POWER QUALITY & RELIABILITY

The Case of Stray Voltage in a Lake

Faulty concentric neutrals on high-voltage underground cables lead to one teenage swimmer’s drowning and two others’ brain injuries.

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When six teenagers gathered at a friend's lake house to hang out for a casual evening, the group quickly decided to enjoy the cool night in an outdoor hot tub. When they'd had enough heat in the Jacuzzi, several of them decided it would be refreshing to run down to the homeowner's small dock and take a dip in the lake. Unaware of any underlying danger, the teens had no reason to believe their spontaneity would soon trigger an unthinkable tragedy.

The accident

After swimming near the dock for several minutes, the teenagers began to notice a strange sensation — what would later be identified as electric current flowing through their bodies. One boy, who experienced the phenomena, recalls being unable to swim, sinking in the water as he lost muscle control.

Seeing the swimmers' plight, the remaining teenagers standing on the dock called to the adults in the house for help. Several of them came running out, called 911, and dove into the water, trying to retrieve the kids who were underwater. (*Note*: It was determined later during testing that the currents in the water were intermittent, thus not causing any harm to the adults.) After multiple dives, the adults retrieved the two boys and one girl who had been submerged for some time.

CPR was immediately administered, until the paramedics arrived. At the hospital, one boy was pronounced dead (cause of death was drowning), and the other two received brain damage due to lack of oxygen caused by the near-drowning experience.

The investigation

After the accident, the first thought by many at the scene was that the dock wiring was somehow faulty, which, in turn, had caused the electric current to flow through the water. Tasked with determining the cause of the electric current in the lake water, I was retained as a professional electrical engineer by the attorneys representing the plaintiffs (parties who filed suit against the electric utility and others).

After numerous investigations by myself and other experts, we concluded that the dock wiring was not the cause of the electric currents in the lake water (**Photo 1**). However, I later discovered that the electric utility had major corrosion problems with the bare concentric neutrals of its high-voltage underground cables, which were buried under and around the lake where the accident occurred. To get a better idea of what a cable with a good and bad concentric neutral looks like, see **Photo 2**. Although these shots come from another case — one in which the corroded neutrals caused a dairy farmer to lose many cows to disease/death as well as suffer significant loss of milk production in the remaining cows — they clearly demonstrate the difference between normal and deteriorated products.

Up to nine years prior to the accident, the electric utility realized through concentric neutral testing procedures that the bare concentric neutrals were in a serious state of deterioration throughout the lake area and housing subdivision around the lake. Despite this discovery, the electric utility did not take immediate steps to fix the problem. Instead, it began a multi-year program of replacing the bare concentric neutral cables with new jacketed concentric neutral cables in the area. However, due to difficulty in installing new cable in two particular sections of underground cable under and around the lake, these sections were not replaced.

It turned out that these two particular sections of cable were the primary paths for the neutral current return for the entire lake area subdivision back to the electric utility substation source. This meant that the electrical load within the subdivision was essentially on an “island” in terms of an adequate return current path. Because of this island effect, the currents took the least-resistant path into the lake water heading to the dock — a structure that was more than adequately grounded to the electric utility system overhead neutral, which was then tied directly to the utility substation source.

To verify the above scenario, we completed numerous on-site tests. During one visit, we installed a recording multimeter at the dock where the accident occurred, leaving it to

record for eight to 10 consecutive days. (The wiring to the dock was totally disconnected and removed during this time.) The voltages were recorded by placing a ground rod off the end of the dock into the lake water where one meter probe was attached. The other probe was attached to the house ground, which was, in turn, attached to the electric utility ground. A 500-ohm shunt resistor was included in the voltage measuring circuit. The currents were measured using the same technique without the 500-ohm resistor in the testing circuit.

The results of the testing indicated that both the voltage and current levels followed the electric loads of the utility in that the measured peaks were at the highest levels during the morning and evening hours. (*Note:* The accident occurred during the evening hours when electric loads were at their highest.) In addition, the frequency of all voltage and current measurements were measured at 60 Hz, a direct indication that the electric utility was the source of these measured voltages and currents. The highest currents measured during this test period reached 0.5A, and the highest voltage reached 6.2V.

During another site visit — with the electric utility present to allow access to their underground cable junction enclosures — numerous readings were conducted to measure the current on both the underground electric utility energized phase conductors and the concentric neutrals. Voltage measurements were also taken from the ground system in the enclosures to a remote ground. In one particular section (right near the lake), the neutral current on the concentric neutral was less than one-tenth of an ampere, whereas the energized phase current was in excess of 6A. Obviously, the remainder of the return current was flowing through the earth and, in this case, the lake water. In addition, the voltage measured from these same junction enclosures was in excess of 7V to a remote ground test point. These measurements were a clear indication that the concentric neutrals on these underground sections were likely absent due to corrosion.

The findings

Using an assumed human body resistance of 300 ohms when immersed in fresh water — and assuming a current range through the human body where muscle control is lost in the range of 6mA to 30mA — and applying Ohm's law, the voltage necessary to cause a drowning in fresh water is in the range of 1.8V to 9V, 60 Hz AC. The above testing results show that the necessary voltage and current levels were at a level well within the range to cause the drowning and near-drowning of the victims.

After going to trial, a jury awarded the plaintiffs a total judgment of $2,325,000. No appeal was filed by the electric utility defendant.

Demonstrating the dramatic effects of stray voltage (**Unwanted Voltage Uncovered** on page 10) in a wet environment, this case serves as a reminder to all electric utilities about the importance of being vigilant in maintaining their distribution systems — in order to keep stray voltages at extremely low levels, levels that do not pose a danger to humans or animals. As electric loads continue to increase across the nation, many experts are even encouraging electric utilities to modify their distribution systems so that the earth is not used as a current-carrying medium.

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Sidebar: Unwanted Voltage Uncovered

Stray voltage is a popular term resulting from electrical currents flowing through the earth or other conductive surfaces not normally expected to carry electric currents. Small amounts of electric currents traveling through the earth are prevalent throughout the nation, primarily due to electric utilities using the earth as a grounding medium for grounded wye distribution systems.

Even though these grounded wye systems feature a neutral conductor return current path — because the neutral conductor is grounded to the earth at multiple locations (as required by the National Electrical Safety Code) — the result is the earth acts as a parallel path for these currents. Typically, depending upon the conductivity of the earth and the amount of return neutral current on the electric distribution system, the amount of current flowing through the earth is small. However, as electric loads across the country continue to increase, these earth currents are increasing as well.

These earth currents became noticeable many years ago on dairy farms when farmers noticed a significantly higher mortality rate among dairy cows along with a major loss of milk production. The culprit was directly tied to the amount of earth currents flowing through the dairy facilities. Electric utilities across the nation have found out the hard way (through multi-million dollar lawsuits) that they must reduce these earth currents to non-damaging levels.