THIS ARTICLE OUTLINES THE EXPERIENCE OF ONE global cement producer that embarked on site surveys and studies to achieve arc flash safety compliance at 13 cement plants in the United States and Canada. The enterprise-wide electrical workplace safety initiative resulted in compliance by all plant sites to the latest standards, with new labels affixed to each openable electrical panel that quantified the hazard. Labels designated the proper personal protective equipment (PPE) required to ensure that electricians performing energized work would be safe from potential arc events. One plant's experience in deploying select new technologies to mitigate arc flash in areas where hazards were very high will be reviewed in detail. Site electrical upgrades resulted in enhanced safety, along with an unexpected benefit: a significant improvement in production reliability. A follow-up project to increase the plant grinding capacity at the site outlines how new additions to the electrical infrastructure employed a safety-by-design approach to ensure arc flash safety.

Background

A cement plant in Western Canada is one of 13 cement-producing facilities in North America owned by a global producer with headquarters in Europe. The plant is a dry-process, coal-fired plant with a four-stage preheater–precalciner. It was constructed during the late 1970s with an original design capacity of 650,000 t of cement per year. Since that time, the facility has been expanded and optimized to its current production capacity of approximately 1.2 million t of cement for a market that includes the Canadian provinces of Alberta, Saskatchewan, and Manitoba. Limestone, the primary raw material, is shipped daily by train from the plant’s quarry located in a city about 350 km west of the plant. Clay is quarried on the property, while sand, iron ore, and bottom ash from a coal power plant are trucked in daily for use in the pyro process. Gypsum used in the cement-grinding process is shipped by rail from the plant's gypsum quarry located at a mine in the neighboring province of Manitoba. The facility includes a hammer mill crusher, a...
vertical roller mill for the preparation of the kiln feed stock, and a smaller vertical mill to produce pulverized fuel coal. There are three finish mills that have a combined grinding capacity of approximately 4,500 t per day.

One of the core values of the global cement-producing owner is adopting industry-leading safety standards designed to ensure employees are out of harm’s way. In 2010, the company’s North American Cement Technical Group teamed with plant operations to implement an arc flash compliance program for all facilities across the United States and Canada. Because its primary business is producing cement, not performing arc flash studies, the company solicited assistance from a global services and solutions provider to complete arc flash studies for all 13 plants. The initiative was completed in 2012, and a technical paper outlining this experience [1] was published shortly thereafter.

The arc flash study and the qualified engineering services provider’s report were delivered to each site based on calculations of arc flash incident energy measured in calories/centimeter-squared (cal/cm²) and required PPE recommended for use as defined by consensus industry standards [2], [3]. The report included calculated incident energy and required PPE at each electrical panel in the plant system. The report also recommended electrical system upgrades where new technology could be deployed to assist in reducing or mitigating arc flash hazards in areas where the incident energy across the electrical system was unusually high. Using this list of recommendations, the plant in Western Canada developed an authorization for expenditure (AFE) document issued to internal leadership seeking capital support to remediate arc flash hazards, and it was issued based on project upgrades implemented in two phases. The first phase included five high-priority medium-voltage equipment upgrades and five high-priority low-voltage equipment upgrades. This article describes the project in detail, including the proposed electrical system upgrades; soliciting bids from suppliers to propose turnkey installation including engineering, procurement, installation, and commissioning; and the project results, including the effect on arc flash remediation and ultimately on process reliability.

Arc Flash Hazards and Industry Standards
The dangers of shock hazards or electrocution are well understood. An electrical shock occurs when the human body comes in contact with an energized conductor. During a shock event, current travels through the body toward ground, and it takes only milliamperes of current to cause serious injury or death. The greater electrical hazard that is somewhat less understood is arc flash. Unlike a shock incident, arc flash is the result of a rapid release of energy due to an arcing fault between phase bus bars, neutral, or system ground. An arc flash event—typically the result of human error while electricians are working on or near energized electrical equipment—is usually caused by a dropped tool or accidental contact of a test probe between an energized conductor and ground.

The energy discharge from an arc flash is massive, resulting in an energy release at temperatures exceeding that of the sun’s surface as well as explosive pressure waves, shrapnel, and toxic gases. The destructive power of an arc flash can be immense, as an enormous amount of concentrated radiant energy explodes outward from electrical equipment in an arc flash event. Solid copper conductors are vaporized, expanding to 67,000 times their original mass, creating a superheated ball of plasma gas that can severely burn a worker’s body. If the arc releases sufficient energy, a worker’s nonflame-resistant clothing will ignite. Workers wearing flame-resistant clothing can also sustain burns if the arc releases energy above the thermal rating of the fabric. The pressure waves can often send loose material flying through the air, including pieces of damaged components, tools, and other objects.

According to industry medical research statistics focusing on preventing workplace injuries and deaths [3], an average of more than 1,000 electrical burn injuries occurs in electrical equipment every year across the United States. These statistics are likely underreported because the numbers don’t include cases where victims are sent to a hospital or clinic for medical treatment. Instead, these recorded incidents typically involve severe injuries where the victim requires treatment from a specialized burn center. Adding unreported cases and near misses would result in an increased number of electrical burn injuries.

The arc flash hazard analysis completed at each plant required that data be collected across the facility power distribution system. The data were derived beginning with the existing electrical one-line drawing reviewed by a field-based power systems engineer, who then surveyed the site, verifying each electrical device in the system along with conductor lengths and protective settings. Once the data were collected, a short circuit analysis and a coordination study were performed. The resulting data were then fed into the equations described by IEEE Standard 1584-2002 [2]. These equations produce the
necessary flash protection boundary distances and incident energy at an assumed working distance, which are then used to determine the minimum PPE requirement.

Once the data are prepared and a flash study has been performed, the calculated arc flash incident energy analysis yields a PPE requirement for people working on or near each energized electrical panel across the facility. After the hazard at each electrical panel was determined, the applicable safety standard, which in Canada was Canadian Standards Association Z462-2016 [4], required that a label quantifying the hazard in cal/cm² be posted on each electrical panel, along with the appropriate PPE needed to perform work in the panel while the system is energized. The label is unique for each electrical panel across the system. The arc flash study identified electrical panels that required frequent energized access for maintenance and troubleshooting and also those with the highest PPE requirements.

Phase 1 of the plant upgrade program focused on implementing electrical system changes required to reduce the arc flash energy to lower the PPE requirement. This involved either adjusting or replacing existing circuit protective devices with more modern counterparts. The goal was to reduce the worker PPE requirements, moving the worker from high-level PPE requirements, such as clothing rated at 40 cal/cm², to a lower level PPE requirement of 8 cal/cm² as shown in Figure 1. Lower levels of PPE reduce the hazard and the risk to those performing energized work.

Typically, higher levels of PPE are required at the main cubicle of a 600-V unit substation and for some medium-voltage circuits. Because an arc flash event is generally limited to systems where bus voltage exceeds 240 V, the system model accounted for system buses operating at potentials above 240 V.

Toward Enhanced Safety

After the arc flash compliance program and site safety training were implemented at the plant, workplace safety for plant electricians made a giant leap forward. Electrical arc flash hazards that were previously unrecognized were now quantified and visible to operators before they began energized work. Proper PPE was issued to site electricians, including 8-cal/cm² arc rated clothing as daily uniforms and a 40-cal/cm² suit used to perform energized work, where higher levels of PPE were determined to be required.

Following several months of safe operation, site electricians learned that, although the highest levels of PPE inherently offered the highest degree of protection from an arc flash event, the higher 40-cal/cm² level of protection was also cumbersome in terms of time required to perform energized work and introduced added risks like heat stress and loss of dexterity required to perform electrical tasks, i.e., troubleshooting. Site operators also realized that many of the electrical substations serving critical loads were determined to have calculated incident arc flash energy in excess of 40 cal/cm². The arc flash label affixed to those substation’s 600-V panels designated a “DANGER” arc flash label, denoting there was no plant-site-issued PPE an electrician could wear and be considered safe when working on equipment while energized. In these instances, the only alternative was turning the power off, which created a new set of challenges, especially in the pyro-processing area of the plant where continuous operation was required.

A total of ten critical 4,160-V to 600/347-V substations were identified with DANGER labels where arc flash hazards were in excess of 40 cal/cm². The electrical panels for these were considered candidates for system improvements, using various technology-based solutions to manage the arc flash hazard down to lower the PPE requirement. To achieve this, originally installed circuit protective devices were generally replaced by their more modern counterparts.

![Figure 1.](image.png)
In all ten identified high-hazard substations, a decision was made to pursue the recommended solution included in the original arc flash study. The primary medium-voltage fuse in a fused load-break switch assembly was retrofitted with a high performance vacuum breaker as shown in Figure 2. This approach has been successfully implemented in other process industry applications [5]. Adding this functionality, along with updated electronic protective relays, offered enhanced protection and device clearing times that reduced the substation secondary bus arc flash energy from levels that topped at more than 100 cal/cm² to levels ranging from 5.8 to 35.7 cal/cm². The arc flash incident energy available for downstream low-voltage switchgear was further reduced by the addition of a primary and secondary bus overcurrent protective relay equipped with an energy-reducing maintenance switch (ERMS). This allowed electricians to set the feeder circuit breaker to a fast-tripping maintenance setting prior to performing energized work in downstream electrical equipment. In select low-voltage switchgear of the same critical substations, energy-reducing existing 600-V main circuit breakers were also equipped with the arc flash maintenance switch to reduce the energy for downstream low-voltage motor control centers (MCCs).

The local plant along with the North America Cement Technical Group issued an AFE document that was sent to local suppliers capable of performing the proposed upgrades. The successful bidder would be responsible for services to complete the arc flash compliance project. A scheduled site visit was included in the AFE, allowing bidders to walk the facility to become familiar with all existing site conditions, including distribution system layout and access to electrical rooms prior to submitting a proposal. The AFE advertised two scheduled shutdowns during 2014: for three weeks in January for inventory purposes and for four weeks in April for a scheduled yearly shutdown.

Up to five of the ten conversions were to be completed during periods other than the scheduled shutdowns. These additional shutdowns were stipulated for up to 24 h scheduled in advance by the owner. After receiving multiple bids and completing a rigorous bid evaluation, a decision was made to have the global services and solutions provider that completed the original arc flash studies assist in completing this work.

The project work commenced in mid-2014 and was completed on time and within the proposed budget. Figure 3 shows one of the ten substations in the process of being upgraded during the scheduled outage. In Figure 3(a), the 4,160-V existing primary fused load-break switch structure with the existing dry-type transformer is shown. The fuse elements have been removed, and the lower compartment in the structure was then up-fitted to accommodate the new fixed mounted vacuum circuit breaker. Figure 3(b) is the new circuit breaker mounted in the existing structure. Secondary control terminals above the breaker are shown along with the open/close controls on the face of the breaker. The device can be mechanically charged via the lever at the left of the breaker controls, but, in this case, the device was supplied as electrically operated so a charging motor was included. Figure 3(c) is the rear of the vacuum breaker, showing new current transformers installed at the load terminals.

Figure 4(a) shows the transformer secondary bus with new current transformers that were added for secondary bus protection. New primary and secondary current transformers were wired to the new protective-relay cabinet displayed in Figure 4(b). The new relay cabinet includes a breaker control switch at the lower section to control the new electrically operated primary vacuum circuit breaker. Breaker position-indicating lights are above the switch, with green indicating open, closed for red, and tripped in yellow. Just above the

**FIGURE 2.** (a) The existing main fused load-break primary switch for each substation with the fuse holders still in place. (b) The modified assembly after modification, with a fixed mounted minivacuum circuit breaker. (Photos courtesy of Eaton.)
lights are shorting block terminations for the new primary and secondary current transformers. Two overcurrent protective relays are at the top of the cabinet, one connected at the primary vacuum circuit breaker for protection of the transformer primary circuit and the other connected at the transformer secondary bus for protection of the 600-V low-voltage bus. The selector switch on the cabinet at the lower left is a switch to enable the maintenance mode. As mentioned previously, the overcurrent relays include maintenance mode settings, a feature that allows users to select an enhanced protection setting while testing or troubleshooting is being performed in downstream equipment. In the maintenance mode, the primary vacuum circuit breaker clears the fault even faster than with the instantaneous trip setting.

A reduced clearing time significantly reduces arc flash incident energy should an arcing fault occur. The tradeoff using the maintenance setting is that, for the time while the mode is engaged, selective coordination with downstream protective devices will be overridden to achieve this fast clearing time. This means that in the maintenance setting, potential nuisance trips could occur during normal operation when, for example, a large downstream motor with a high inrush current is called on to start. Protecting people when they are at risk of a potential arc flash event is considered a good tradeoff, so users are generally willing to accept a possible circuit breaker nuisance trip to keep workers out of harm’s way. Figure 5 is an updated single-line diagram of one of the upgraded substations. Note that the low-voltage switchgear also includes a tripping system with maintenance mode functionality. This protective setting is used when secondary feeder...
Circuit breakers are being racked from the energized 600-V bus, again lowering the arc flash incident energy to protect plant workers.

Following the installation to retrofit the ten substations, the engineering services provider revisited the arc flash study, updating the calculated values and providing new arc flash labels to affix to each assembly. Table 1 shows the ten existing bus locations and the resulting incident energy at each bus after the upgrade was complete. Each of the bus locations includes a calculation for the selective coordination setting (line) and ERMS setting. The last two bus calculations include three operating conditions, as the electrical system for these substations includes a tie-breaker, so scenarios with the tie open and closed were calculated.

**New Grinding Mill Addition**

In 2015, the plant embarked on a new grinding mill addition. Electrical equipment within the scope of this project included a new 2,500-kVA, 4,160-V substation with a dry-type substation transformer close-coupled to a 3,200-A, 600-V secondary low-voltage metal-enclosed switchgear assembly. The switchgear included a 3,200-A main low-voltage power circuit breaker, two 1,600-A feeder circuit breakers, and two 800-A feeder circuit breakers. Although the company's corporate engineering group was responsible for developing project specifications and lead procurement, the organization was now well aware of the importance of specifying the assemblies that would perform in accordance with consensus electrical workplace safety standards [4]. The new electrical
### Table 1. An arc flash analysis summary (updated study results after upgrade)

<table>
<thead>
<tr>
<th>Bus</th>
<th>Bus (kV)</th>
<th>Bus Bolted Fault (kA)</th>
<th>Device Bolted Fault (kA)</th>
<th>Arcing Fault (kA)</th>
<th>Trip Time (s)</th>
<th>Breaker Opening (s)</th>
<th>Arc Flash Boundary</th>
<th>Working Distance (in)</th>
<th>Incident Energy (cal/cm²)</th>
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<tr>
<td>MCC 2408E (Line)</td>
<td>0.6</td>
<td>28.25</td>
<td>22.33</td>
<td>16.17</td>
<td>0.2</td>
<td>0.083</td>
<td>7 ft, 8 in</td>
<td>18</td>
<td>17.2</td>
</tr>
<tr>
<td>MCC 2408E (ERMS)</td>
<td>0.6</td>
<td>28.25</td>
<td>22.33</td>
<td>16.17</td>
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</tr>
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<td>22.82</td>
<td>16.52</td>
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<td>0.083</td>
<td>4 ft, 5 in</td>
<td>18</td>
<td>17.4</td>
</tr>
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<td>22.82</td>
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<td>0.017</td>
<td>0.083</td>
<td>4 ft, 5 in</td>
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<td>7</td>
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<td>24.13</td>
<td>17.4</td>
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<td>0.083</td>
<td>8 ft</td>
<td>18</td>
<td>18.4</td>
</tr>
<tr>
<td>MCC 2430E (ERMS)</td>
<td>0.6</td>
<td>29.87</td>
<td>24.13</td>
<td>17.4</td>
<td>0.017</td>
<td>0.083</td>
<td>4 ft, 7 in</td>
<td>18</td>
<td>7.3</td>
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<td>BUS A2 2500A</td>
<td>0.6</td>
<td>35.05</td>
<td>23.01</td>
<td>15.32</td>
<td>0.9</td>
<td>0.083</td>
<td>19 ft, 11 in</td>
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<td>5 ft, 2 in</td>
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<td>11 ft, 7 in</td>
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<td>18</td>
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<td>23.43</td>
<td>16.91</td>
<td>0.017</td>
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<td>7 ft, 2 in</td>
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<td>34.65</td>
<td>28.53</td>
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<td>11 ft, 11 in</td>
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<td>34.65</td>
<td>28.53</td>
<td>20.33</td>
<td>0.017</td>
<td>0.083</td>
<td>4 ft, 2 in</td>
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<td>8.5</td>
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<td>43.42</td>
<td>33.17</td>
<td>21.61</td>
<td>0.3</td>
<td>0.083</td>
<td>13 ft, 7 in</td>
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<td>43.42</td>
<td>33.17</td>
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<td>9 ft, 7 in</td>
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<td>6 ft, 2 in</td>
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<td>33.17</td>
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<td>0.3</td>
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<td>13 ft, 7 in</td>
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<td>BUS 2445 T2 SEC</td>
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<td>6 ft, 2 in</td>
<td>24</td>
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power distribution equipment was specified to include low-voltage circuit breakers with integral overcurrent protective relays, including ERMS functionality. Adding the new equipment required an update of the arc flash study, so new labels could be affixed to the new power distribution assemblies; forward thinking by the owner’s engineering team ensured the incident energy for the newly installed equipment would, as designed, address the hazards of arc flash energy.

### Other Plant Reliability Enhancements

The successful arc flash compliance project was an unexpected trigger of a quest by the plant’s electrical engineer to survey the entire plant electrical system and identify areas that were compromised or in need of upgrades. Added power systems protection installed during the arc flash project included updated protective relays on the 5-kV bus. These new relays began, on occasion, to shut the operation down due to ground fault and other spurious nuisance trip conditions. Further investigation to determine the cause of these unexplained trips revealed that the newly installed protective relays were functioning as designed. A combination of the seasonal climate change in the region coupled with the lack of a disciplined electrical preventive maintenance program identified the need to implement several overdue system upgrades. Included in this section are a few of the key areas where additional upgrades were implemented.

### Ground Grid

As discussed in [6] and [7], the installation and maintenance of the ground grid is the single most important structure of any electrical installation. A faulty or nonexistent ground grid can produce lethal step and touch potentials to personnel, cause destructive damage to equipment (electrical and mechanical), and contribute to costly down time. Low impedance is the key to electrical equipment protection. An operating plant should have maximum ground impedance (resistance) of 1–2 Ω. Testing throughout the plant site revealed ground impedance at 100–120 Ω of resistance, extremely high levels with step potentials that could cause serious personnel injury and equipment damage. Existing ground cable and ground rods at various locations throughout the plant site were unearthed, revealing that several 4/0 ground cables and rods were either severely damaged or heavily oxidized.

There were several incidents of premature motor failure, nuisance ground faults, instruments faulting on calibrations, and so on. Repairs were implemented, including adding 1,800 ft of 4/0 bare ground cable and installing 200 ground rods to protect each low-voltage MCC. After the upgrades, a time versus voltage chart dropped from a worst case of 127 V to 10–12 V. Nuisance ghost trips of larger motors—which had resulted in the plant shutting down—almost immediately stopped. In addition, flash-overs to the programmable logic controller racks, instruments, and MCCs subsided; dangerous sheath currents on cables were dramatically reduced; and occurrences of ground fault trips on larger motors were significantly reduced.

### 5-kV Cable Upgrades

An investigation of the medium-voltage cables installed at the plant revealed areas where they were nearing imminent failure. Critical polyethylene insulation plant cables were showing signs of water tree aging [8]. Water trees grow from defects, e.g., contaminants (ions), protrusions, or voids, when the insulation is subjected to electrical stress and moisture. These lower the dielectric strength of cable insulation and cause a large number of failures of cables in service, particularly in older vintage cables, which have higher levels of defects than more recently installed cables. Electrical failure usually occurs when an electrical tree initiates from a water tree and bridges the insulation or by thermal runaway when a water tree that bridges the insulation reaches a sufficiently high conductivity. All of the 5-kV main feeder cables that supplied power to each of the ten MCCs (approximately 14 km in total length) showing signs of extensive water tree defects and insulation cracks were replaced with new conductors. The implementation of the 5-kV cabling upgrade began during the arc flash compliance upgrade and continued after installation was complete. The installation of the 5-kV cabling was accelerated because newly installed protective relays on the 5-kV systems were sensitive enough to detect insulation cracks, sheath currents, and ground faults for the existing cables. In some cases, the newly installed protective-relay settings did not allow plant operators to reenergize substations until the faulty cables were replaced. Figure 6 shows examples of ground grid and cable systems issues.

### Annual Synchronous Motor Testing (3,000 hp and 4,500 hp)

Annual testing of the mill transformers along with the most critical coal, roller mill, and kiln synchronous motors was put in place to ensure reliability and efficiency. At the beginning of the new test program, multiple inefficiencies were detected, including capacitors bulged and leaking, cable stress cones deteriorated, exciter and stator dowel pins missing or loose, defective
instruments, and faulty wiring. Further testing was implemented with laser scans of synchronous machines to check for alignment of the rotor with the stator and exciter. The plant found a rotor out of alignment with the stator on a 4,500-hp mill synchronous motor. On another mill, an exciter field was found out of alignment on a 3,000-hp synchronous motor. With the air gap not symmetrical, the magnetic field symmetry was oblong due to an uneven field buildup at the stator coils.

During operation, key components of large mill motors are subjected to severe mechanical stresses. Air gap eccentricity resulted in increased levels of vibration due to the uneven magnetic field created between the circumference of the rotor and stator. These elevated vibration levels resulted in excessive movement of the stator winding, which led to increased friction and potentially a turn-to-turn or coil-to-coil failure or a ground fault. Increased mechanical vibration accelerates bearing failure, which could seize the motor shaft, overheat the windings, or allow additional movement of the shaft, leading to a rotor-to-stator rub. Uneven magnetic stresses applied to the rotor, coupled with the increased vibration, also contribute to mechanical looseness developing in the rotor assembly. The risk of rotor pull-over increases exponentially with the amount of air gap eccentricity. Upon finding these alignment problems and because of other concerns, a total upgrade to the protection and control of these critical motors was completed to enhance the plant reliability. After this testing was initiated, the reliability of large rotating machines markedly improved.

**Cleaning all ten substation transformers and reinsulating the main bus bars eliminated the erratic nuisance trip conditions.**

**Annual Transformer Testing (5 kV/600 V/347 V)**

Many of the existing power transformers were operating at temperatures above the manufacturer's recommendations. Increased heat would randomly transfer between the three-phase coils, resulting in operating efficiencies below factory specifications, reduced transformer life, and wasted energy. An aggressive testing procedure was completed on the affected transformers. Plant maintenance discovered that cracked and deteriorated arc arrestors on the 5-kV primary feeders caused magnetic stresses and extreme heat. Heat buildup melted the insulators supporting the main transformer ground that separated the arc arrestors from the main frame of the transformer, effectively grounding the main transformer base. Extreme magnetic stresses and heat caused damage to the resin coating that encapsulates each coil. Eddy currents, which are generated when a conductor is placed in a changing magnetic field, also contributed to heat buildup. Voltage surges at the 5-kV distribution system with steep rise times rapidly propagated eddy currents in the transformer primary conductors. Current waveform distortion in the form of harmonics affected the transformers and other electrical equipment. Inspections and immediate repairs were conducted on all ten substation transformers.

Because of concerns of long-time elevated operating temperatures, an oil analysis was performed for plant liquid-filled transformers as outlined in industry standards [9]. Evidence of contamination with potentially explosive gases in the oil was discovered. In these cases, mechanical repairs were completed on the damaged components.

**FIGURE 6.** The as-found ground connections (a) compromised or (b) severed grid and (c) the 5-kV existing replaced cable. (Photos courtesy of Lehigh Cement.)
tap changers immersed in oil, and transformer oil was replaced to bring the coolant back to within factory specifications. Since putting new processes in place to routinely test transformer oil, equipment reliability for both liquid filled and dry-type substation transformers has markedly improved.

Following a disciplined process of new upgrades and testing, one of the main finishing mills continued to experience numerous erratic, unexplained nuisance shutdowns. An in-depth investigation of the MCC determined that corona was the most probable cause of nuisance trips. Corona occurs when there is an excessive localized electric field gradient causing the ionization and ultimate electrical breakdown of insulation. It is characterized by a colored glow frequently visible in a darkened environment with an audible discharge that increases in intensity with increasing voltage potential. Ozone, an odorous, unstable form of oxygen, can frequently be generated because of the effects of corona. Rubber is destroyed by ozone, and nitric acid can be created if sufficient moisture is present. These have detrimental effects on electrical insulators.

Irregularities (e.g., nicks and scrapes on conductor surfaces or sharp edges on suspension hardware) concentrate the electric field at a pinpoint location, increasing the electric field gradient and the resulting corona. Although corona is a low-energy phenomenon, it can substantially degrade insulators over time, causing system failure due to dielectric breakdown. To address insulation breakdown issues caused by corona, substation transformers were thoroughly cleaned, affected control wires were repaired, and bus bars were rewrapped with a high-voltage insulating tape. Cleaning all ten substation transformers and reinsulating the main bus bars eliminated the erratic nuisance trip conditions.

**Annual Main Substation (138 kV/5 kV) Testing**

Following testing and calibration of the electromechanical relays and the 5-kV air circuit breakers, tests results showed inconsistencies in set points and calibrations for the overcurrent protective relays. Because many protective relays were vintage induction disk devices, set points of the electromechanical relays constantly drifted from targets. An aggressive project was initiated to upgrade and replace substation switchgear protection with solid-state protective relays.

To address added arc flash safety concerns by plant electricians, a new remote switching station was manufactured and installed outside the substation building. This station included switchgear circuit breaker controls along with indicating lights to demonstrate a zero energy state, signaling to workers that it is safe to enter the substation.

**Conclusions**

After the critical electrical substations were upgraded, the plant electrical maintenance employees were very pleased. The company's focused commitment on employee safety was obvious, given the visible investment to upgrade the plant's electrical infrastructure. As a result, employees were better able to focus on operating the plant more efficiently and effectively. One unexpected benefit was a dramatic improvement in operating uptime. Unplanned outages dropped significantly following the arc flash compliance upgrade project coupled with the reliability initiatives itemized previously. Today, the operational uptime and reliability of the plant have increased significantly, elevating the site as a new benchmark performer among its industry peers.

The dramatic safety and operational improvements can be attributed to the electrical and instrumentation projects supervisor at the local plant with support from the plant manager. Interestingly, both of them have an electrical engineering background, so there was a clear understanding and appreciation for the value of safe and reliable electrical distribution and control systems. Typically, these assets are some of the most overlooked in the global cement industry, but that is not the case at the Western Canada cement plant.

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**References**