Testing for safe and efficient branch circuits

Written by Chad Reynolds, Product Manager,
IDEAL Test and Measurement Division

Branch Circuit Testing

Branch circuit wiring and testing practices are primarily code driven with little thought as to why such stringent requirements are necessary. But these practices are necessary to ensure safe and efficient branch circuits. Hidden problems within a branch circuit can result in fire, electrocutions and equipment failure.

Fires

Based on the National Fire Protection Association (NFPA) and the US Consumer Product Safety Commission data, there was an estimated 406,000 residential structural fires in 1997, resulting in an estimated 3,390 civilian deaths and 17,775 injuries. Approximately 9% of the structural fires and 7% of the deaths were determined to be the result of the electrical distribution system. Residential fires were by far the biggest problem, accounting for 97% of all structural fires and 87% of deaths.[1]

The most common cause of residential electrical fires is problems within the branch circuit wiring. These problems resulted in 14,600 fires, 420 injuries and 110 deaths in 1997.[2]

Electrical Distribution	Fires	Injuries	Deaths
Installed Wiring	14,600	420	110
Cord, Plug	6,300	320	90
Switch, Outlet	4,900	160	10
Lamp, light Fix.	9,900	350	30
Other	4,600	10	10
Total	40,300	1360	250

[1] *Fact Sheet on Fire in the US and Canada, National Fire Protection Agency (NFPA) 1997*
[2] *1997 Residential Fire Loss, Consumer Product Safety Commission, 1997*

Arc Fault Circuit Interrupters

There are two main causes of fires to installed wiring within the electrical distribution system. The first is arcing within the circuit. An arc fault is characterized by an erratic flow of electricity. Because normal breakers were designed to protect against short circuits, arc faults occurring in damaged cable can continue undetected. These leads to hazardous situations such as high temperatures that could ignite nearby combustible materials[3]

To offer protection against these conditions, the 2002 edition of he National Electrical Code (NEC), requires the installation of Arc Fault Circuit Interrupters (AFCI) in bedroom circuits in new residential circuits.[4] Currently, the only devices that meet the new NEEC guidelines are Arc Fault breakers. These breakers, which are manufactured by a number of companies, have a special circuit within the breaker to detect arc fault conditions on the branch circuit.

These devices should be tested upon installation to ensure that the breaker will adequately protect the circuit. An independent arc fault tester simulates an arc fault condition on the line to determine if the breaker will protect the circuit.

High resistance connections

The second major cause of residential fires is a high resistance point in the circuit, such as a loose connection, poor splice or defective electrical device. Current flowing through these high resistance points causes heat to build up behind the wall. This can create a smoldering fire if there are combustible materials nearby, and no way to dissipate the heat.

Loose wire connections create a high resistance point within the electrical system, which can lead to a breakdown in insulation or even a fire.

Identifying potential problems

Most fixed wiring and receptacle hazards are hidden from inspection. A visual inspection in the rough-in stage of residential construction may identify obvious problems, such as a staple cutting through the conductors, but they may not identify a loose wiring connection or a bad splice.

Normal instrument testing of a static circuit reveals little about the quality of wiring or the integrity of the circuit. However, testing under load and calculating the voltage drop can identify 90% of these hidden defects.

---

[3] IEC Fact Sheet, Arc-Fault Circuit Protection, Illinois Electric Council, Fact Sheet #28
[4] NEC code Articles {210.12 (A)}

Voltage Drop

Voltage drop is a measure of how much a circuit's voltage fluctuates (or drops) once a load is applied. Voltage drop can be calculated by comparing a voltage measurement with no load on the circuit to a voltage measurement under full load.

The voltage drop calculation will be most accurate when no-load conditions are compared to full load conditions. When using a digital multimeter to calculate voltage drop, remove all loads from the circuit to take the no-load measurement. For the full load measurement, use a space heater or some other appliance that will draw close to 15 amps.

$$\% \text{ Voltage Drop} = (V_{(no\text{-}load)} - V_{(load)}) / V_{(no\text{-}load)}$$

Voltage Drop can also be measured with a SureTest® Circuit Analyzer. It uses a patented technology to place a full load onto the circuit without tripping a breaker or causing any interruption to equipment on the line. The SureTest compares the voltage measurement at full load, with a measurement at no load and calculates the voltage drop.

Voltage drop at a full load can be easily taken by simply plugging the SureTest into a receptacle.

How Much Voltage Drop is Acceptable?

The National Electrical Code (NEC) recommends that the combined voltage drop of the electrical system (branch circuit and feeders) not exceed 5% for optimum efficiency.[5] It is important to note that this is a recommendation and that local inspectors, or other governing bodies, may use their own judgment on an acceptable level of voltage drop for the electrical system.

For example, the Philadelphia Housing Development Corporation (PHDC) requires contractors to calculate the voltage drop prior to installing blown insulation in existing homes[6]. If the voltage drop is 10 % or higher contractor must replace/repair the circuit prior to proceeding with the insulation.

Prior to instituting this requirement, half a dozen smoldering fires resulted from the blown insulation installations. In the 2,500 homes insulated during a two-year period after this electrical integrity test was instituted, there were no fires reported. At least 15 other municipalities have followed the PHDC's lead in requiring the load test as part of their winterization programs.

---

[5] *NEC code Articles {210-19(a) FPN No. 4} {215-2(d) FPN No. 2*

[6] Kinney, Larry "Assessing the Integrity of Electrical Wiring" *Home Energy* Sept/Oct 1995: 5,6

Troubleshooting a Circuit

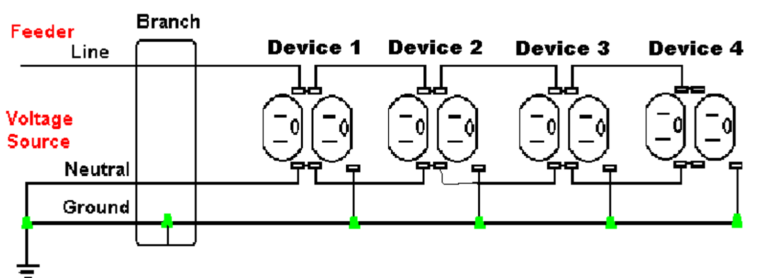
Troubleshooting to identify the cause of the high impedance within the electrical system is actually quite simple. First measure the voltage drop at the furthest receptacle from the panel on the branch circuit under test. If the voltage drop is high, than further investigation is necessary.

Testing the remaining receptacles in sequence, from next furthest from the panel to the closest to the panel, will identify the problem.

If the voltage drop reading changes significantly from one receptacle to the next, then the problem is a high impedance point at or between the two receptacles. It is usually located at a termination point, such as a bad splice or loose wire connection, but it might also be a bad receptacle.

If the reading steadily decreases as you get closer to the panel, with no significant decreases between receptacles, then the wire may be undersized for the length of run, or for the load on the line. Check at the panel to see if the wire is sized per code, and measure the current on the branch circuit.

The reading may not decrease at all from the last receptacle to the first. This would indicate that the problem could be at the first splice, or at the panel itself. Most poor panel connections show up as hot spots on the panel. These can be checked quickly with an infrared temperature meter.



By testing receptacle in sequence from furthest from the panel to closest with a load test, hidden defects can be identified and corrected

Testing the integrity of the branch circuit under load can have a dramatic effect on the ability to positively identify hidden defects within the branch circuit.

Electrical shock

An estimated 58 people loose their life each week as a result of electric shock. These deaths are a result of consumer products, large appliances and installed home wiring. In an electrical system, the grounding system is the primary protection against electrical shock hazards. It provides a low resistance pathway to ground to protect against electrical faults.

There are several conditions that can occur within the grounding system that would lessen the protection against electrical shock. Three of the most common are high impedance grounds, false grounds, and a poor earth grounding system.

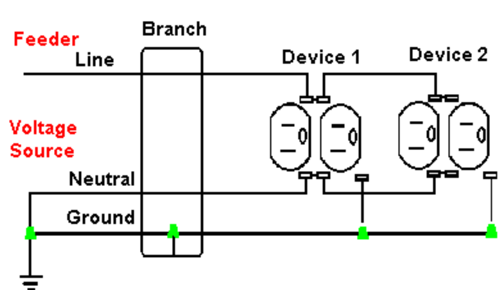
High Impedance Ground

A good electrical ground is more than following NEC requirements, it must also be a low impedance system. The ground path is the fault path for stray current. If electricity follows the path of least resistance, than the ground circuit must have a lower resistance than an individual to protect them. The rule of thumb for protecting people is to maintain a ground impedance of less than one Ohm.

Maintaining a good quality ground starts with wiring the circuit correctly. The NEC requires that the removal of any device cannot interrupt the ground path. Receptacle manufacturers have responded by supplying receptacles with only a single grounding connection. This would prohibit electricians from wiring the device in series with the grounding circuit.

Pigtail Connections

A common method of ensuring that the ground remains intact is through the use of a pigtail connection. To make a pigtail connection, take both ground wires and join them with a 6-inch wire of the same color that has been stripped on either end. Hold all three tightly and bind them together with a wire connector. Be sure to use the right size connector for the size and number of wires.



The grounding circuit must not rely on any device to maintain the circuit. The NEC requires that the removal of any device cannot interrupt the ground path

Special connectors are available to make this job easier, such as the Greenie® Grounding Connector from IDEAL. With the Greenie, a bare copper wire is inserted through a hole at the top of the connector. All the wires are then bound together, by twisting the Greenie until tight.

Special connectors, like the Greenie, make pigtailing easy, saving time and ensuring code compliance

Pre-made pigtails are becoming more popular because of the time-savings involved. The Term-a-Nut® Pigtail Connector combines a twist-on wire connector with a pre-crimped pigtail. The ultra-flexible, six-inch lead provides hassle-free positioning in a junction box, and the grounding pigtails come with a pre-crimped fork connection for quick and easy installation of the device.

By combining a twist-on connector with a pre-crimped pigtail, the Term-a-Nut Pigtail facilitates pigtailing of hot, neutral and ground conductors, reducing labor by two-thirds

Bonding the Junction Box to the Grounding Conductor

In many wiring applications, more than one equipment-grounding conductor enters a junction box. According to section 250-148[7] of the NEC, where more than one equipment-grounding conductor enters a box, all such conductors shall be spliced or joined within the box or to the box.

The only exception is for isolated receptacles, covered in section 250-146 (d),[8] where isolated receptacles are required for the reduction of electrical noise (electromagnetic interference).

For metal junction boxes, the grounding conductors from each device also needs to be connected to the box with a listed grounding device, or a grounding screw, that is not used for any other purpose.

The Term-a-Nut grounding products come in a variety of configurations for fast and efficient grounding to Article 250 of the National Electrical Code

[7] *NEC code Article {250-148}*
[8] *NEC code Article {250-146(d)}*

Bonding the Receptacle Grounding Terminal to the Junction Box

A device may have to be bonded to the junction box with a jumper. According to section 250-146[9] of the NEC, an equipment bonding jumper shall be used to connect the grounding terminal of a grounding-type receptacle to a grounded box unless grounded as in (a) through (d).

(a) A surface mounted box, where the device yoke and the box have direct metal-to-metal contact. This connection can be used to ground the device. This provision does not apply to cover-mounted receptacles unless the box and cover combination have been listed as providing an acceptable ground continuity between the box and receptacle.
(b) Contact devices or yokes designed and listed for providing the grounding connection between the device and the junction box. These shall be permitted in conjunction with the supporting screws to establish the grounding circuit between the device yoke and flush-type boxes.
(d) Floor boxes designed for and listed as providing satisfactory ground continuity between the box and the device. Isolated receptacles that is required for the reduction of electrical noise (electromagnetic interference) on the grounding circuit. In these applications, the grounding terminal is purposely insulated form the receptacle mounting to reduce the electrical noise coming from other loads on the branch circuit.

The receptacle grounding terminal is connected to an insulated equipment grounding conductor run with the circuit conductors. This grounding conductor is permitted to pass through one or more sub-panels without connection to the panel board grounding terminal as permitted in Section 384-20[10].

Note that the use of an isolated equipment grounding conductor does not relieve the requirement for grounding the raceway system and junction box.

False Grounds

The neutral conductor can only be bonded to the ground conductor at the main neutral buss, where a large copper conductor carries all the return and faulted current back to the earth. Sometimes through error or ignorance, the neutral and ground are connected upstream from the service entrance. This is called a false, or bootleg ground. If the neutral and ground are connected anywhere else in the building, all grounded metal becomes part of the neutral conductor, constantly energized and creating various voltage potentials on electronic equipment.

When using common receptacle testers, this condition shows up as normally wired. Only the SureTest® Circuit Analyzer can correctly identify a false ground condition within 15 feet of the receptacle under test.

---

[9] *NEC code Article {250-146(a) through (d)}*
[10] *NEC code Article {384-20}*

Earth Ground

The pathway to ground extends beyond the main panel to the earth ground system. The earth ground could be a single ground rod, multiple ground rods, a mat or a grid system. Section 250-56 addresses the system by stating that if the ground electrode is not less than 25 ohms a second electrode should be added at least 6 feet from the first.[11] The grounding system can be tested with a three-pole earth resistance tester, or a ground resistance clamp meter.

A ground resistance clamp meter enables electricians to measure the resistance of the ground electrode in a fraction of the time required using the traditional three-point fall of potential test.

Large ground systems, such as those found in substations and power stations,may requires a large grounding grid to obtain a sufficiently low value of ground resistance. In these applications, the soil resistivity can play a large role in determining the requirements of the grounding grid. Inaccurate resistivity tests can lead to unnecessary costs in the design of the system. To ensure a low impedance grounding system, include the ground electrode, or earth ground as part of your standard testing procedures in your facility.

By using a four-pole ground resistance meter, the soil resistivity can be tested to determine what the grounding requirements are. Inaccurate resistivity tests can lead to unnecessary costs in the design of the system.

---

[11] *NEC code Article {384-20}*

Ground Fault Circuit Interrupters

Electrical code requires the installation of ground fault circuit interrupters (GFCIs) in residential dwellings to protect against shock. Receptacles in bathrooms, garages, outdoors, crawl spaces, unfinished basements, kitchens and near wet bar sinks require protection.[12]

A GFCI is a receptacle with a built in circuit to detect leakage current to ground on the load side of the device. When the GFCI detects leakage current to ground, it will interrupt power to the load side of the device, preventing a hazardous ground fault condition.

These devices should be tested regularly, because they rely on mechanical connections that will degrade over time. According to a recent study performed by the Leviton Institute on average 15% of GFCIs were inoperative when tested. "Voltage surges from lightning, utility switching and other sources all take their toll on the devices, which is why Underwriters Laboratories (UL) requires that GFCIs be tested monthly."[13]

Using proper grounding techniques, testing and maintaining a good electrical ground and installing protection devices are the best ways to protect people and equipment from electrical shock.

Equipment Failure

When sensitive electronic equipment fails, the initial reaction is to throw our hands up and blame it on poor power quality. This makes the problem seem unmanageable and out of our control. Most of these problems are actually under our control, because 80% of all power quality problems are found in the electrical distribution and grounding system.

In addition to preventing the possibility of fire, a good low impedance electrical system will protect electronic equipment. A high resistance connection, like a loose wire, will cause the voltage to fluctuate, or drop, when a large load is applied. If the voltage drops low enough, it can cause electronic equipment to lock up, reset or shut down completely.

Grounding is another concern for electronic equipment. While ground impedance of one Ohm or less may protect people from electric shock, it may not be adequate protection for electronic equipment. IEEE recommends a ground impedance to be less than 0.25 Ohms for proper protection.

---

[12] *NEC code Article {210-8 (a)}*

[13] *Study Identifies potential GFCI weaknesses*, Electrical Marketing, August 18, 2000

Isolated Grounds and Dedicated Circuits

It is often easier to isolate sensitive electronic equipment than to re-wire an entire circuit. This can be done by running an isolated ground for the equipment in question, or by running a new dedicated circuit.

An isolated ground protects the equipment from other equipment on the same grounding circuit. Electronic equipment can create noise, which can interfere with the operation of other equipment on the circuit. It is important to note than an isolated ground will not protect equipment from harmonic distortion running through a shared neutral.

In some cases, running a dedicated circuit is necessary to completely isolate a piece of equipment in order to ensure protection.

Branch Circuit Testing

The hidden dangers associated with branch circuit wiring are very serious, but fortunately the precautions are straightforward. We can protect ourselves and equipment by using certified devices and testing equipment from reputable manufacturers and implement policies on branch circuit testing. These policies should include verifying proper wiring, testing devices, checking the integrity of the branch circuit, and measuring the integrity of the grounding system.

Check all devices immediately after installation to verify proper wiring and test devices. Receptacles should be checked to avoid common wiring errors, such as reversed polarity or an open neutral. Checking the voltage level with a voltage tester quickly verifies that the receptacle has been correctly wired for either 120 or 220VAC. Checking continuity across a switch verifies that it working correctly. A variety of testers are available on the market to test these devices quickly and accurately.

Test electrical circuits under load to test the integrity of the branch circuit. The voltage drop test can identify high resistance connections, which can lead to fires, breakdown in insulation, and poor efficiency of the electrical system, which can contribute to erratic equipment operation.

Test the integrity of the grounding system, which includes not only the grounding conductors, but also the ground rod or grid system. A low impedance on both of these systems is essential to protect against electrical shock.

In summary branch circuit testing is an important part of wiring any circuit. It verifies that devices have been wired up correctly and allows you to protect yourself against the hidden defects in an electrical system.