Switchgear Malfunction Results in an Electrician's Death

Aug 1, 2004 12:00 PM, By John A. Palmer, Ph.D., P.E., Knott Laboratory, Inc.

Correct application of safety procedures is no substitute for properly functioning equipment

Early on a July morning in 1999, a master electrician was electrocuted while replacing a power transformer at a surface quarry and cement plant in the western United States. The plant was undergoing a major renovation and hadn't operated continuously for years. Several weeks prior to the accident, a 4,160/480V 3-phase transformer that served the crusher/finish grinder system had been identified as defective. The plant electrician switched the transformer's load circuit interrupter into the open ("off") position and applied a padlock to secure it. He also opened the associated upstream circuit breaker, which was located in a building several hundred feet away, but didn't follow appropriate lock-out/tag-out procedures. Having thus de-energized the transformer, he disconnected it from the cables that powered it to prepare for its replacement.

A week before the accident, the local electric utility followed through with a planned power outage for the area, including the cement plant. Upon loss of power, all of the 4,160V circuit breakers in the plant tripped, as intended and designed. After utility power was restored, plant personnel closed all of the 4,160V circuit breakers, including the one that supplied power to the crusher/finish grinder system, which the electrician had previously opened.

Early on the morning of the accident, the electrician entered the transformer enclosure to install the replacement transformer, which had arrived that day. At about 6:55 a.m., two welders found the electrician unconscious in front of the transformer enclosure and were unable to revive him. It appeared he had contacted an energized high-voltage cable while examining the connections. The autopsy concluded the cause of death was electric shock and identified an entry wound on the forefinger of his right hand.

Mine Safety and Health Administration officials who investigated the accident observed that the load circuit interrupter was open and locked out, but had internal components stuck in the closed position, allowing the voltage to pass through to the transformer leads. The electrician hadn't been shocked when he first disconnected the old transformer because the upstream breaker was open, but when he went back after the circuit breaker had been closed, the transformer leads were energized even though the disconnect was still locked out.

The electrician's widow brought litigation against the manufacturer of the circuit interrupter. The plaintiff then retained me as an electrical engineering expert. The investigation entailed an analysis of the equipment itself, as well as a review of safety and maintenance issues. In conjunction with this investigation, I reviewed various documents, including current standards and standards from the time of manufacture. In addition, I visited the facility where the accident occurred and examined the relevant electrical equipment. I also obtained, examined, and partially disassembled a load circuit interrupter that was virtually identical to the unit involved in the accident.

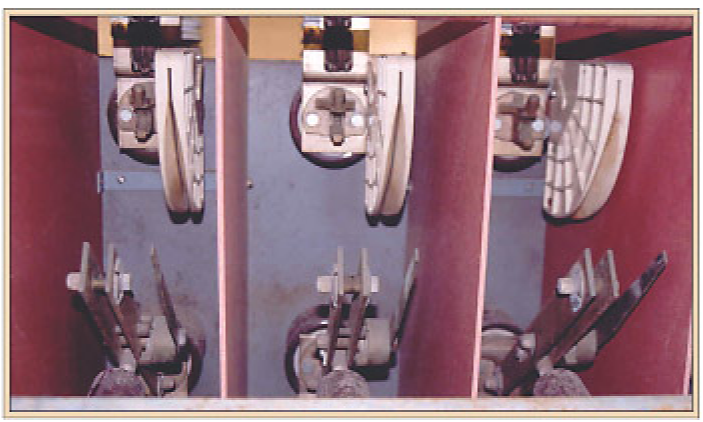

Photo 1. At least one of the flicker blades in this load circuit interrupter failed to operate.

Description and operation of equipment. The subject load circuit interrupter is a 3-phase, 3-pole, 4,160V, 600A device capable of interrupting the full 600A of rated current. The device is manually operated with a handle on a spring-loaded mechanism. Each of the three poles of the device consists of two movable contacts or blades: a main contact, or main switch blade, and an interrupting contact, or flicker blade (**Photo 1**). In the closed position the main switch blade fits tightly around a stationary primary contact and the flicker blade slides into the arc chute to fit between spring-loaded pieces of metal that form the stationary arcing contact. The flicker blade is mounted to the main blade with a loaded spring on the hub or point of rotation. Under normal operating conditions, the main contact carries the load current. The flicker blade is used to facilitate the rapid opening of the circuit to minimize arcing.

When the switch is in the closed ("on") position, the handle is intended to be nearly vertical pointing up (**Photo 2** here). When it's pulled down the main spring is compressed. However, the blades don't move during the first approximately 90° of handle rotation. After the first 90° of handle rotation, the mechanical coupling engages to force the main switch blades to move from the closed position, and the force of the main spring is applied to drive the contacts open while friction in the arc chute restrains the interrupting contacts from moving (**Photo 3**here)). The momentum of the rotating main switch blades under the force of the main spring and a charged spring at the base of the flicker blade then pulls the flicker blade free of the arc chute. Because the flicker blade is driven with a spring, it moves at a consistently high speed, minimizing the duration and destructive effect of arcing. **Photo 4 (**here) illustrates the fully open position of the handle and contacts. Note that a hole is provided in the handle mechanism through which maintenance personnel may insert a padlock to secure the switch against accidental closing during maintenance procedures.

Photo 5. When a flicker blade stays in the arc chute, the corresponding phase remains energized.

Mode of failure. After the accident, inspectors found that the flicker blade of at least one of the poles was engaged in the arc chute, despite the fact the handle was in the open position and locked with a padlock. I observed a similar intermittent malfunction in two of the load circuit interrupters not associated with the accident that I tested. Sometimes, when the handle was moved from the closed position to the open position, one or more of the interrupting contacts were left in the arc chute although the main contacts were opened, as illustrated in **Photo 5** above.

The failure mode occurs in some circumstances that may vary with temperature, humidity, dust accumulation, and other factors when the frictional force between the arcing contact and arc chute exceeds the opening force of the interrupting contact spring and the opening force of the main spring. Thus, when the operator-applied force is stopped by the limit of travel in the handle, motion of the main switch blade is arrested, leaving the contacts in the position shown in Photo 5. At this point, the spring on the flicker blade isn't sufficiently strong to break it free of the arc chute, leaving the arcing contact engaged and energized, despite the fully open position of the handle. So the device could be locked open even with one or more of the flicker blades still engaged, showing that the primary cause of the accident was a faulty design in the load circuit interrupter.

Safety procedures. On the surface, the electrician appeared to have followed appropriate safety protocols. He opened the load circuit interrupter and applied lock-out/tag-out procedures. He opened an upstream circuit breaker for additional protection. He may have even tested for voltage prior to disconnecting the transformer. However, seemingly minor or redundant details could have prevented the accident.

The load circuit interrupter is provided with a window to allow an individual to directly examine the contacts to verify that they're all fully separated. Dust on the window or lighting conditions may have obscured the electrician's view of the contacts, or the electrician may have looked in and seen at least one contact opened and assumed that all three were open. Nevertheless, if he had deliberately examined each pole of the load circuit interrupter, he would have noticed that at least one of the flicker blades hadn't cleared the chute. In this situation, simply testing for the presence of voltage wasn't adequate to verify proper operation of the interrupter. He should have repeated the test for the presence of voltage when he resumed work after a 3-week interval.

Subsequent to the accident, the load circuit interrupter was put back into service after cleaning and lubricating all internal parts. This suggests improved maintenance might have prevented the accident. However, under the loosely written periodic maintenance guidelines provided by the manufacturer, the maintenance on the unit was likely adequate. The mismatch could be resolved by a careful review of maintenance procedures and equipment condition by plant management, but without an awareness of the potential problem, management wouldn't know to increase the maintenance beyond the manufacture requirements.

In the end, the litigation was resolved before going to trial. Based on the results of the investigation and engineering analysis, the electrician's widow settled her case with the manufacturer for a sizeable sum.

Ultimately, the common idea that everyone is responsible for safety proves to be true in this case. An equipment malfunction on a device as critical as a load circuit interrupter is a rare, though extremely dangerous, situation. Nevertheless, conscientious and deliberate focus on safety at all levels, including manufacturers, electricians, and plant management, can provide a greater degree of protection for electricians and other personnel, even under such adverse conditions.

Palmer is a senior engineer at Knott Laboratory in Centennial, Colo.

Find this article at:
http://www.ecmweb.com/mag/electric_switchgear_malfunction_results/index.html