# Reliability of switches that generate current in the grounding conductor

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Illumination accounts for about 8% of all the energy consumed in the United States, so it is not surprising that many steps are being taken to increase efficiency of lighting systems, reduce lighting energy consumption, and decrease the lighting-related carbon footprint. For example, incandescent lamps with simple resistive loads are being outlawed and they are being replaced by compact fluorescents or new light-emitting diode (LED) technology, which have complex high impedances. Also, electronic lighting control devices are being installed in switch boxes to automatically or remotely control lighting assemblies based on room occupancy, time of day, daylight harvesting, and remote user input. Electronic lighting control devices that control the operation of the switch (such as motion or photoelectric sensors), however, require small amounts of constant standby power that is not interrupted by the operation of the switch or the dimmer. This current can be supplied via a circuit that is completed from the hot conductor through the lamp (Figure 1), through a neutral conductor (Figure 2), or through the equipment grounding conductor (Figure 3).

In residential and commercial buildings, light switch enclosures generally have an AC line (typically identified by a black wire), a switched/line conductor connecting the switch and the lamp, and an equipment grounding conductor (typically identified by a green wire). Most current switch enclosure installations do not include a grounded conductor (neutral); however, the National Electric Code (NEC) now requires installation of the circuit neutral wire in the switch enclosure (NEC-2011 Section 404.2 (C)).

A circuit, for example, consisting of an incandescent lamp and an occupancy sensor may be completed as shown in Figure 1, where the incandescent lamp is part of the circuit used for the sensor's standby power. For correct functionality of the circuit shown in Figure 1, the amount of current passing through the resistive filament of the incandescent lamp must be high enough to power the occupancy sensor, but low enough so that the resistive filament in the lamp does not produce noticeable heat or light. When the circuit is completed through the lamp, high impedance lamp loads (such as compact fluorescent lighting or LED light fixtures) connected and controlled by light switches present an obstacle to the reliable and constant presence of the standby power supply and, therefore, affect the reliability of such a lighting load control switch. As low energy lighting solutions replace traditional incandescent bulbs, a circuit schematically shown in Figure 1 becomes an unreliable method for powering electronic lighting control devices within switches. Even without the use of low energy lighting solutions, the impedance of traditional light fixtures is highly variable and completing the electronic lighting control circuit through the lamp may be unreliable.

The addition of Section 404.2(C) of the 2011 NEC requires installation of a grounded conductor (neutral) in the switch enclosures hence circuits shown in Figure 2 can be configured. With the addition of this section in the NEC, electronic lighting control devices installed in switches can be powered by directly using the hot and neutral conductors. This configuration is consistent with other electrical installations and removes the reliability issues associated with completing the circuit through the lamp as shown in Figure 1. The provisions of the 2011 NEC are not retroactive; therefore, there is no requirement to upgrade existing structures per NEC-2011 Annex H Section 80.9. There is also some delay associated with state governments adopting the NEC into law. The design shown in Figure 2 is not possible in structures that are not built to the NEC-2011 Section 404.2(C) requirement.

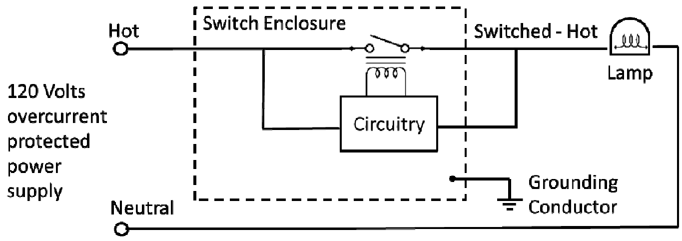

Figure 1 Standby power for electronic light switch passes through incandescent lighting assembly. The very low current passing through the lamps does not produce visible incandescence.

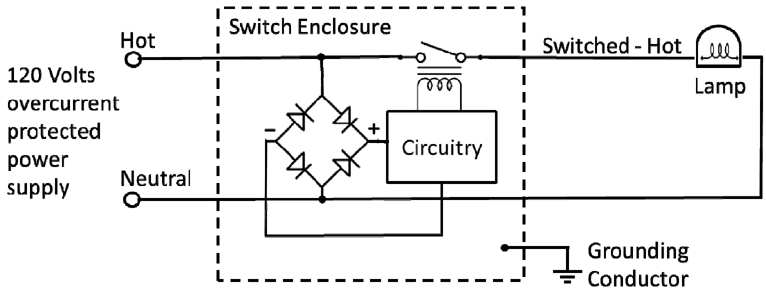

Figure 2 A simplified schematic of a light switch using a standby power supply installed according to Section 404.2(C) of the 2011 National Electric Code.

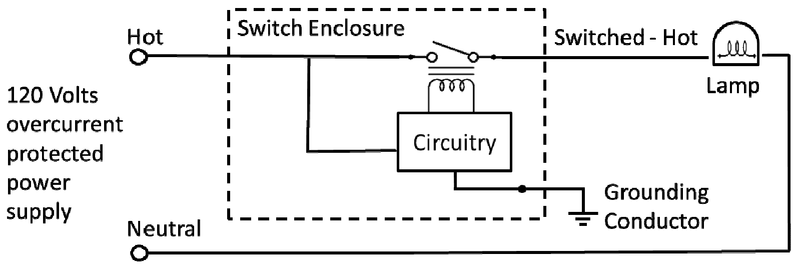

Figure 3 A simplified schematic of an electronic light switch using an equipment grounding conductor for the standby power supply.

In installations not designed to NEC Section 404.2(C), the equipment grounding conductor may provide an alternative current path for standby power as shown in Figure 3. A low amount of current is passed through the equipment grounding conductor to power the sensor circuitry. The current typically may be below leakage currents allowed by UL or other standards organizations. The growing use of the equipment grounding conductor as a normal current carrying conductor suggests a review and understanding of the potential equipment reliability issues is appropriate since Section 404.2(C) of the NEC will not be immediately implemented. Here, two issues are addressed: operability of branch circuits and safety concerns for the particular case of 120 V branch circuits.

The first issue regarding operability of a branch circuit concerns nuisance trips of ground fault circuit interrupters (GFCI) installed within breaker panels. Based on the UL244A-2003 standard in Section 19.1.3 Exception No. 2 [1], the standby current allowed from a single switch controlling a set of lamps is

0.5 mA, which is approximately 10 times lower than the 4 mA to 6 mA current rating of GFCIs per breaker required by the NEC [2]. Multiple switches, however, may produce a total current that would enable nuisance trips of a GFCI, but the number of switches that are required seems high and unlikely to be installed per branch circuit.

The intent of equipment grounding conductors is for protection during abnormal conditions. The intent of grounding of electrical equipment is explained by the NEC in Section 250.4 (A)(2), "Normally non-current-carrying conductive materials enclosing electrical conductors or equipment, or forming part of such equipment, shall be connected to earth so as to limit the voltage to ground on these materials." The NEC, however, has not quantitatively defined the limit on how much current can be tolerated through a ground wire, and this lack of definitiveness is open to interpretation.

For example, the UL244A standard in Section 19.1 Exception No. 2 states, "A current not exceeding 0.5 mA may be conducted along an equipment-grounding or the equipment-bonding conductor or connection," and Section 4.9 of UL 1472 states, "If an external, nonisolated sensing circuit is provided or the yoke or cover plate is conductively connected to live parts of the supply circuit for touch operation, the energy available shall be limited through the use of impedance to a leakage current not more than 0.5 mA as determined in accordance with the leakage current test for touch dimmers" [3].

These UL current limits are below the limits of perception and painful sensations associated with AC current flowing through the human body. The limit of perception of 60 Hz AC currents through the human body is around 1 mA peak [4,5,6], and a current of 5 mA peak could create a "painful sensation" [7]. There may be substantial physiological differences from person to person, so currents that would cause muscle contraction (also called "let go current") fall within a range of 8 mA to 25 mA peak [8].
If 10 switches each ran 0.5 mA in parallel onto the same equipment grounding conductor, there would be a point along the equipment grounding conductor that would have a total current of 5 mA. The impedance of the human body is much greater than a properly wired grounding conductor, so only a small fraction of the current from the grounding conductor would flow through a body in contact at that point. There is no potential for a shock hazard unless the cumulative ground current available from all switches is above 5 mA, there is a fault in the grounding conductor, and the grounding conductor at the specific location that has 5 mA of current is accessible for human contact. Since several unlikely factors would need to occur simultaneously to present a shock hazard, the risk of inadvertently creating a shock hazard by using the grounding wire to complete the circuit for electronic lighting control devices in switches is negligible.

In summary, a 120 V branch circuit with fewer than 10 electronically controlled switches per branch circuit and with switches that operate with a ground current less than 0.5 mA, as allowed by UL244A Section 19.1 and UL 1472 Section 4.9, has little risk of nuisance tripping of branch GFCI and no electric shock hazard. If 10 or more switches are in parallel on the same branch, there is a possibility that the cumulative ground current will approach 5 mA, which is in the range of tripping currents for most GFCIs and also in the range of being painful for humans, but below let-go current limits (assuming a fault exists that allows the current to travel through the human body). It should be noted that for lighting circuits utilizing voltages higher than 120 V, 20 A, the number of lighting switches installed on a single lighting circuit could exceed the limits indicated in the above analysis. Therefore, an independent and separate analysis for lighting circuits utilizing higher voltages is required.

**References**


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