FLUKE®

Diagnosing power problems at the receptacle

Application Note

Three quick measurements can tell you a great deal

When there is suspicion on the reliability of the building's electrical supply, you are called in. Why? Because of your straightforward approach to troubleshooting. Before you break open a panel, much less the three-phase monitor, you first grab your Fluke digital multimeter (DMM) and take a few measurements at the outlet nearest to the problem load. You take three quick measurements because there are only three measurements to make: hot-neutral voltage, neutral-ground voltage, and hot-ground voltage. Armed with this information, you are well on your way to answering these questions:

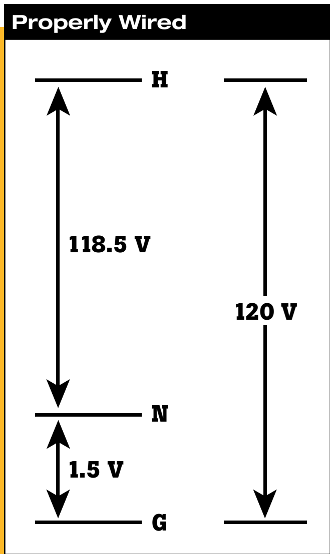
- Is the outlet mis-wired?
- Is the branch circuit too heavily loaded?
- Do sensitive electronic loads have the voltage they need?

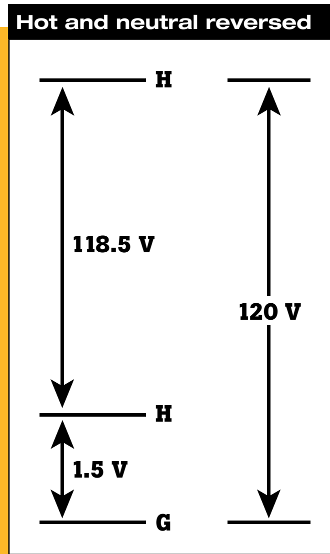
Everyone is impressed that you could glean so much information from such simple measurements. But you know it's just effective problem solving. These three measurements, all taken quickly at one outlet, provide you with a solid understanding of the building's electrical supply.

Testing a three-slot receptacle for grounding, polarity

Mis-wired receptacles are not uncommon. A three-slot receptacle has a hot slot, a neutral slot, and a grounding slot. The short slot is the hot, the long slot is the neutral and the U-shaped slot is the ground. Are the hot (black) and neutral (white) wires reversed? Are the neutral and ground (green) wires reversed or shorted? These conditions can often go undetected for a long time. Many loads are not sensitive to polarity. In other words, they don't care if hot and neutral are reversed. Electronic loads generally are indifferent to ac polarity because they are just converting the ac to dc in their internal power supplies. On the other hand, sensitive electronic loads such as computer equipment and instrumentation do care about a clean ground; i.e., a ground with no voltage and no load currents on it. A single reversed neutral and ground can compromise the entire ground system.

You could unscrew every receptacle and make a visual check for correct wiring, but you know it's much easier to take some measurements using your Fluke DMM or a clamp meter (one with voltage measurement capability, like the Fluke 330 Series).





Of course you made these voltage measurements during office hours and under normal load conditions. And what did you find?

- **Hot-neutral.** This is the load voltage. Voltage should read about 120 V (typically 115 V to 125 V). You measure exactly 118.5 V.
- **Neutral-ground.** As will be explained below, this is a voltage drop (also called IR drop) caused by load current flowing through the impedance of the white wire. Let's say you measure 1.5 V.
- **Hot-ground.** This can be thought of as the source voltage available at the receptacle. You read 120.0 V. You note that hot-ground is higher than neutral-ground. In fact, hot-ground is equal to the sum of the hot-neutral and neutral-ground voltages.

Are these readings normal? Is the outlet wired correctly?

The most common mis-wiring occurs if hot and neutral are switched, or if neutral and ground are either switched or shorted. How do you spot these conditions?

1. Measuring hot-neutral by itself doesn't tell you if they've been switched. You have to measure neutral-ground or hot-ground. If neutral-ground voltage is about 120 V and hot-ground is a few volts or less, then hot and neutral have been reversed.
2. Under load conditions, there should be some neutral-ground voltage—2 V or a bit less is pretty typical. If neutral-ground voltage is 0 V—again, assuming that there is load on the circuit—then check for a neutral-ground connection in the receptacle, whether accidental or intentional.
3. To check if neutral and ground are switched, measure hot-neutral and hot-ground under load. Hot-ground should be greater than hot-neutral. The greater the load, the more the difference. *If hot-neutral voltage, measured with load on the circuit, is greater than hot-ground, then the neutral and ground are switched.* This is a potential safety hazard and the condition should be corrected immediately after turning off the power at the panel.

Let's investigate hot-ground voltage a bit more. Hot-ground reading should be the highest of the three readings. The ground circuit, under normal, non-fault conditions, should have no current and therefore no IR drop on it. You can think of the ground connection as a wire running back to the source (the main panel or the transformer), where it's connected to the neutral. On the receptacle end of the ground path, where the measurement is being made, the ground is not connected to any voltage source (again, assuming there is not a fault). So the ground wire is like a long test lead back to the source voltage. When there is a load connected, the hot-ground receptacle source voltage should be the sum of the hot-neutral voltage (the voltage across the load), and the neutral-ground voltage (the voltage drop on the neutral all the way back to its connection to the ground circuit).

Testing for voltage drop

On an ideal circuit, there should be no voltage drop: the less the voltage drop, the more "stiff" or reliable the source. But in reality, there is always some voltage drop through the system wiring.

- Wire gage will affect voltage drop—the smaller the wire, the higher its impedance.
- The longer the wire run on the branch circuit, the greater the impedance and the greater the IR drop.
- And finally, the more heavily loaded the circuit, the greater the voltage drop ($V = IR$, so the more current, the more the voltage drop).

Since the first two factors are hard to change, it's the last question—is the circuit overloaded—that you are usually trying to answer. To measure voltage drop, we use the most "mysterious" of all these measurements, the neutral-ground voltage. Let's first run an "experiment" to explain neutral-ground voltage. Plug in a load, such as a hairdryer, in a lightly loaded circuit. A 1500 W hairdryer will draw about 12 A, enough to create a noticeable IR drop. One set of possible measurements is shown below:

Voltage Measurement	Dryer OFF	Dryer ON	Difference
Hot-neutral	121.4 V	116.2 V	5.2 V drop
Neutral-ground	.31 to .33 V	3.0 V	2.7 V increase
Hot-ground	121.6 V	119.2 V	2.4 V drop

These readings show that the neutral-ground voltage increases with loading, just like the voltage drop. To measure voltage drop, you could have first gone to the panel, and measured hot-neutral voltage at the branch circuit breaker, then measured the hot-neutral voltage at the receptacle. The difference would be the voltage drop through the wiring. Obviously, performing a single neutral-ground voltage measurement at the receptacle is a shortcut.

In most office environments, a typical reading of neutral-ground voltage is about 1.5 V. If the reading is high, above 2 to 3 V, then the branch circuit *might* be overloaded. Another possibility is that the neutral in the panel is overloaded. Check the neutral-ground voltage at the panel. What are we looking for? To accommodate computers and other electronic loads, the neutral should be at least as large as a feeder, and preferably twice as large.

By the way, notice how the hot-neutral voltage drop (5.2 V) about equals the sum of the neutral-ground and hot-ground voltage changes (2.4 V + 2.7 V). The combined black wire and white wire IR drops subtract from the voltage available to the load, the hot-neutral voltage. The white wire IR drop is easy to measure as neutral-ground voltage, but the increased current causes an IR drop on the black wire as well as the white wire. This *black wire IR drop is measurable by the difference between the no-load and load hot-ground voltage* (2.4 V). In the real world, it's not that easy to switch all the loads on and off to make this measurement. That's why the neutral-ground measurement is so useful.

Measure peak voltage

The outlet is the farthest point in the wiring system from the source. That means it is the most vulnerable to voltage supply problems. But to the single-phase load, reliable or not, it's the only point in the system that matters. All our voltage measurements so far have been in rms values. You know that you need to measure the peak value as well. Many meters will specify a 1 ms peak or peak hold option. Since a half-cycle of 60 Hz is about 8.3 ms, the 1 ms peak function can capture the half-cycle peak. The normal peak, assuming that the ac voltage is a more or less perfect sine wave, is 1.4 times the rms. For 120 V, that equals about 168 V. Now why is it important to measure the peak? Because electronic loads care about peak value, since that is what they use to power their ac-to-dc conversion circuits. When almost all the loads on a circuit are electronic, they are all drawing power at the same time, from the peak of the wave. As a result, the sine wave tends to become "flat-topped." This makes it harder for electronic power supplies to charge. An rms reading alone won't spot this problem.

When the problem doesn't go away

After everything at the receptacle tests okay, you conclude that it was likely that the equipment problems were caused by something other than the receptacle wiring. The problem might be voltage fluctuations or transients caused by other problems in the building or at the utility. Of course it could be the load itself that's acting up. A good next step would be to connect a voltage recording device to the receptacle and check the voltage over time.

Work safely

The high voltage and currents present in electrical power systems can cause serious injury or death by electrocution and burns. Consequently, only trained, experienced electricians who have knowledge of electrical systems in general and the equipment under test should perform testing and modification of electrical systems.

Fluke cannot anticipate all possible precautions that you must take when performing the measurements described here. At a minimum, however, you should:

- Use appropriate safety equipment such as safety glasses, insulated gloves, insulating mats, etc.
- Be sure that all power has been turned off, locked out, and tagged in any situation where you will be in direct contact with circuit components. Be certain that the power can't be turned on by anyone but you.
- Read and understand all of the applicable manuals before applying the information in this application note. Take special note of all safety precautions and warnings in the instruction manuals.
- Do not use instruments on applications for which they are not intended, and always be aware that if the equipment is used in a manner not specified by the manufacturer, the protection provided by the equipment may be impaired.

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