Check the Effectiveness of an Earth Connection Using ACPL-K376

Overview

Any electrical equipment that works by tapping its power supply from an AC power mains runs the risk of earth leakage. If not properly grounded, the leakage will cause an electrical short circuit to the surroundings, creating a risk of fire or explosion and endangering human lives. When the earth connection is effective, any leakage is shorted to earth; the Earth Leakage Circuit Breaker (ELCB) senses the leakage current and breaks the mains supply to the equipment immediately, protecting property and human lives.

But how can one determine whether the earth connection is effective or not?

This white paper provides a solution to check the effectiveness of the earth connection using the Broadcom® ACPL-K376 voltage/current threshold sensing optocoupler.

Earth Connections

Figure 1 illustrates a typical earth connection of an AC input mains supply:

- There are two earth rods, one at the substation transformer and another at the distribution panel (DP) ground point.
- The neutral point (N) is connected directly at the substation to the earth rod but not at the downstream points.
- All of the 3-pin power points have a ground pin that connects to the DP ground point through its own ground cable, to allow for earth protection of any electrical equipment.

Figure 1: EV Charger with Normal Ground Connections

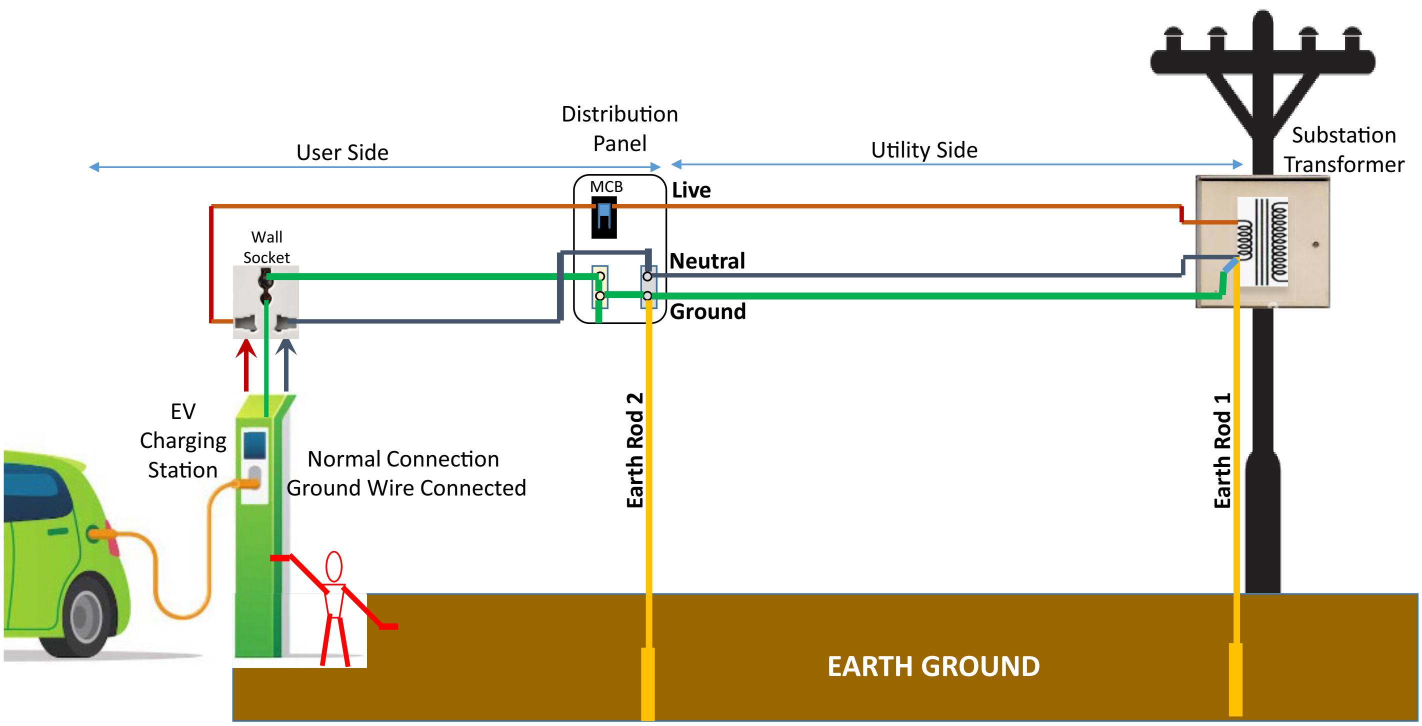
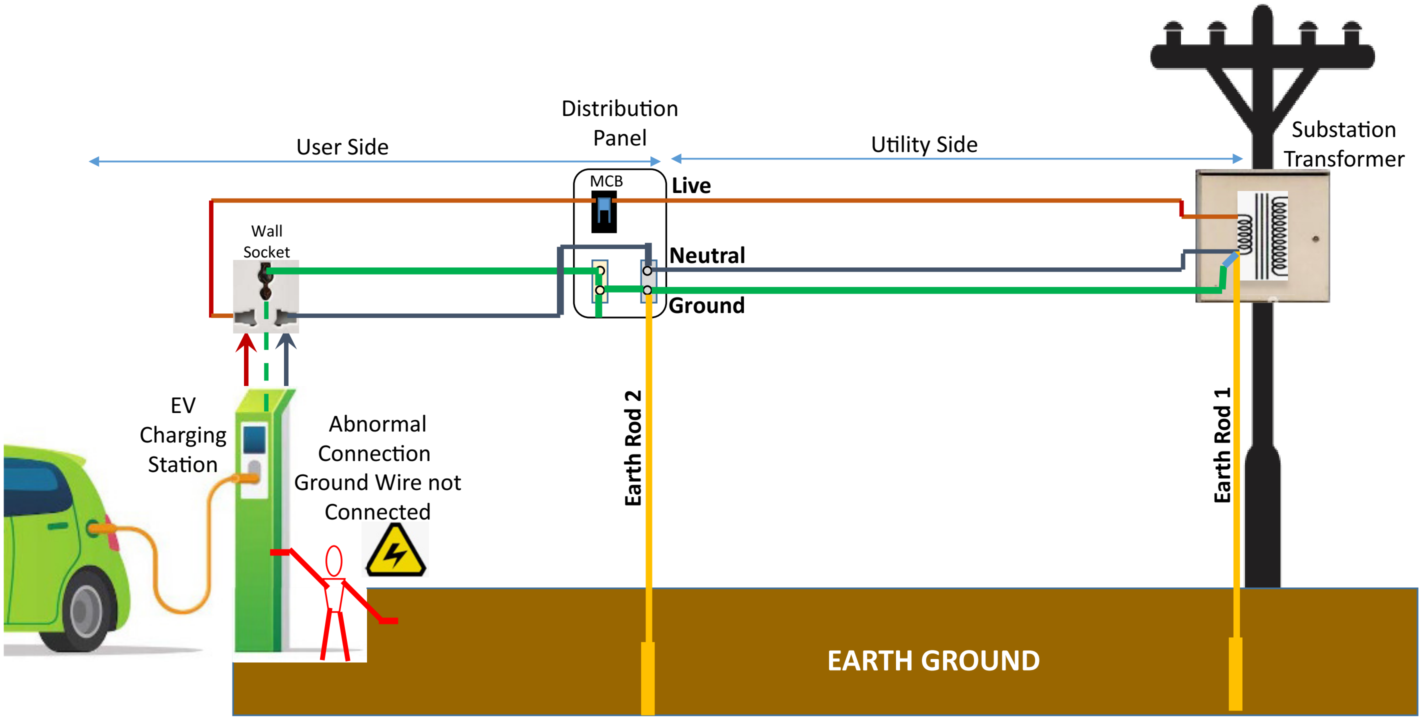


Figure 2 illustrates an abnormal connection where the ground wire is not connected to the EV charger. This is represented by the dashed green vertical line in the drawing.

Figure 2: EV Charger with Missing Ground Connection



Leakage current is caused by insulation failures in the internal circuit, often due to aging or thermal faults. With effective earth grounding, when equipment is plugged into a 3-pin power supply, the equipment's metal case should be connected to the ground wires. This ensures that the metal case of the equipment is grounded. If the earth connections are effective and leakage current occurs, the leakage current is shunted to the earth through the ground wires and earth rod. The ELCB senses this leakage current, typically when it is greater than 30 mA, and will shut down the circuit breaker protecting the equipment.

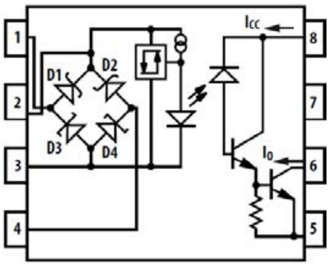
There are situations when earth rod connections are not effective, or the ELCB or Residual Current Circuit Breaker (RCCB) sensing the leakage current is not effective. In this case, the protection against earth fault and earth leakage might not be sufficient. Earth leakage is especially concerning because while the leakage-triggering current can range from 5 mA to 30 mA, a human can experience a significant shock or be killed when the leakage current is higher than 1 mA[1].

The Broadcom ACPL-K376 can be used as an effective earth leakage current threshold-sensing device.

1. The effectiveness of earth leakage protection is beyond the scope of this white paper.

Triggering Characteristics of ACPL-K376

Figure 3: ACPL-K376 Circuitry



The input-triggering current and voltage thresholds of the Broadcom ACPL-K376 family of devices are as shown in Table 1.

Table 1: Input Current and Voltage Detection Thresholds

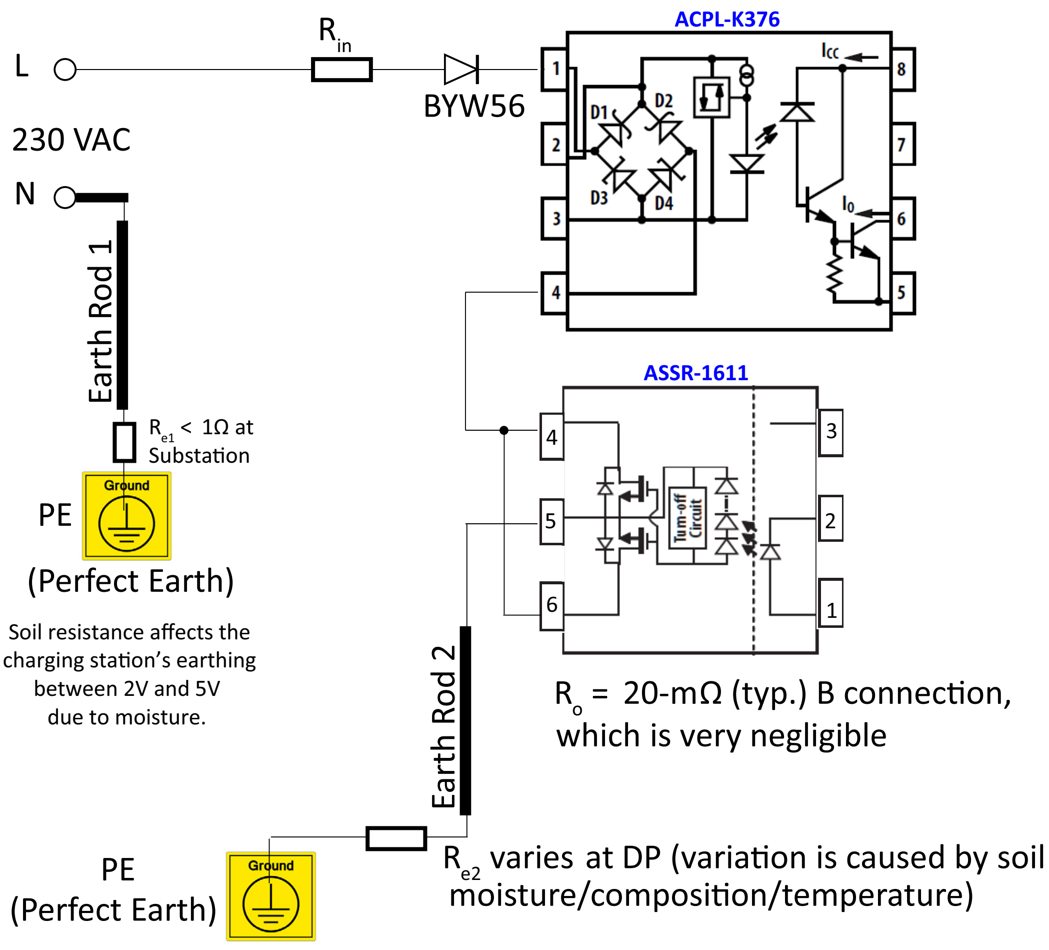
Part Number	Input Threshold Current, I_{TH+} (mA)			Input Threshold Voltage, V_{TH_DC} (V)		
	Min.	**Typ.**	**Max.**	**Min.**	**Typ.**	**Max.**
ACPL-K370 (40°C to 105°C)	1.96	2.50	3.11	3.60	3.80	4.00
ACPL-K376 (40°C to 105°C)	0.87	1.20	1.56			
HCPL-0370 (0°C to 70°C)	1.96	2.50	3.11	3.35	3.70	4.05
HCPL-3700 (0°C to 70°C)	1.96	2.50	3.11			
HCPL-3760 (0°C to 70°C)	0.87	1.20	1.56			
Hermetic HCPL-5760 (–55°C to 125°C)	1.75	2.50	3.20	3.18	3.60	4.10

As illustrated by the table, when the current that flows through the input side of the ACPL-K376 circuit is higher than the I_{TH+} threshold of 1.2 mA (typical) or 0.87 mA (minimum), the output of the device will go low.

We can use this characteristic to check the effectiveness of earth connections.

Using ACPL-K376 to Check Earth Connection Effectiveness

Figure 4: ACPL-K376 Used in a Protective Earth Circuit



The circuitry for checking earth connection effectiveness is shown in Figure 4. The ASSR-1611 allows for the activation and deactivation of the check by turning on and off its LED.

The AC mains input goes through a series resistor (R_{in}) and is rectified by the BYW56 rectifier before feeding to the input of the ACPL-K376 circuit, and then to the power MOSFET output terminals of ASSR-1611 in B connection. Refer to the *ASSR-1611 Data Sheet* for additional information.

Earth rod 2 represents the earth connection at DP, and R_{e2} represents the total earth resistance there. We can trust the effectiveness at earth rod 1, as the substation transmission earth connection is governed by the IEEE standard, which is < 1Ω. The effectiveness of the earth rod 2 connection could be called into question, as it could have changed due to application usage over time. Use the proposed circuit periodically to check the effectiveness of the earth rod 2 connection.

The objective of the proposed circuit is to check the input voltage when the input current threshold is crossed, typically at 1.2 mA. The lower the input voltage, which is represented by the voltage across R_{e2}, the safer or more effective the earth connection of the earth rod 2 will be. It calls for extra low voltage (ELV) under the EN IEC 62368-1 Regulation. The ELV for the AC level is 50 VAC, maximum.

Therefore, if the input voltage is checked to be lower than 50 VAC when the threshold current of 1.2 mA is crossed, then the earth connection is effective. Conversely, if the input voltage is found to be higher than 50 VAC when the threshold current of 1.2 mA is crossed, then the earth connection is not effective. When that happens, further improvements on the earth rod 2 connection, to lower the R_{e2} value so that V_{e2} < ELV, must be done to render it to be effective.

Without the implementation of ACPL-K376 to trigger a shutdown, during dry weather conditions the earth rod 2 voltage can exceed a voltage of $126V_{pk}$ (= 30 mA x 4.2 kΩ) before the ELCB or RCCB is activated to shut down the faulty circuit. This is obviously unsafe as the voltage is far greater than the threshold of $70.71V_{pk}$, unless the R_{e2} is less than 2.4 kΩ. To get to that low R_{e2} in those instances, the earth rod 2 needs to be buried deeper, which can become expensive and cost prohibitive.

NOTE: The circuit can be further expanded to include a voltage sensor such as the Broadcom ACPL-C87B, which would sense the input mains voltage. When the input current threshold of 1.2 mA is crossed, it would feed back to the MCU and allow smart controls to decide whether to cut off the mains supply to the equipment if the ELV level is breached, before the voltage becomes harmful to users.

Theoretical Verifications

When the earth current reaches 1.2 mA, the voltage at the earth rod must not be higher than the ELV at 50 VAC, or $70.71V_{pk}$, for the earth connection to be effective.

[ELV (Rectified) – V_{F1}(ACPL-K376) – V_{F2}(BYW56)] / R ≤ 1.2 mA, where R is the total resistance

Or, R ≥ [ELV (Rectified) – V_{F1}(ACPL-K376) – V_{F2}(BYW56)] / 1.2 mA

The total resistance from the Live terminal to PE: $R = R_{in} + R_{e1} + R_{e2} + R_{ssr}$, assuming ASSR-1611 is used.

For ASSR-1611, $R_{ssr} = R_{on}$ = 20 mΩ, typically
At ELV of 50 VAC, its peak rectified voltage = 50(√2)

V_{F1}(ACPL-K376) = 1.2V which is the D1 and D4 diode drops for ACPL-K376
V_{F2}(BYW56) = 0.62V

R ≥ [ELV (Rectified) – V_{F1}(ACPL-K376) – V_{F2}(BYW56)] / 1.2 mA

R ≥ [50(√2)V – 1.2V – 0.62V] / 1.2 mA
≥ [70.71V – 1.2V – 0.62V] / 1.2 mA
≥ 57,408Ω

Since R $= R_{in} + R_{e1} + R_{e2} + R_{ssr}$
$= R_{in}$, assuming that the other terms are negligible

Or R_{in} ≥ 57,409Ω

Therefore, we can select R_{in} = 59 kΩ in standard resistance.

Earth Resistance Due to Moisture

Earth resistance (R_{e2}) is not constant. It is affected by the depth of the earth rod 2 beneath the surface, the moisture of the soil, and the temperature.

From a typical application using an EV charging station and its earth rod 2, the voltage (V_{e2}) is found to be 3.5V on a typical day. The voltage can vary around 3V between a wet day (2V) and dry day (5V).

The voltage across the earth rod 2, or V_{e2} to PE, can be obtained by the following formula:

V_{e2} = 1.2 mA x R_{e2}, assuming that $R_{e1} << R_{e2}$

For R_{e2} to cause a drop of 2V ~ 5V
2V < V_{e2} < 5V
Or, 2V < 1.2 mA x R_{e2} < 5V
Or, 1.7 kΩ < R_{e2} < 4.2 kΩ

R_{e2} has to vary from 1.7 kΩ to 4.2 kΩ.

Recalculations

Recalculate V_{e2} for wet conditions, assuming R_{e2} = 1.7 kΩ:

$$R = R_{in} + R_{e1} + R_{e2} + R_{ssr}$$
$$= 59k + 1.7k + 0.021 = 60.721\ k\Omega$$

$$V_{e2} = (1.7k / 60.721k) \times 70.71V = 1.98V$$

Recalculate V_{e2} for dry conditions, assuming R_{e2} = 4.2 kΩ:

$$R = R_{in} + R_{e1} + R_{e2} + R_{ssr}$$
$$= 59k + 4.2k + 0.021 = 63.221\ k\Omega$$

$$V_{e2} = (4.2k / 63.221k) \times 70.71V = 4.7V$$

In order for the earth rod 2 installation to be effective, the implementer has to ensure that in both wet and dry conditions, the mains voltage is less than the ELV at 50 VAC when earth current is less than 1.2 mA. This can be accomplished with this Broadcom ACPL-K376 solution.

The earth rod 2 voltage at both wet and dry weather conditions is tested as shown in Figure 5 and Figure 6, using ACPL-K376. The upper trace (red) is the output signal and the lower trace (yellow) shows the earth rod 2 voltage measured. The output triggers at an earth current of 1.2 mA.

Figure 5: Earth Rod 2 Voltage V_{e2} (≈ 2V) in Wet Weather Conditions

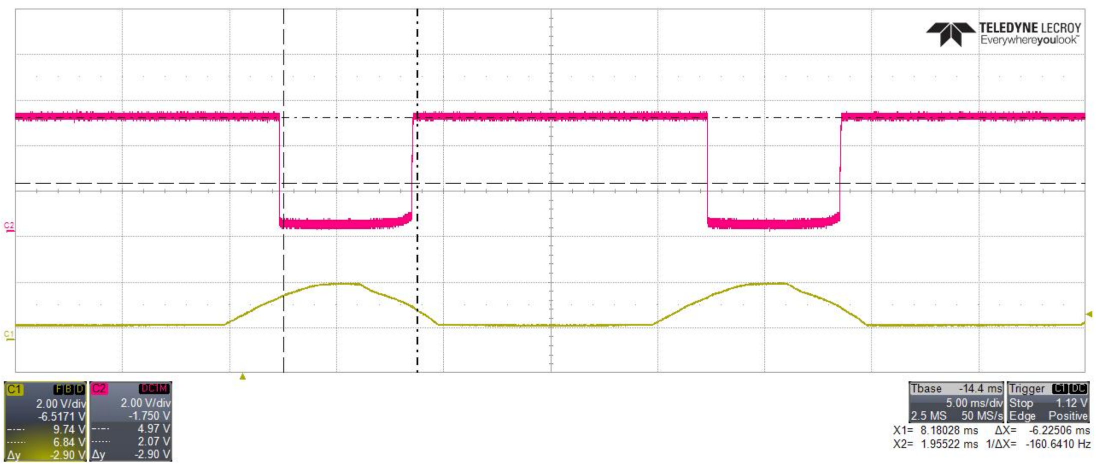
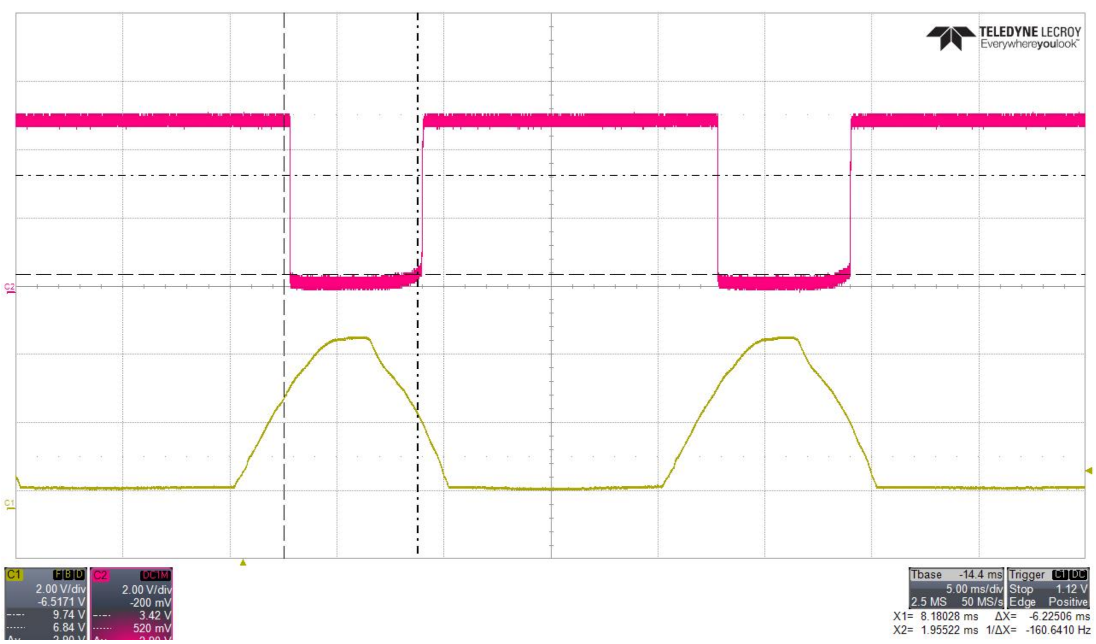


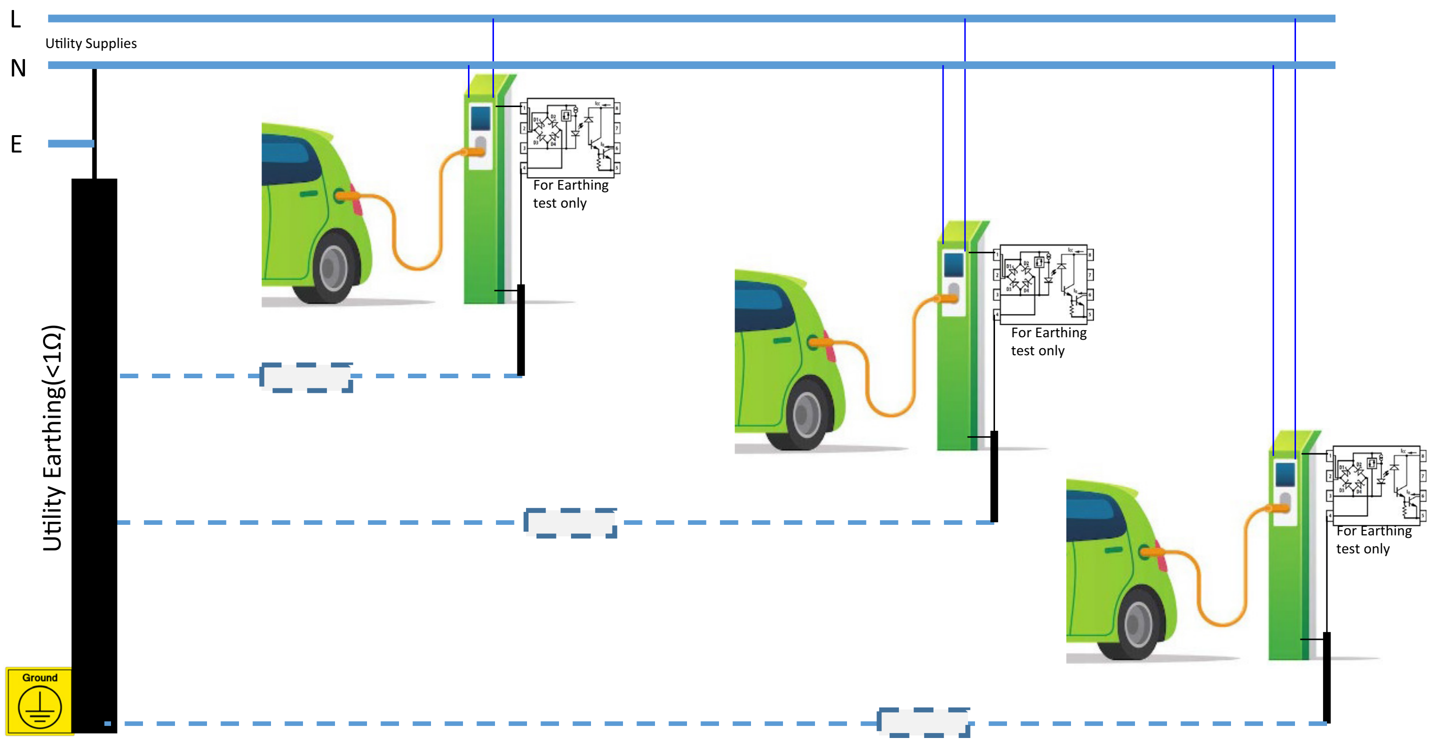
Figure 6: Earth Rod 2 Voltage V_{e2} (≈ 4V) in Dry Weather Conditions



Typical Applications

One of the most common application of this ACPL-K376 solution is to check the effectiveness of the earth connection at EV charging stations. Figure 7 illustrates this application, using simplified schematics that show only ACPL-K376.

Figure 7: EV Charging Application for an Earth Connection Effectiveness Check Using ACPL-K376



Application Board

An application board is currently under development that includes the above earth connection check circuits.

Summary

The Broadcom ACPL-K376 current/voltage threshold sensor provides an excellent way to check the effectiveness of the earth connection from DP earth ground to the substation earth ground. It is also able to determine the actual earth resistance at wet and dry soil conditions. Most importantly, when it senses the earth connection is not effective, it allows for the protection of human lives by shutting down the mains supply to the equipment load before the voltage reaches an unsafe level.