EPRI

# technical brief

## Pool Shocking—"Fun in the Sun" Can Be a Shocking Event

*Power Quality Information Services and Support Target*

### The Situation

Utilities receive numerous complaints of shocking incidents by residential customers each year. While some of these incidents occur in the home at locations around the sink, stove, refrigerator, and tub/shower, the greater percentage of these events take place outside the home. Each year numerous customers experience a slight shocking sensation when they come in contact with the electrical service equipment, aluminum siding, gutters, and fences, and even around a utility apparatus such as guy-wires and metallic street light poles.

Most causes of shocking are relatively easy to diagnose, however, they are not all so easily resolved. Incidents of shocking around swimming pools, water faucets, and metallic ductwork can present particular difficulties as they often relate to the elevation of neutral/grounding system voltages to earth. The neutral/grounding system of an electric distribution system is the usual low-impedance source for stray voltage. Load, leakage and/or fault currents flowing through the neutral conductor, grounding conductors, and earth produce voltages across these impedances.[1]

Stray voltage is a small voltage that can be measured between two points of contact and is usually less than 10 volts. While stray voltage is present year-round, there are more reports of shocking incidents in the summer months because of 1) dry soil conditions, and 2) the fact that people are more likely to have exposed skin which can come in contact with surfaces of differing potentials. This is readily seen around wet areas like swimming pools or bodies of water such as lakes and streams.

Figure 1. Swimming pool still under construction.

### The Complaint

The customer was in the construction stage of a swimming pool, shown in Figure 1, and had experienced several incidents of shocking while working around the pool. The swimming pool cavity in the ground was 4" to 6" larger than the fiberglass pool shell. The 4" to 6" gap between the shell and the surrounding earth had to be back-filled with dirt before the concrete deck was poured. The customer indicated he was getting shocked while standing in the pool water and reaching out to pull dirt into the gap. Every time he came in contact with the earth, he experienced a shocking sensation.

### The Investigation

Investigations of pool shocking inquiries can often require an extensive study of the utility power system(s) in the general location of the complaint. It is important, therefore, to have an accurate map of these facilities. Locations of creeks, streams and/or large bodies of water are important as well. With a detailed map of area geographics and power lines, an investigation team can accurately assess the contribution of the utility power system to the shocking event. Figure 2 is a detail map showing the distribution circuits in the area of the inquiring customer.

It is recognized that the severity of the shocking sensation can vary throughout the day with such factors as time of day and weather conditions. The reason



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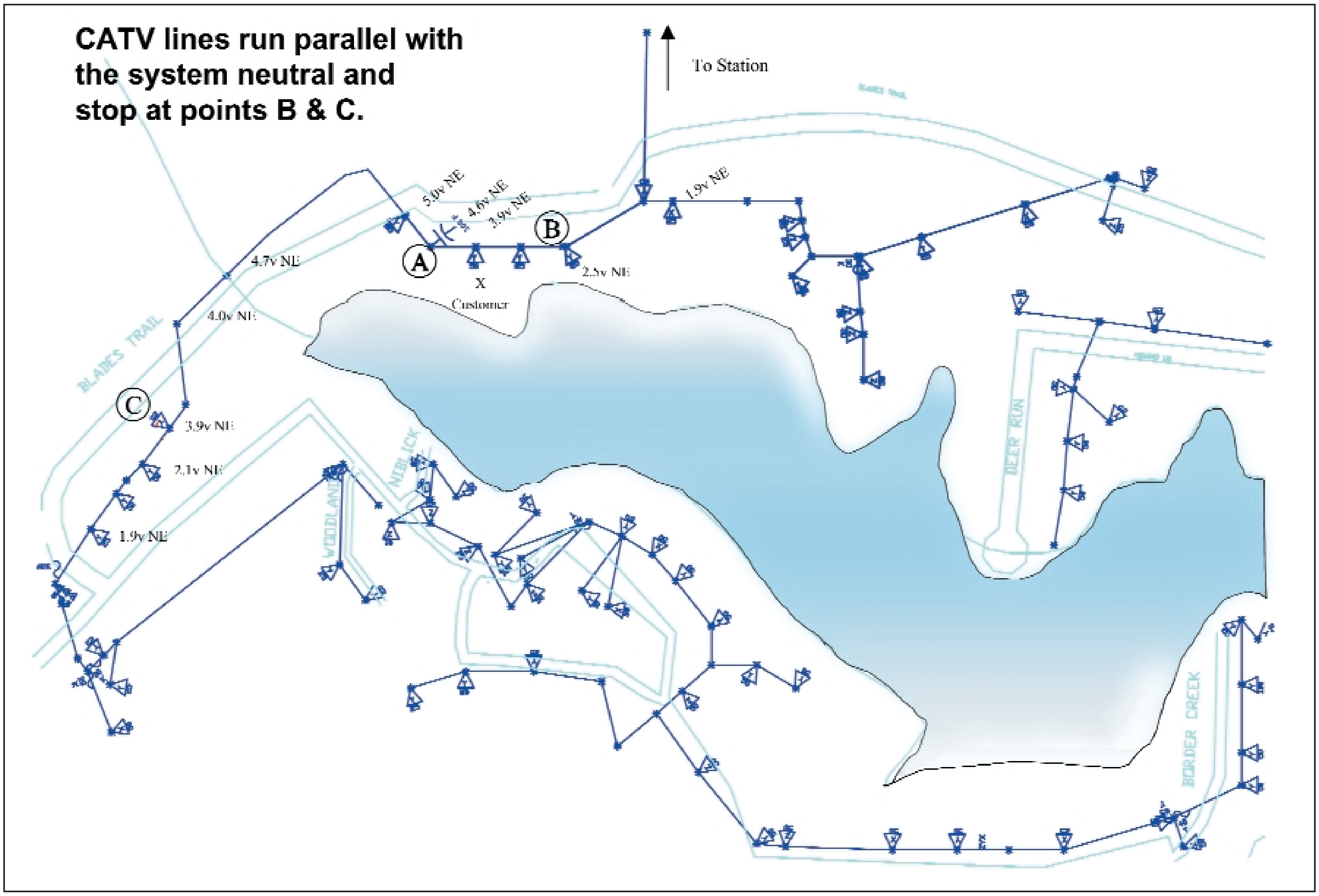


Figure 2. Distribution circuits and geographics in the area of inquiring customer.

for this is that the occurrence of stray current is influenced by circuit loading, the imbalance between phases in a three-phase system, and the degree of loading on any two-phase or single-phase systems. Therefore, the customer meeting was arranged to correspond as near as possible to the time the customer experienced the incidence of shocking.

The initial investigation considered several possibilities:

- Faulty wiring on the customer side
- Open current-limited fuse on the capacitor bank, point A in Figure 2
- Open or damaged system neutral on either of the two circuits.

Table 1 addresses these possibilities.

## Findings

The shocking voltage was measured to be $3.1V_{ne}$ ac from the pool's water to the soil around the pool. The potential difference was created by the pool's water being held at the elevated system neutral level (via the pool's grounded ladder and submerged light fixture) while the surrounding soil was being held at earth potential. The swimming pool's metallic components (pump, handrail, ladder, coping stone, etc.) were all properly bonded and grounded.

The next step in the investigation was to take load and source amp measurements at the nearby capacitor bank, shown in Figure 2. If any of the current-limiting fuses were open, the capacitor

**Table 1**
**Initial Investigation Activities**

| Activity | Result |
|---|---|
| Pulling the power meter, thereby temporarily de-energizing the customer's electrical wiring. | No effect on shocking voltage at the swimming pool. |
| Measuring the load and source amps at the capacitor. | All phases of capacitors were on-line and, therefore, not contributing to circuit imbalance. |
| Inspecting the system neutrals for the two circuits, since this area is subject to tree-related damage. | No discontinuities in the system neutrals were found. |
| Taking current measurements on the two circuits at points where the system neutral is grounded to earth, i.e grounding electrode conductors. | No appreciable current flow to earth. All measurements were basically identical, indicating no open points in the system neutral. |

**Table 2**
**Primary and Neutral Amps at the Capacitor Bank**

| Near-by Capacitor Bank | Primary Amps X Phase | Primary Amps Y Phase | Primary Amps Z Phase | Neutral Amps | Phone Cable Amps | CATV Cable Amps |
|---|---|---|---|---|---|---|
| Load Side | 61.1 amps | 63.9 amps | 54.3 amps | 3.9 amps | UG | N/A |
| Source Side | 75.4 amps | 79.8 amps | 71.1 amps | 5.3 amps | UG | N/A |

**Table 3**
**Human Resistance for Various Skin-Contact Conditions[2]**
**(Values indicate total human resistance: skin plus tissue)**

| Description of Skin-Contact Conditions | Resistance (OHMS) Dry | Wet |
|---|---|---|
| Hand holding wire | 15,000 to 50,000 | 3,000 to 6,000 |
| Palm touch | 3,000 to 8,000 | 1,000 to 2,000 |
| Hand around $1^1/_2$-inch pipe | 1,000 to 3,000 | 500 to 1,500 |
| Hand immersed | | 200 to 500 |
| Foot immersed | | 100 to 300 |

**Table 4**
**Degree of Shock[2]**

| Degree of Shock | Time Duration (Seconds) | Critical Current Range (Amperes) |
|---|---|---|
| Perception | 0.01 to 5.0 | 0.0005 |
| Let-go | — | 0.009 |
| Fibrillation | 0.01 | 1.16 |
| of the Heart | 0.1 | 0.37 |
| | 0.5 | 0.163 |
| | 1.0 | 0.116 |
| | 5.0 to 20.0 | 0.052 |

bank might be contributing to a circuit loading imbalance. The results are shown in Table 2. The amp readings indicate that all three-phases of the capacitor bank are on-line. The circuit loading is fairly well balanced.

The next step in the investigation was to take amp readings and neutral-to-earth voltage measurements on the circuit in the vicinity of the inquiring customer. The circuit construction was three-phase with 1/0 ACSR primary and 2 ACSR neutral. The values measured are indicated in Figure 2. There was no appreciable current on the grounding conductors along the circuit, therefore no current values are offered. This is an indication that the system neutral is intact having no open points in this area.

The increasing and decreasing magnitude of the neutral-to-earth voltages between points B and C is an indication that there is a relative increase in the neutral impedance in that region. A close inspection of the circuitry in this area reveals the culprit. The local cable company has installed CATV conductors in all regions around this part of the lake, with the exception of the circuitry between points B and C. The elevated neutral-to-earth voltages measured in this area are related to the increased neutral impedance resulting from the absence of CATV cables.

## Discussion

Stray voltage is a relatively small potential difference between two remote points. When an animal or person bridges these points, current will flow. The amount of current will depend on the potential applied and the circuit impedance, including the source and contact impedances, and body resistance. In the case of pool shocking, the two remote points are typically the system neutral and earth. In most cases, the pool water is elevated to the system neutral potential by virtue of the fact that a grounded/bonded object is in the pool, i.e. step ladder or light fixture. The surrounding earth is most likely closer to a true "zero" potential. Stray voltage sources include:

- leakage through degraded insulation, e.g., motor windings
- hot conductor contacting a ground conductor
- field coupling such as that between primary and phone lines, and
- current flow through earth.

The customer's experience of the shocking sensation is a function of skin contact resistance, body weight, amperage and duration of contact. A typical human resistance value of 500 ohms is used for estimating shock current for the human body. Human resistance values are listed in Table 3. The shocking sensations result in varying degrees of trauma. Shocking voltage and shocking current are directly related: if the measured shocking voltage is high, then the shocking current is high. But most importantly, as shown in Table 4, very little current is needed to induce significant human trauma.

It is apparent, therefore, that the human body can feel and be affected by small amounts of current. When resistance is low, as is the case when a person is standing in water or their skin is wet, sensitivity to stray voltage/current is increased. Typically, AC values of 3.0 volts or higher will be perceived by females and children and AC values of 5.0 volts or higher will be perceived by males, although lower perception voltages for each have been documented[3].

**The Real Problem.** The real problem in most pool shocking complaints relates to an elevated system neutral with respect to ground. The cause is either a relatively high impedance neutral path, or a relatively high neutral current, or both. When either of these is reduced, the neutral to earth measured in the vicinity of the power lines will likewise be reduced.

*High Impedance Neutral Path*—A high impedance neutral path will create excessive voltage drop along the neutral conductor. This voltage drop will appear as a potential difference between the neutral/grounding system and earth. Any metallic objects effectively bonded to the system neutral will consequently be at a higher potential than the surrounding earth.

When evaluating the system neutral path, it is important to recognize that the return current path for system load is comprised of more than just the system neutral conductor. Investigations need to consider all parallel paths back to the source transformer. The following can be parallel paths back to the source, as shown in Figure 3.

- System neutral wire
- CATV cable
- Phone cable
- Other joint-use cables
- Metallic water lines, etc.
- The earth and large bodies of water

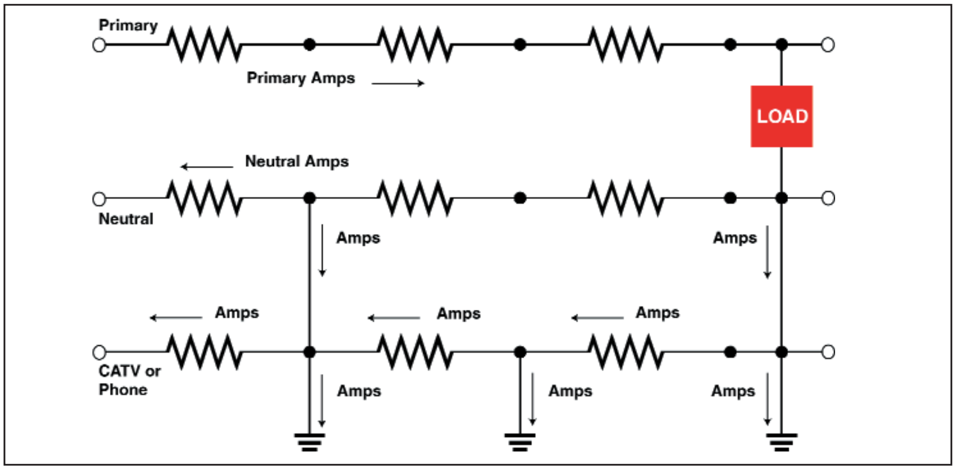


Figure 3. Single-phase circuit with parallel paths for the system neutral.

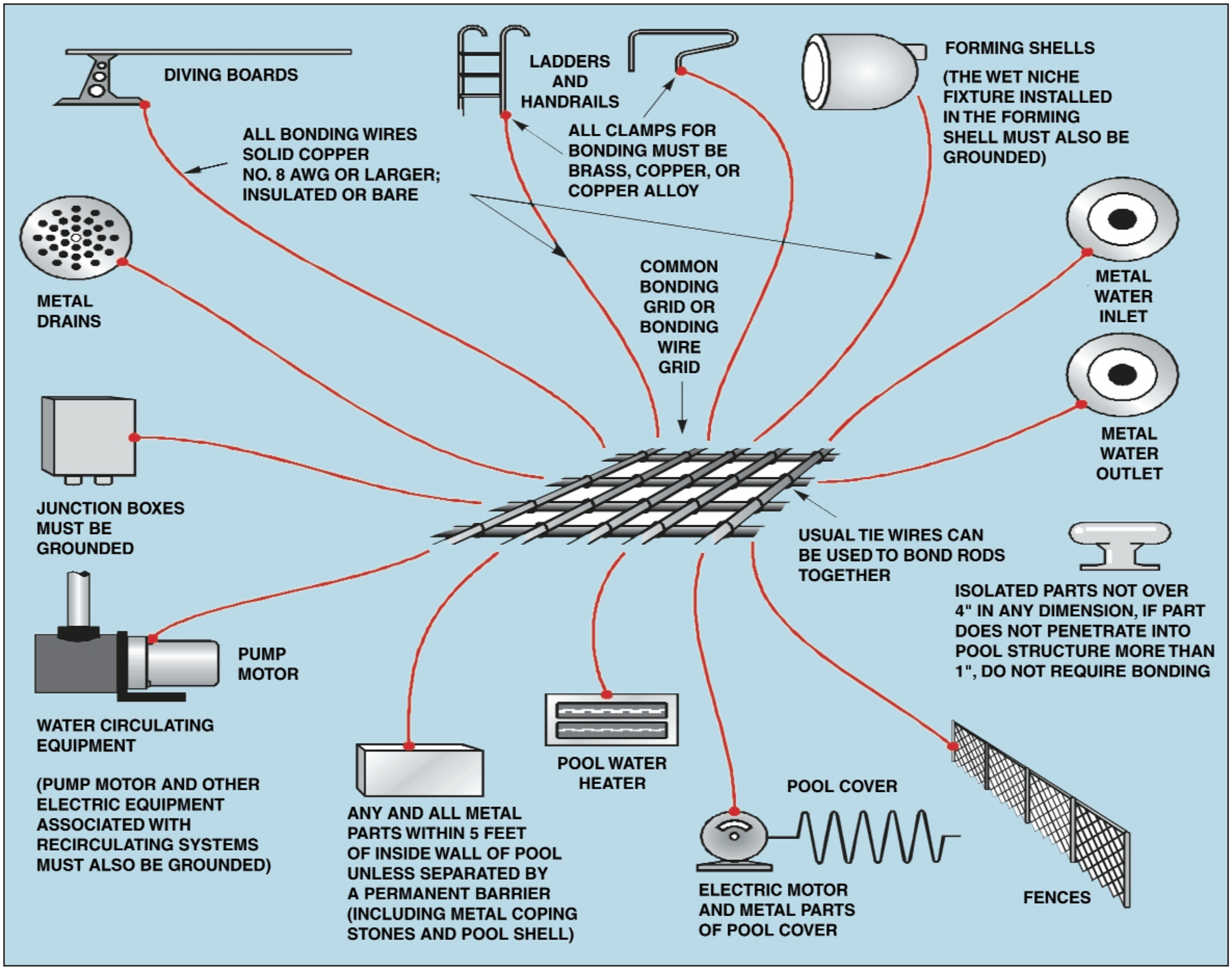


Figure 4. Bonding and grounding requirements of a swimming pool.

A high percentage of the incidence of pool shocking where the impedance of the system neutral is the culprit occurs because of deteriorating neutral conductors or connections. Extreme weather conditions, tree damage and improper installation practices contribute significantly in these incidents. Occasionally, a neutral conductor will be found where the aluminum part of the conductor has been gnawed away by squirrels leaving only the steel core intact. There are also situations where the system neutral is undersized for the amount of load it carries and the distance over which it must be carried. Finally, where the neutral path is completely open, return current is forced into the ground, which is a much higher resistance path.

*High Neutral Current*—A relatively high neutral current can also create excessive voltage drop in the neutral path. Attempts to resolve pool-shocking incidents should include efforts to minimize neutral return current. Relatively high neutral currents will be associated with long, heavily loaded single-phase lines or three-phase lines that are significantly unbalanced.

On average for single-phase lines, the portion of return current flowing along the system neutral and its parallel paths will be 40% of the primary current. The remaining 60% will flow in the earth. It is the author's experience that single-phase lines with 30 amps or more primary current will have a higher incidence of shocking along its connected customers than those with less. If this is the case, or for any instance where excessive return current is present, the loading can be reduced by any of the following standard engineering practices:

- Transfer the load to adjacent taps by back-feeding the single-phase line.
- Convert the line to open-wye (add a second phase). Converting the single-phase line to open-wye should cut the shocking voltage in half.
- Convert the line to three-phase. Three phasing the line and balancing the primary current should effectively reduce the shocking voltage to near zero.
- Convert the primary line to a higher voltage (ex. 2400 volts to 7200 volts).
- Tie together circuit neutrals with buried bare conductors leaving the loading as it exists.

Three-phase lines will have higher neutral currents when the individual phases are unbalanced in load. This is an inherent characteristic of residential three-phase circuits as loads are added randomly through new construction. Applications of line capacitors can contribute to load unbalance should one or two phases of the capacitor bank become disconnected from service.

**Pool Bonding per the NEC.** The effect of bonding all metallic parts of a pool is to eliminate the potential difference between any two adjacent objects or areas of the pool. The result is that shocking sensations around the pool are eliminated. Typically, No. 8 or larger solid copper wire is used to bond together the pool equipment, such as ladders, handrails, coping stones, etc. This bonding is normally completed before the concrete deck is poured. For other safety reasons, **the swimming pool shall be bonded per Article 680-22 of the National Electrical Code (NEC).** Figure 4 illustrates the various components to be bonded together.

**What Happens When All Is Not Bonded?** Without proper bonding, a difference of potential can exist between the metal parts of the pool and the pool water or any wet surfaces around the pool. The result can be a slight, yet painful shock. All pool shocking investigations should evaluate the bonding between the pool's metallic components. A good way to do this is with the use of an ohmmeter, see Figure 5. Typical bonding ohm values are listed in Table 5.

In some cases, shocking occurs at the poolside in only certain areas around the pool. This is usually an indication that

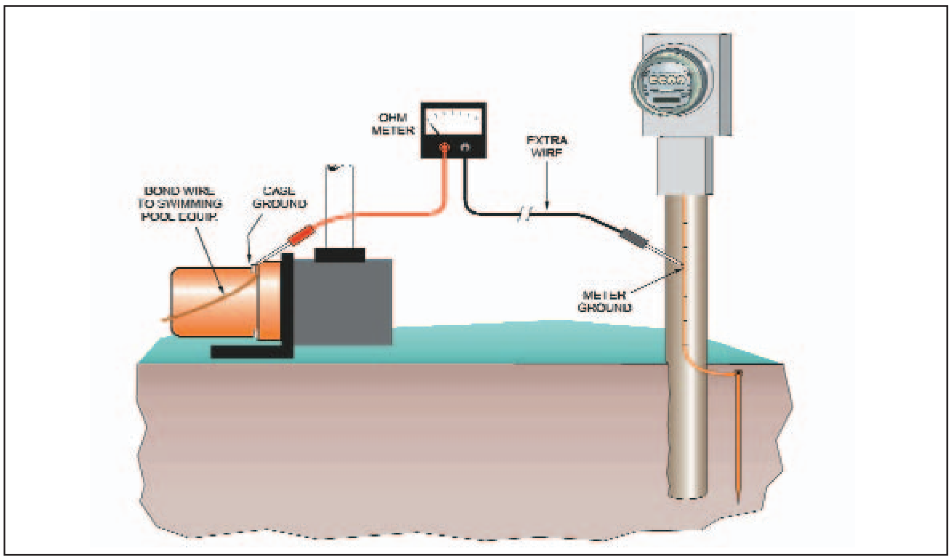


Figure 5. Ohm measurements taken between the grounding electrode conductor at the meter and the pool pump motor.

**Table 5**
**Bonding Ohm Values**

| Ohm Values[1] (ohms) | Description |
|---|---|
| 0.0 to 2 | Low ohm value indicates that the pool equipment is bonded. |
| 100 to 10,000 | Medium ohm value indicates that equipment has a loose connection[2]. |
| Open or Infinite | Very high or open ohm value indicates that equipment is not bonded. |

Notes:

1. The ohmmeter leads and any extra wire used should be zeroed out to obtain an accurate ohm measurement.
2. The medium ohm value of 100 to 10,000 ohms may indicate that pool ladder or handrail supports are not tightened properly. Tell the customer to clean and tighten the pool ladder or handrail supports.

one or more coping stones are not bonded together and/or to the grounded grid network of the pool structure. In other cases, the shock is experienced around ladders and handrails. All these issues are addressed primarily by proper bonding.

Other cases occur where the customer is standing or kneeling on the concrete decking and, while reaching into the pool experiences a shock. These cases almost always exist because the decking structure is not built with grounded/bonded rebar. The result is that the decking beside the pool is not at the same potential as the pool water. Most of these situations will have to be resolved by addressing the neutral/grounding system to earth voltage issues.

## Conclusion

Most pool shocking complaints arise long after the pool's construction has been completed. For these situations, cost-effective solution opportunities are limited. For the utility, minimizing neutral return current and/or neutral path impedances can be employed. In some cases, this can require extensive construction efforts and expense. For the customer, bonding and grounding of all the metallic components of the pool is a requirement, NEC 680-22. Above and beyond that, cutting and retrofitting concrete decking with grounding conductors to form a grounding grid network can be costly and, in most cases, will diminish the appearance of the decking surface.

Other solutions to pursue include primary/secondary neutral isolation, which should be evaluated with great care. For pools without under-water lighting, a double-insulated circulation pump may be an option.

In this case study, there was an additional option because the construction of the concrete decking had not been completed. Although the contractor refused to install rebar in the concrete decking to be used as a grounding grid system, the customer was persuaded to employ a single conductor ground ring around the pool structure. The ground ring was installed approximately 18 inches away from the pool's edge and was bonded back to the coping stones, the ladder, and hand rail, as shown in Figure 6. The ground ring effectively becomes a single conductor grounding-grid around the pool structure.

The ground ring held the concrete decking immediately above it at the neutral/grounding system potential. The 18-inch gradient to the pool's edge was minimal such that there was very little potential difference between the pool water and the surface at the pool's edge. The customer has not experienced any incidence of pool shocking since the pool's completion.

## References


1. "Effects of Electrical Voltage/Current on Farm Animals: How to Detect and Remedy the Problem," *US Department of Agriculture, Agricultural Handbook,* No. 696.
2. R.H. Lee, "Electrical Safety in Industrial Plants," *IEEE Transactions on Industry and General Applications*, January/February 1972.
3. *Identifying, Diagnosing, and Resolving Residential Shocking Incidents*, EPRI TR-113566, 1999.

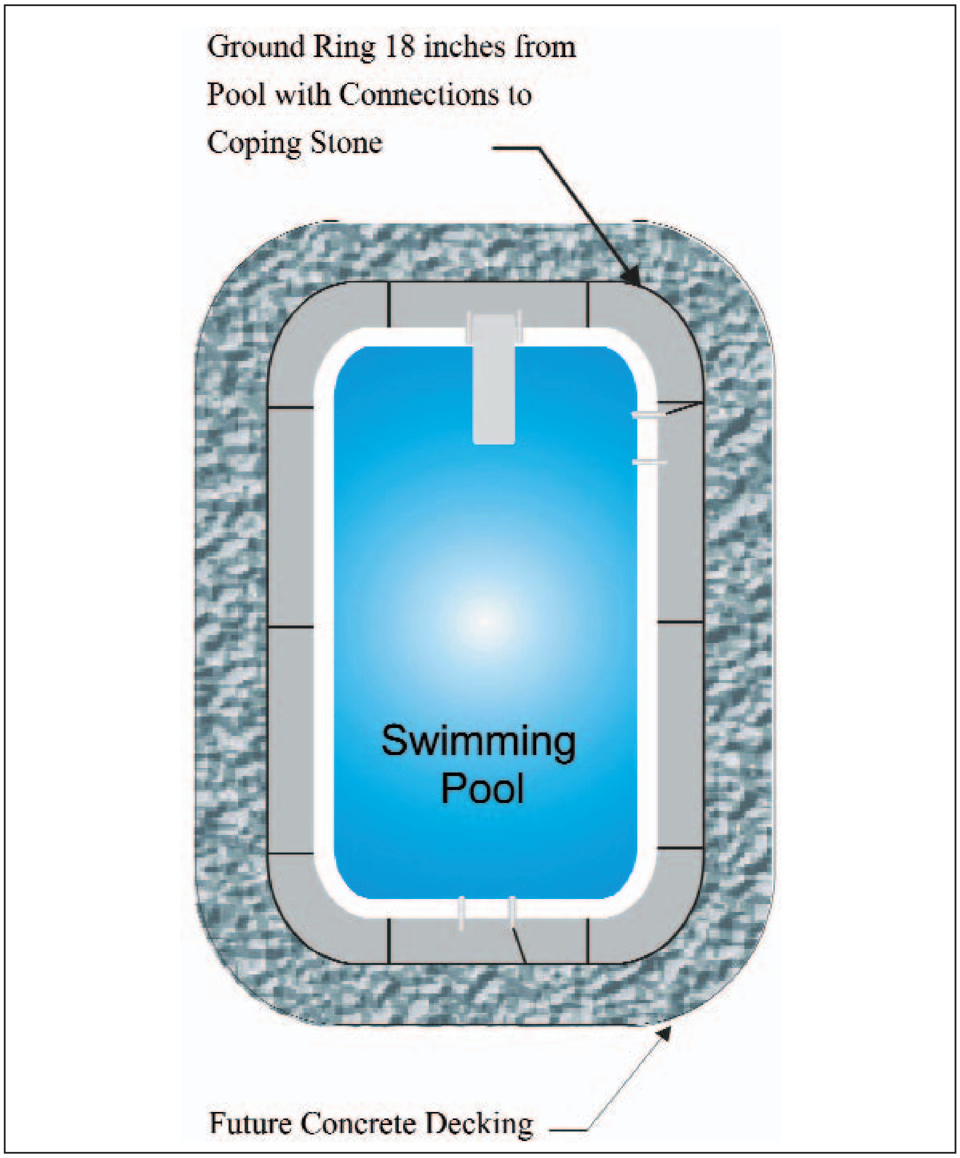


Figure 6. Swimming pool with ground ring installed.

## Causes of Shocking

**Causes of Shocking Related to the Customer Premise**

1. Defective electric hot water heaters
   - Defective thermostats
   - Partial grounds in the heater element
   - Bare wire touching the water heater case
2. Defective well pump motor
   - Fault on the conductor serving the pump
   - Dampness penetrating poor insulation on the wire
   - Bare wire touching the grounded pump casing
3. Defective electrical appliances
4. Defective wiring where the hot wire is in contact with the safety ground
   - Rodent damage to the conductor insulation
   - Mechanical damage by a nail or dry wall screw to the conductor insulation
   - Deteriorated conductor insulation
5. Improper earth grounding at the meter enclosure

   Note: In older homes the metal water pipe may be used for the grounding electrode, and the metal pipe may not be continuous to earth due to plastic fittings installed while under repair.

**Causes of Shocking Related to the Secondary or Service System**

1. Defective lightning arresters or broken insulators on the transformers
2. Defective service or secondary conductor
3. Improper earth-grounding at the transformer

**Causes of Shocking Related to the Primary System**

1. Defective concentric neutral on the primary underground cable
2. Defective neutral connector (i.e., a loose bolted connector or an improper die compression connection, etc.)
3. Open system neutral (i.e., missing wire strands, missing connector, etc.)
4. Long heavily loaded single-phase feeders
5. Three-phase feeders where the load amps are unbalanced due to
   - Open-wye construction
   - Blown fuses on a capacitor bank
   - Unbalanced circuit loading
6. High ground resistance
7. Inadequate system neutral wire size
8. Excessive harmonic currents

**Acknowledgement**

This *Technical Brief* was developed in cooperation with the staff of Duke Power.

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