Causes of Neutral-to-Ground Voltage and Proper Remediation Methods

Vincent P. Luciani, Sr. Sales Engineer,AMETEK Electronic Systems Protection

It is well known that a measured potential of a few volts between the NEUTRAL and GROUND connections at the electrical service outlet (N-G voltage) can cause sensitive electronic equipment that contain microprocessors to work erratically leading to system lockup and a need to reboot.

The purpose of this paper is to explain the causes of N-G voltages, reasons why N-G voltage adversely affects electronic equipment and present some solutions to N-G voltage issues.

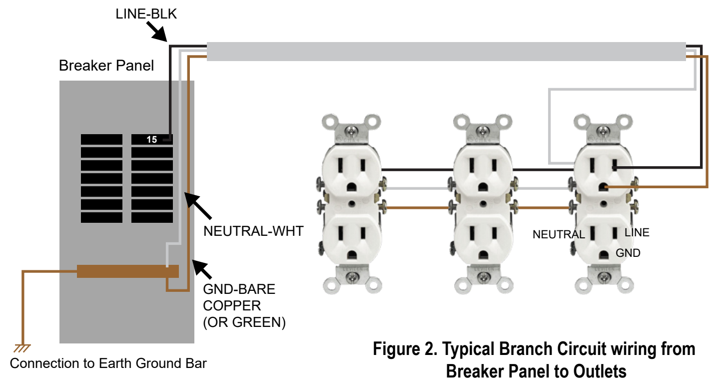


Figure 2. Typical Branch Circuit wiring from Breaker Panel to Outlets

Power Distribution Basics and N-G Voltages

Modern power distribution within a home or commercial building located in North America consists of LINE, NEUTRAL, and GROUND. The LINE wire is energized with the circuit voltage of 120V. The NEUTRAL wire is the return path for the current and is not energized. The GROUND (sometimes referred to as "Safety Ground") was added during a revision of the National Electrical code in the early 1970's to provide an alternate path for return current to flow back to the panel in the case of a system failure. This alternate return path ensures that the breaker will trip when there is a fault.

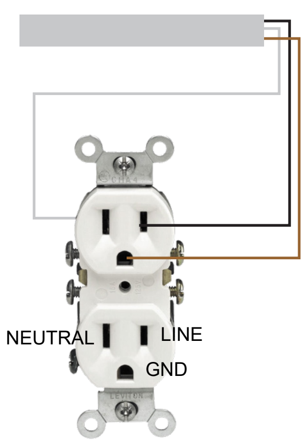


Figure 1. Wiring of a standard NEMA 5-15 Outlet

Inside the breaker panel at the service location, LINE wires (usually black or red in color) are terminated on to circuit breakers, while NEUTRAL wires (usually white in color) and GROUND (usually green or bare copper wire) are terminated on the Earth Ground buss within the panel. This buss bar is called Earth Ground because a wire from this buss bar is connected to one or more ground rods which are 5-foot-long metal rods that are literally pounded into the ground. The important point here is that inside the breaker panel, both NEUTRAL and GROUND are connected to the same point. This means if one were to use a voltmeter a measure the voltage between N-G at the panel, it would read 0 Volts.

Ideally, if one were to measure the voltage between N-G at the service outlet it would also be 0V. However, often when the voltage between N-G is measured at the outlet, it does not read 0V.

Causes of N-G Voltages

In an electrical circuit, the LINE and NEUTRAL wires provide a path for electrical current to flow to and from the Electrical Load. In other words, if the load requires 10 Amperes, this current is supplied through the LINE wire and returns to the breaker panel through the NEUTRAL wire.

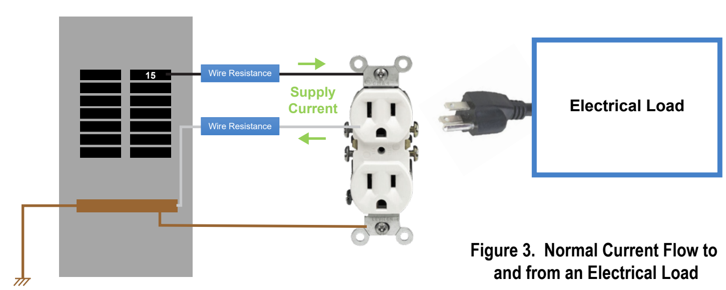


Figure 3. Normal Current Flow to and from an Electrical Load

The wire used in electrical distribution systems is usually made of copper. While copper wire is a very good conductor, it still has resistive characteristics per unit of length. If the wire is especially long, resistances can build up to a point where it does affect the performance of the system.

When the wire length from the breaker panel to the service outlet is long and the connected equipment is pulling a large amount of current, the resistance in the wire will cause a voltage drop along the NEUTRAL wire. When this NEUTRAL voltage is measured with reference to the GROUND, this is referred to as an N-G Voltage.

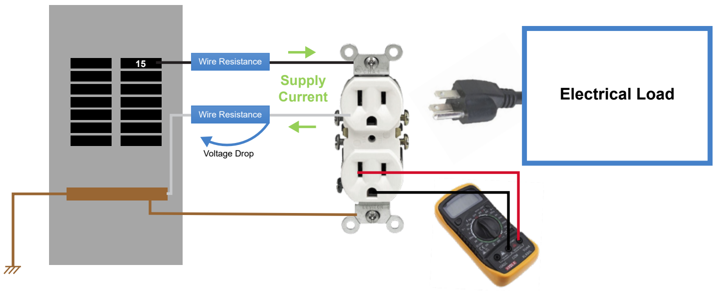


Figure 4. N-G Voltage caused by increased Wire Resistance

Another source of N-G voltages is the practice of sharing the NEUTRAL connection in a 3-phase system. In commercial structures, the electrical service is most likely supplied as 3-phase Wye or Delta. In some older electrical installations, it was common practice to share the NEUTRAL connection between the three phases. The theory was that since the three phases were out of phase with each other (each phase peaking at a different point in time), that the return current would balance out rather than actually traveling back through the NEUTRAL line. So, not only was the NEUTRAL shared between the phases, it was often undersized in order to save money.

This theory holds true if the current draw between the three phases is balanced. Phase balancing is easy if all three phases are going to the same load, such as a motor. As long as the motor is working correctly, the current draw per phase is about the same, and the smaller, shared NEUTRAL is not a problem.

However, our use of electricity has changed with modern electronics. Switch-mode power supplies pull current in bursts rather than in a consistent manner. In addition, not much attention is paid to making sure we equalize the number electronic loads across the three phases. So, when you place modern electronic loads in a building with an older electrical distribution infrastructure, imbalances between the phases occur, higher than expected current will travel down the undersized NEUTRAL wire, and N-G voltages are created.

Effects of N-G Voltage on Electronic Equipment

While measuring N-G voltage is relatively easy, the effects it has on electronic systems are hard to diagnose because N-G voltages may affect some equipment and not others. It might even affect a piece of equipment only if it is connected to another piece of equipment. It really has to do with the design of the circuitry inside the device.

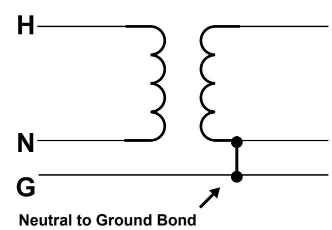
For example, if the regulation or feedback circuity of an internal switch-mode power supply is referenced to the metal chassis of the equipment (which is connected to GROUND as per UL standards) but the DC (-) terminal is not, than any small amount of N-G voltage may cause fluctuations in the DC voltage, resulting in lockups. These types of issues amplify when the internal system architecture of the electronic equipment is comprised of multiple sub-systems tied together with communication busses such as I2C or a standard serial port.

Troubleshooting the effects of N-G voltages can be difficult. Some equipment that might be impervious to N-G voltages when used by itself can be susceptible to N-G voltage and becomes unstable when connected to other pieces of equipment via data communication ports. Consider a system where Equipment A has a circuit architecture where the internal DC power supply and circuitry is isolated from chassis GROUND by design. One might have no issues if installing it in an environment with N-G voltage issues. However, Equipment A contains an RS-232 port for communication with Equipment B. Equipment B has been designed where its DC power supply is referenced to chassis GROUND. Through the data communication cable, Equipment A is now referenced to GROUND which was not intended by the designer, causing unstable behavior in data communications between the two pieces of equipment and/or system lockup.

Solutions for N-G Voltage Problems

As N-G voltage problems are caused by internal wiring issues, the best way to solve the problem is to ensure proper electrical distribution inside the building. Have a licensed electrician rewire the branch circuit to your equipment to provide an independent, dedicated set of wires from the breaker to the outlet. The dedicated circuit should consist of (3) individual conductors (L-N-G). All conductor's wire gauges should conform to recommendations set by the National Electrical Code that minimizes wire resistance for the specific wire length between the breaker panel and outlet, as well as supplies the required current to the electrical load. This may require oversizing the wire 1 to 2 gauge sizes. Use certified National Electrical Code practices for connecting oversized wires to wiring devices and circuit breakers. Have the electrician check to the NEUTRAL connections in the distribution system, especially at the buss bar in the breaker panel.

There may be situations where the wire from the breaker to the outlet is just too long for increasing the wire gauge to be effective, or replacing the wire is not feasible. In these situations, there is an accepted practice for creating a new NEUTRAL to GROUND bond at the point of use.



An Isolation Transformer is a 1:1 transformer that galvanically isolates the source from the load. Electrical energy is magnetically transferred from the input to the output of the isolation transformer while keeping the current flow between the source and the load isolated. When an isolation transformer is used, it is acceptable to NEC and IEEE standards to reestablish the NEUTRUAL – GROUND bond that is found inside the breaker panel. This is the only acceptable method for bonding NEUTRAL to GROUND downstream from the breaker panel.

In addition to cancelling N-G voltages due to insufficient wire sizes and load imbalances in systems that share the NEUTRAL connection, it has the added benefit of cancelling out common mode N-G noise voltage created by Electro-Magnetic Interference and Radio Frequency Interference (EMI/RFI). Using an isolation transformer is a good practice in professional and residential audio/video systems requiring a very low noise floor to enhance performance.