was cut to length. Lugs were applied and landed on the appropriate locations in the cabinet or on the door, based on provided wire tags. Finally, a new jumper was added to complete the design. The mounting and wiring took about three hours.

Manufacturer A's equipment has good spacing with large rear compartments and a break between the relaying and the 480 V breakers located on the front. These characteristics allowed the arc-flash fiber sensors to start being installed while the relays were being changed out. The bare-fiber loops were mounted in the two rear bus compartments. Each compartment received its own loop, which circled the entire space. Sticky backs were used to secure the fiber, so first the interior walls of the gear were wiped down to ensure proper adhesion, and then the fiber was routed and sticky backs were placed every couple of feet to secure it in place. The fiber was routed such that it was never located directly over the buswork. This was done so that a sticky-back failure would not result in a fiber falling onto the bus. This work required getting into the bus sections of the gear and took approximately two hours to complete.

The circuit breaker compartments were protected using fiber-optic point sensors to better sense the light of an arc-flash event on the breaker disconnect points. To mount these

sensors, quarter-inch holes were drilled above each breaker in the rear of the compartment. The fiber back to the relay was fed through existing pass-throughs and dropped along the gap to the side of the breaker compartment to reach the lower breaker. To ensure that no metal shavings would be left in the gear from the holes being drilled, magnets and a small box taped below the drill point were used to collect shavings. Mounting the point sensors took another two hours.

Following the installation and commissioning, engineers began the checkout process. The wiring was validated using a blue line, point-to-point method. Connections were made to a test set (which required some rewiring due to the lack of test switches) to complete a functional checkout. The instantaneous overcurrent elements were tested at three points on the curve to verify compliance. The arc-flash protection was tested by applying arc-flash current to the relay and then using a high-power camera flash on each sensor. The flash simulates the light while the test set simulates the above-load current required for quick and secure operation. The test values indicated that the trip output closed within a millisecond of the light and current being detected. The plant remained in service during the pilot installations, preventing a timing test up to the high side breaker. The trip test was carried through to trip the lockout relay. Operating the lockout allowed testing of the contact impedance and cleaning of the contacts for relays that had become grimy in high-moisture and high-dust locations. Following the testing, the wiring was reconnected and verified. The full testing process was completed in two hours.

Once the full testing process was complete, the gear was returned to normal service. The lockouts and grounds were removed, and the disconnect switch was placed back into the connected position. The reconnect took another hour. The full process took just over 12 hours to complete for the first installation.

The following day, the second pilot was completed in much the same fashion on the Manufacturer B equipment. The Manufacturer B equipment was more cramped, meaning the point sensors could not be mounted while the relays were being replaced. There is also more variability in the relay mounting location on Manufacturer B equipment, as some relays were mounted in the lowest cubicle, some in the center, and some at the top. This resulted in less consistency in where the relay wires needed to land and potentially non-ideal worker positioning for the low-mounted relays. This second installation took nearly 13 hours from start to finish. Additional time was taken to discuss best methods and take photos during the installation to prepare for the remaining installations.

After reviewing the initial installation, it was decided that dividing the prewired connections on the rear of the relay into bundles, which would go into the cabinet or stay on the door, would speed up installation. A step-by-step guide was created for each installation using pictures and notes from the first two pilots to make the installation easily repeatable by different crews. The time and steps required to complete the pilot installations showed that multiple installations would need to happen simultaneously and around the clock during the mill outage.

To validate the outage plan, a second group of pilot installations consisting of four substations was scheduled for February 2018. The plan for this outage was to use the documentation and lessons learned during the first pilot and to have two teams work in parallel, each on its own unit with one design and commissioning engineer between the two. The lockout-tagout process continued to take about two hours due primarily to the limited number of people qualified to perform the work. The installation documentation took the demolition time down to half an hour. Dividing the wires into bundles took the relay installation time down to approximately two hours. One commissioning engineer was found to be sufficient for two installation teams working close to one another. With the updates, two teams were able to finish two separate pilots in about 12 hours total. This was still longer than the original goal; however, it was consistent across installations, and that time was used to plan the remaining 44 installations during the full-mill outage.

B. Cold Mill Outage Installations

A cold mill outage is scheduled every five years and includes an overnight isolation of the 13.8 kV bus. Maintenance is done on all mill equipment, not just the power system, so all outages must be carefully coordinated.

A detailed schedule was created with two 12-hour shifts, each running from 6:00 to 6:00, to provide around-the-clock installation support. Each set of teams was scheduled to install two to four upgrades per shift, with an estimated completion of all installations in Day 12 of the outage. Installations done in the same shift were collocated whenever possible. Auxiliary lighting and power were also planned for, as necessary.

On each of the first two shifts, four installation teams doubled up on two installations for training purposes. The installers and engineers who were present for the pilot installations guided the teams on the best practices established during the pilot installations. There was a dedicated set of four teams with one commissioning engineer and one member of the mill engineering team on the night shift and a separate set for the day shift. Each crew had its own dedicated equipment, no gear was shared between the night and day shifts to ensure that any overrun of time by one crew would not delay the other. The installation was front loaded, and three to four installations were completed during each shift in the second and third days. To accommodate the accelerated installs, two additional commissioning engineers worked overlapping shifts to ensure that engineering checks did not delay re-energization.

Efficiencies were gained throughout the installations. Required jumpers were made up ahead of time. Test equipment was connected directly off the current transformer secondaries where they were visible to reduce the rewiring necessary during testing. Commissioning test plans were written while construction was underway to speed the test-out process. Electrical contractors were trained in lockout-tagout procedures, providing more hands to accomplish the task.

The teams also learned the tasks and were able to complete them more quickly with less input from engineers. By the final installations, teams were completing their work in 10 hours rather than the original 12. The final installation was completed as planned by 6:00 a.m. on Day 12 of the outage.

IV. RESULTS

The results (shown in Table I) from installing the arc-flash relays exceed expectations. An arc-flash study was conducted on the six pilot installation substations. The findings revealed an arc-flash energy reduction average of 91 percent. Most of the ratings were well above 40 cal/cm² prior to the relay upgrade, with some exceeding 100 cal/cm². Following the upgrade, the six original unit substations all dropped to Category 1 or 2 level arc-flash hazards. With these high incident energy ratings reduced to a manageable level, mill personnel can now perform maintenance on scheduled intervals, de-energize equipment safely, and—most importantly—provide a safer working environment. This does not eliminate risk completely, but it does remove a big portion of it. This system is online 100 percent of the time, so there is no need for human interaction prior to performing work. Each installation also has a new digital relay that can produce outputs the old electromechanical relays could not, including real-time metering data that can be trended to help predict maintenance issues in the mill. The mill understands that this may not be the ideal solution for every situation, but in this case it worked well.

TABLE I
ARC-FLASH STUDY DATA FOR PILOT
INSTALLATION SUBSTATIONS [2] [3]

480 V Location	Incident Energy Before (cal/cm ²)	Incident Energy After (cal/cm ²)	Incident Energy Reduction (cal/cm ²)	Incident Energy Reduction (%)
H202BB	62.3	5.8	56.5	91
H207-10	104.1	10.1	94.0	90
H207-6	67.7	6.3	61.4	91
H207-5	83.9	8.0	75.9	90
H207-4	84.1	7.8	76.3	91
H207-2	83.3	8.1	75.2	90
Average Incident Energy Reduction			72.8	91

V. REFERENCES

- [1] M. Zeller, A. Hargrave, and D. Haas, "Using the SEL-751 and SEL-751A for Arc-Flash Detection," SEL Application Guide (AG2011-01), 2016.
- [2] NFPA 70E Standard for Electrical Safety in the Work Place, 2015.
- [3] IEEE Standard 1584-2002, IEEE Guide for Performing Arc-Flash Hazard Calculations.

VI. BIOGRAPHIES

Haley Newton, PE, received her B.S. degree in electrical engineering from Lawrence Technological University in 2012 and her M.Eng. degree in electrical engineering from the University of Idaho in 2015. Haley has been a licensed engineer since 2015. She has worked as a protection and design engineer with Schweitzer Engineering Laboratories (SEL) since 2012. She also taught as an adjunct in the electrical engineering department at Lawrence Technological University in the spring of 2018.

Jordan McCrory formerly held an electrical engineering position for Verso Corporation. He was the power system owner for the Quinnesec Mill in addition to his duties as an electrical project engineer. During his five years at Verso, he led the mill's electrical safety team and arc-flash remediation efforts. Jordan is currently employed as a corporate electrical engineer with Georgia-Pacific LLC. He graduated from Michigan Technological University in 2013 with a B.S. degree in electrical engineering technology.