The How's and Why's of Isolated Grounding

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Abstract

The grounding of sensitive electronic equipment is often believed to be black magic. One grounding technique often encountered with sensitive electronic equipment, which has contributed to this aura of mystery, is isolated grounding. There is much confusion over what is an "isolated ground" (IG), how is an IG technique implemented, and why is it used. This article seeks to explain what are the proper implementations of IG in low-voltage AC power systems as allowed by the National Electrical Code (NEC) and points out some of the potential incorrect and unsafe interpretations of IG. Further, the article explains why IG techniques can be beneficial in reducing common mode noise, as well as why IG techniques can sometimes cause common mode noise problems.

Introduction

Electronic equipment has greatly proliferated in recent years. In fact, electronics has been increasingly applied to most traditional electrical equipment such that it is hard to find a new electrical device that does not contain electronics: electronic adjustable-speed, variable-frequency drives have been applied to traditional AC motors; electronic ballasts have been applied to gas discharge lighting; electronic controls have been added to equipment that had previously been totally electro-mechanical, such as washing machines and refrigerators; electronics have even been applied to circuit breakers and relays. With electronic equipment has come greater sensitivity to power disturbances and electro-magnetic interference (EMI) along with their resulting operational problems.

One type of power disturbance which can be particularly troublesome to control is common mode noise. Common mode noise, as its name implies, is any unwanted signal that is common to all circuit conductors simultaneously. The other form of noise is normal mode noise (also known as transverse or differential mode noise) which is any unwanted signal that exists between the circuit conductors. In AC power systems, the difference in potential between neutral and ground is one form of common mode noise, since any change in neutral potential relative to ground also affects all of the other power circuit conductor potentials to ground. Another more troublesome form of common mode noise is the differences in ground potentials throughout an electrical system. When multiple electronic devices are interconnected by way of control, data, or communication cables, any difference in ground potentials between the interconnected pieces of equipment is common mode noise to the control, data or communication circuits. It is virtually impossible to keep all of the (chassis) ground potentials of distributed electronic devices at the same potential under all possible circumstances. Therefore, some level of common mode noise immunity must be designed into electronic devices intended to be interconnected. Further, the surge suppression,

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wiring, shielding, and grounding of the building electrical system (including the control, data, and communication cabling) can have a pronounced effect on the levels of common mode signals to which the electronics are exposed.

Because equipment ground potentials (or changes in them) have been observed to affect the operation of certain electronic devices, designers, installers and service personnel often have very specific and sometimes special grounding requirements. Most of these special grounding techniques have evolved based on empirical (trial and error) testing rather than on detailed analysis. Some of the more creative grounding arrangements are devised in the name of noise reduction, but they often ignore the basic principles of electricity, such as electricity follows the paths of least impedance, electricity flows in complete paths, and electricity flows because there is a potential difference. Further, when trying to reduce the effects of "noise," the fundamentals of noise coupling are sometimes ignored. For information on the fundamentals of noise control, see reference [1].

One such special grounding technique used in low-voltage AC power systems to reduce interference is known as isolated ground (IG). IG is allowed in the U.S. by the National Electrical Code (NEC)[2] and in Canada by the Canadian Electrical Code (CEC)[3]. In both cases, IG is an exception to the standard grounding requirements. NEC 250-74 and 250-75 allow IG wiring only "where required for the reduction of electrical noise on the grounding circuit."

Definition of IG Receptacles

IG receptacles differ from standard receptacles in two major ways. See Figure 1 for a comparison of standard and IG receptacles. First, with an IG receptacle, the receptacle grounding terminals are electrically insulated from the receptacle mounting, which insulates the receptacle grounding circuit from the metallic conduit grounding system when the receptacle is installed in a metal outlet box. Hence the term *isolated ground*. Second, to differentiate the IG receptacle from standard receptacles, the face of the receptacle is colored orange or marked with an orange triangle. While insulation of the ground terminal from the receptacle mounting is the significant electrical difference, an IG receptacle is sometimes used because of its distinctive marking. In this way, the bright orange receptacle indicates that the receptacle is to be used exclusively for sensitive electronic equipment and that other "dirty" loads are not to be plugged into the IG receptacle.

It should be noted that the primary purpose of grounding in AC power systems is equipment and personnel safety. The secondary purpose of grounding in AC power systems for sensitive electronic equipment is equipment performance, namely the reduction of common mode disturbances. Many times these two purposes are viewed as being at odds with each other and as being mutually exclusive. However, what good is a system that works but isn't safe or vice versa? It must be the goal of grounding sensitive electronic systems to provide systems that are both safe and that work. As such, the performance purpose of grounding can never take precedence over the safety purposes. Therefore, the safety grounding requirements of the NEC cannot be compromised for the sake of performance. (For more information on safety grounding requirements, see reference [4]).

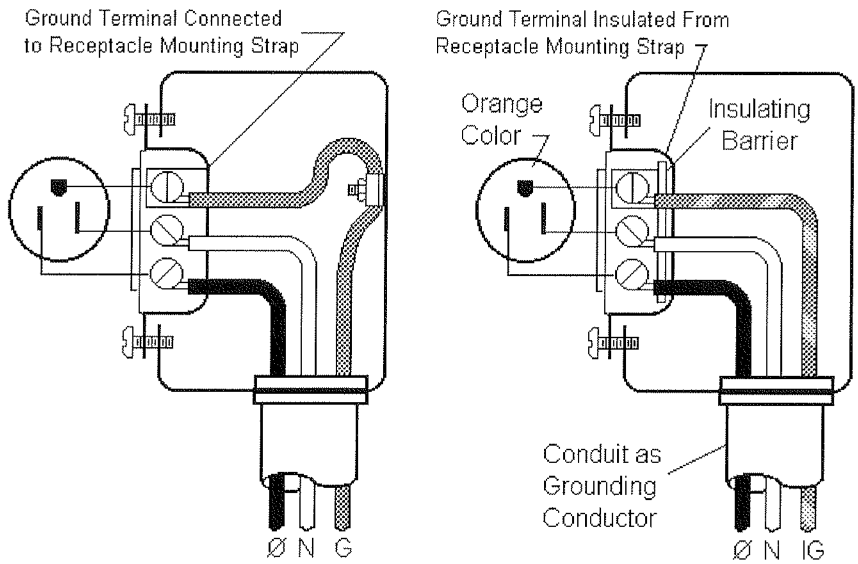

Figure 1
Comparison Of A Standard Receptacle With An IG Receptacle

The basic reasons for grounding AC power systems are to limit the circuit voltages, stabilize the circuit voltages to ground, and facilitate the operation of the overcurrent protection device (OPD) in the event of a ground fault. For solidly grounded low-voltage AC power systems, the NEC requires that all of the metallic enclosures of the electrical system be effectively grounded to minimize the electrical shock potential and to facilitate the operation of the OPD to clear a ground fault. The NEC defines *effectively grounded* as having a ground path that: (1) is permanent and continuous, (2) has ample current-carrying capacity to handle potential ground fault current, and (3) has sufficiently low impedance to allow the operation of the OPD to clear a fault quickly [NEC 250-51]. These requirements necessitate that an equipment grounding conductor

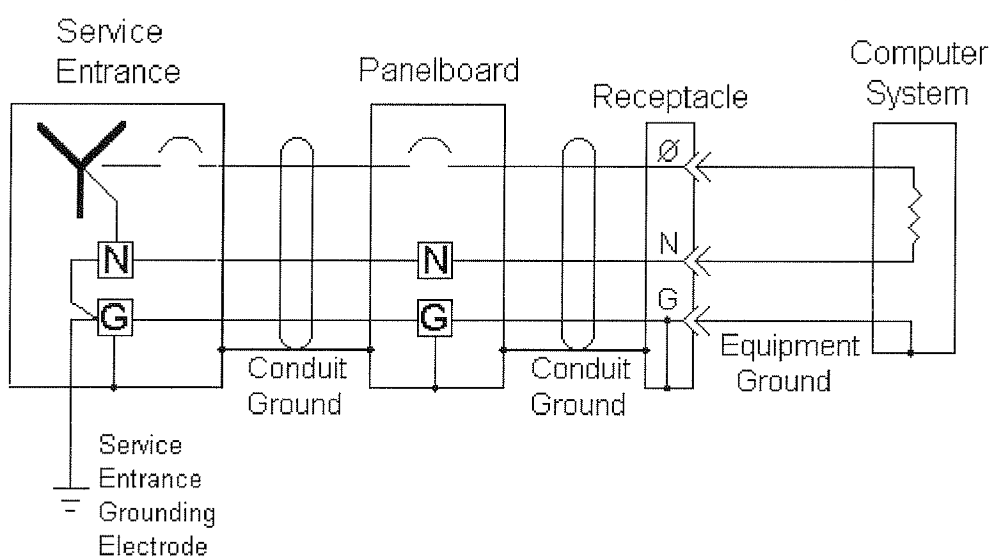

Figure 2
Typical Power System With Conventional Grounding And Standard Receptacles

permanently connect all of the metallic enclosures of the electrical system and any other conductive parts that could become energized. In order to facilitate the operation of the OPD to clear a ground fault, the equipment grounding conductors must be connected to the power system grounding point. Figure 2 is an example of a typical low-voltage power system using standard receptacles.

If a ground fault were to occur at the load equipment, as depicted in Figure 3, the grounding system would provide an effective ground path because: (1) the equipment grounding conductors or raceway are suitable to be used as a grounding conductor by the NEC and are permanent and continuous, (2) the equipment grounding conductors are sized according to the NEC and have ample current carrying capacity to handle potential ground fault current , and (3) again, the equipment grounding conductors are sized according to the NEC and have sufficiently low impedance to allow the operation of the OPD to clear a fault quickly.

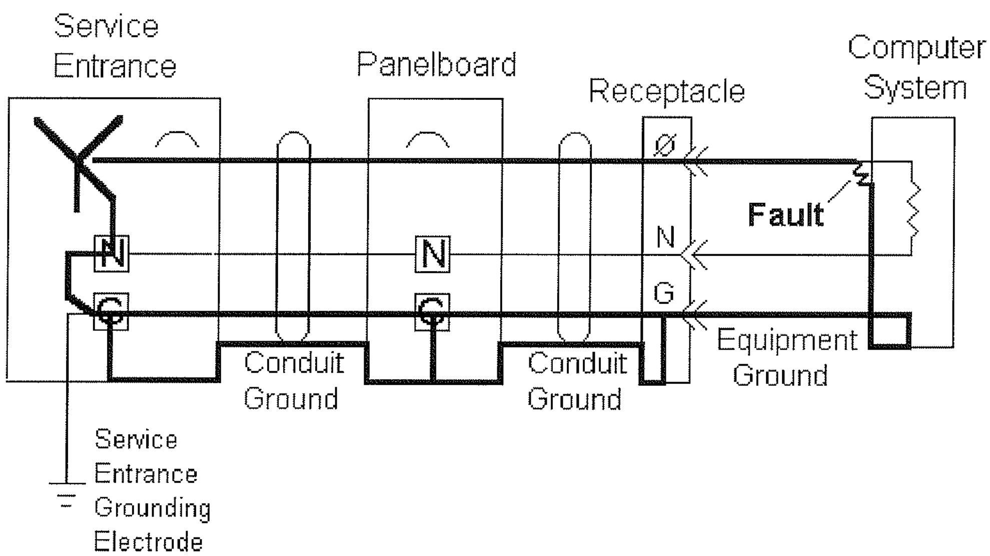

Figure 3
Example Ground Fault With Standard Receptacles

The Kaufmann experiment[5] demonstrated the importance of routing the grounding and power conductors in the same raceway. The basic experiment setup is shown in Figure 4. A current source was connected to the phase conductor and to pairs of possible ground return paths. In a comparison of the relative impedances of 100 feet of rigid steel conduit vs. an insulated #4/0 grounding conductor routed external to the conduit, 90% of the ground fault current flowed on the conduit and only 10% flowed on the equipment grounding conductor routed outside the conduit. In other words, the impedance of the conduit was nine times lower than the impedance of the grounding conductor routed external to the conduit. On the other hand, when the #4/0 equipment grounding conductor was routed with the phase conductor *inside* the conduit, 80% of the fault current flowed on the equipment grounding wire and only 20% flowed on the conduit. The impedance of the equipment grounding conductor was four times lower than that of the conduit. Hence, the recommended practice for sensitive electronic equipment is to use an insulated equipment grounding conductor routed in the same conduit as the power conductors and not to rely on the conduit which is subject to corrosion, loose connections, etc. (And to complete the comparison, when the building steel was compared to the rigid conduit, 95% of the fault current flowed on the conduit and only 5% flowed on the building steel.)

The Kaufmann experiment had a pronounced effect on the NEC. Prior to the experiment, grounding conductors were allowed to be routed external to the raceway. Afterwards, the code was changed to require that the grounding conductors be routed with the circuit conductors in the same raceway.

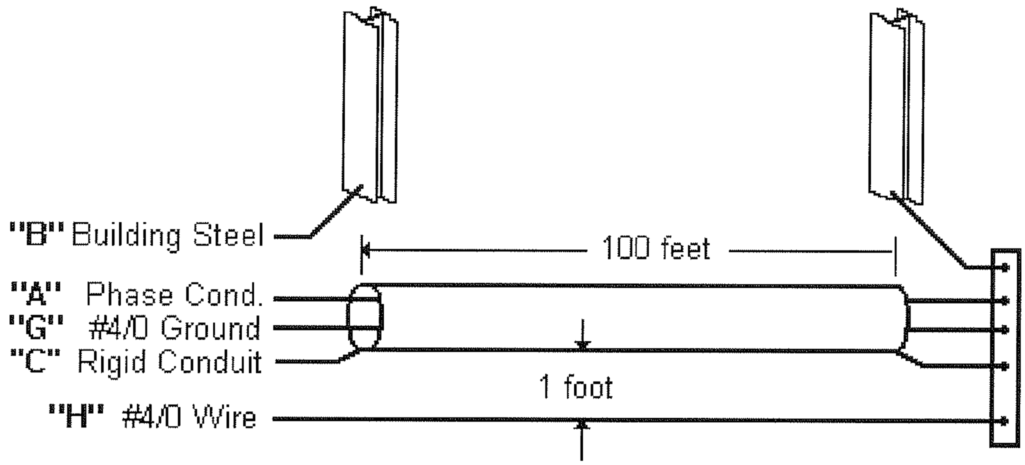

Figure 4
Kaufmann Experiment Determined the Relative Effectiveness of Various Ground Fault Paths [5]

Paths Compared	Amount of Fault Current Returning On Path "C"	"G"	"H"	"B"
"C" & "G"	20%	80%	---	---
"C" & "H"	90%	---	10%	---
"C" & "B"	95%	---	---	5%

Likewise with IG circuits, it is important that the IG wiring provide an effective ground fault path from the connected equipment back to the power source. Figure 5 is an example of a typical low-voltage power system using IG receptacles, as allowed by the NEC. Note that the ground terminal of the receptacle is not connected to the conduit grounding system at the receptacle. An IG wire is connected to the receptacle ground terminal and is routed with the power conductors, passing through one or more panelboards, remaining insulated from the metal conduit and enclosure grounding system until its termination at the power system grounding point (at the service entrance, in this example).

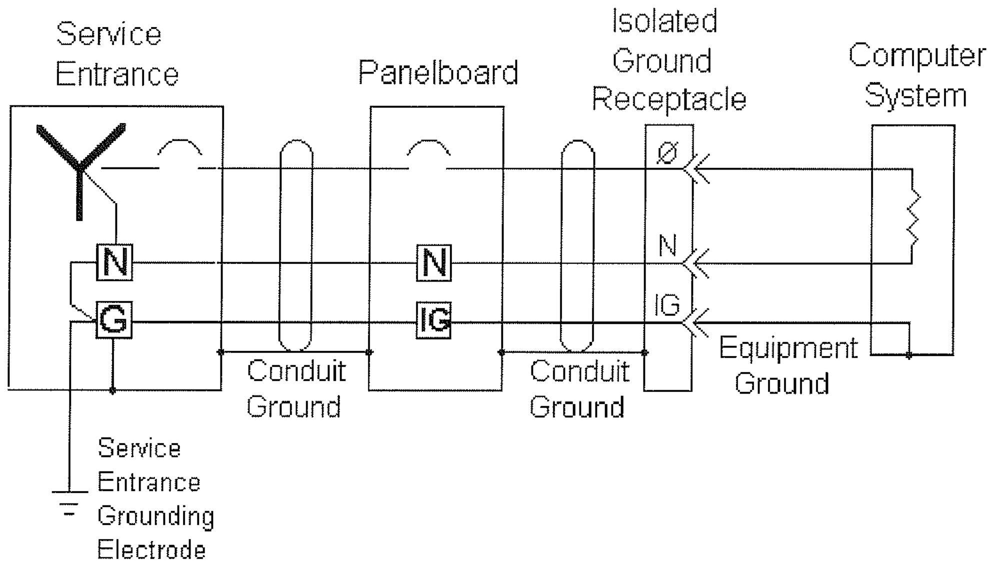

Figure 5
Typical Power System with IG Wiring

If a ground fault were to occur at the load equipment, the IG grounding system would provide an effective ground path as depicted in Figure 6. The IG conductor: (1) is permanent and continuous, (2) has ample current capacity since it was sized according to the NEC requirements, and (3) has a low enough impedance path to allow the OPD to clear the ground fault.

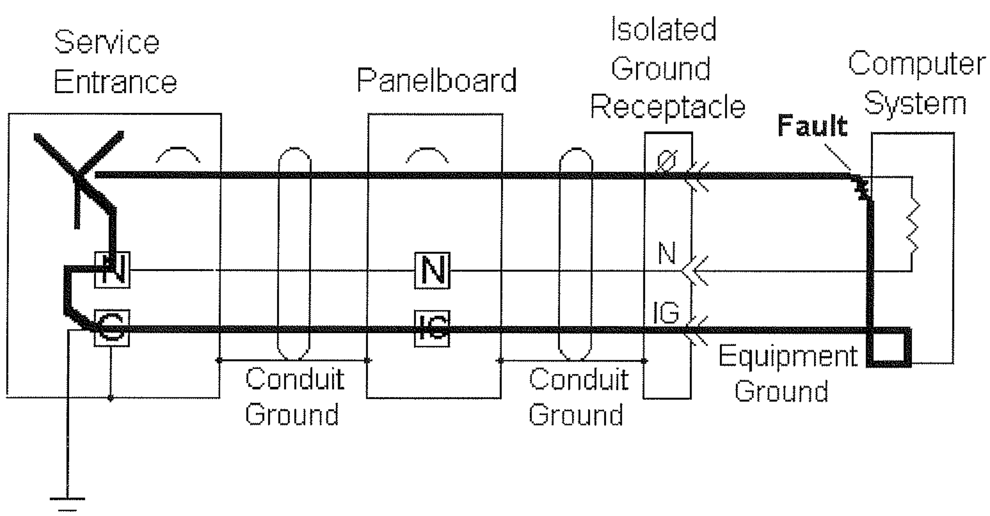

Figure 6
Example Ground Fault with IG Wiring

One other form of IG wiring is allowed by the NEC in NEC 250-75 (also by exception). Hardwired load equipment (which is direct-connected without plug and receptacle) also can be grounded using IG wiring. Since with hardwired equipment there is no IG receptacle to insulate the equipment grounding conductor from the metal conduit and enclosure system, a non-conductive bushing or conduit fitting may be inserted at the termination of the conduit or raceway system to the load equipment enclosure. See Figure 7. In this way, the equipment ground is isolated from the metal conduit and raceway system at the load equipment but is still effectively grounded for safety, the same as previously discussed for IG receptacles.

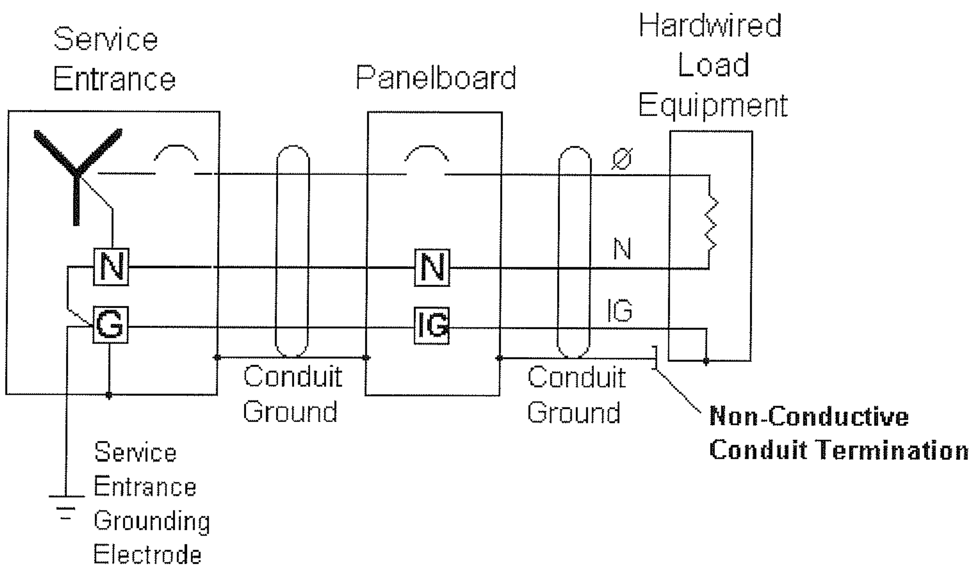

Figure 7
IG Wiring for Hardwired (Direct-Connected) Equipment

The IG exception to NEC 250-75 for hardwired equipment has only been recently added to the NEC. There is still some controversy as to whether IG wiring for hardwired equipment is effective at reducing common mode noise or is always safe. One concern is that to achieve the isolation of the load equipment grounding, the metal frame of the load equipment also must be insulated from its grounded surroundings. This insulation could allow shock potentials or side flashes to occur between the grounded surroundings (building) and the IG equipment enclosure during certain conditions when large ground currents flow. [See the discussion of the unsafe IG wiring that follows.]

Unsafe and Incorrect IG Wiring

Sometimes, IG requirements are misinterpreted and IG circuits are thought to be truly isolated. Efforts are wrongly made to ensure that the sensitive equipment grounding conductor is connected to an *isolated, dedicated ground*, never ever to be connected to the "dirty" power ground. Figure 8 is an example of just such an incorrect interpretation of IG. The ground terminals of IG receptacles are collected at an IG busbar and are then connected to a separate earth grounding electrode. Sometimes even extraordinary attempts are made to ensure a very good connection to the earth for the dedicated grounding electrode, in the hopes of providing a "quiet ground" for some sensitive electronic system.

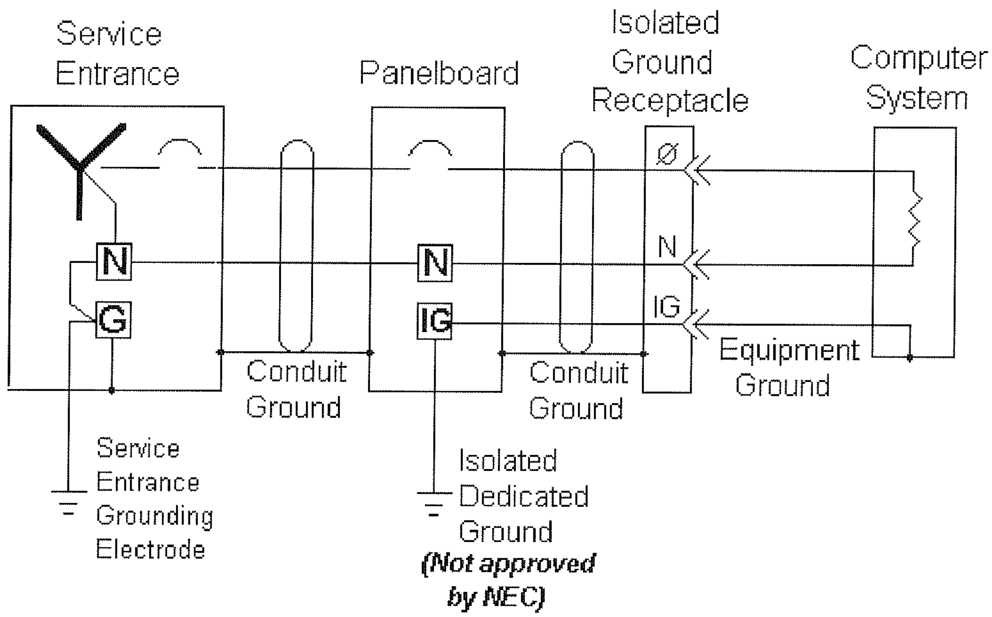

Figure 8
Example of an Incorrect and Unsafe Interpretation of IG

Despite the good intentions of the *isolated* IG approach shown in Figure 8, it fails to meet the basic safety requirements of the grounding system. The *isolated* IG approach does ***not*** provide the effective ground path required by the NEC and results in unsafe and hazardous conditions. Consider the possibility of a ground fault occurring at the load equipment, which is depicted in Figure 9. Note that an effective ground path is ***not*** provided between the *isolated, dedicated ground* and the power source (service entrance) grounding electrode system. It is not known if the ground path between these two earth electrodes is permanent and continuous or of ample current-carrying capacity. Further, the ground path surely does not have a low enough impedance to allow the OPD to clear the ground fault quickly and safely. The impedance of ground electrode connections to earth is measured in ohms, while the required ground fault path impedance must be in the milli-ohms.

Additionally, any difference in potential occurring between the isolated, dedicated ground electrode and the power system grounding electrode (which must exist because one is referred to as the "quiet" ground while the other is referred to as the "dirty" ground) will appear as a common mode (N-G) voltage at the load equipment. So, while the original intent of this *isolated* IG approach was to reduce electrical noise, the result is actually an increase in the common mode noise potentials at the sensitive loads. Significant ground potential differences can occur whenever there are large ground currents flowing, such as during ground faults, lightning, or even when electrical storm charge clouds move over the area. A common result of incorrect *isolated* IG wiring during these events is damage to the connected load equipment.

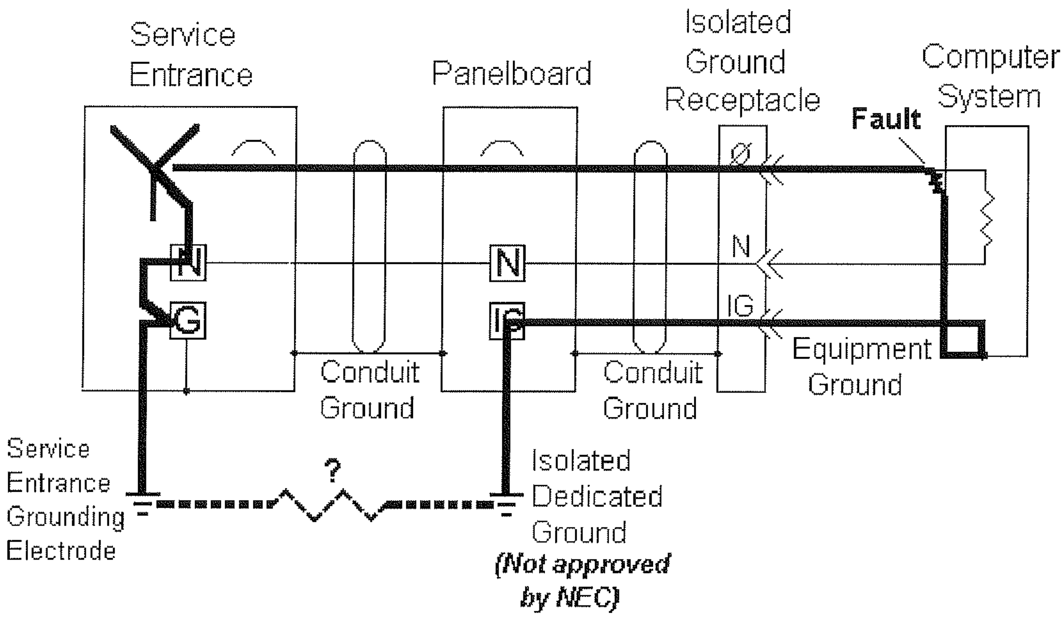

Figure 9
Isolated, Dedicated Grounds Do Not Provide An Effective Ground Fault Path

One interesting observation of incorrect and unsafe grounding practices is that the equipment may still operate even though it is improperly grounded and that the safety hazard may occur only under a specific set of conditions, such as during a ground fault or during a lightning storm.

Perhaps the name *isolated ground* contributes to the misinterpretation of the IG wiring techniques. A better name would be *insulated ground,* since the intent of IG is not to isolate the ground of the sensitive load from the power system ground, but rather to insulate it and to control where the connection to the power system ground is made.

Benefits of IG Wring Techniques

An old sage, experienced in the black magic of power quality, once stated that IG wiring, when properly implemented, was an important power quality enhancement tool which sometimes improved the noise situation, sometimes had no effect, and at other times made the condition worse. The trick is obviously in knowing which time is which!

Often, electronics engineers will balk at the proper implementation of IG wiring, as shown in Figure 5, because they see no isolation of the sensitive electronic equipment ground path. A common comment is "What good is it when the IG is connected to the 'dirty' AC power ground, as required for safety?"

The obvious answer is that the conduit and metal enclosure system provide EMI/RFI shielding of the power and IG conductors contained within them. But that is only part of the benefit of IG wiring. A more practical benefit is that IG wiring controls the grounding connections of the sensitive electronic equipment to minimize the problems associated with stray ground currents. Consider the example shown in Figure 10 for a standard (non-IG) grounding configuration. Stray ground currents flowing on the grounding system cause changes in the ground potentials throughout the grounding system. Stray ground currents are a reality with virtually every power system and exist under a variety of conditions, most of which are very dynamic (as opposed to steady-state). Stray ground currents can be the result of electrostatic discharge to the enclosures, ground fault currents, or even the capacitively coupled ground current surge when a load is energized.

For the example shown in Figure 10, any stray ground current will cause the ground potential of the panelboard enclosure to rise relative to the power ground reference at the service entrance. With the standard grounding configuration, the computer system's equipment ground reference relative to the power ground will also rise because the ground terminal at the panelboard is connected to the enclosure and changes as the enclosure's ground potential changes.

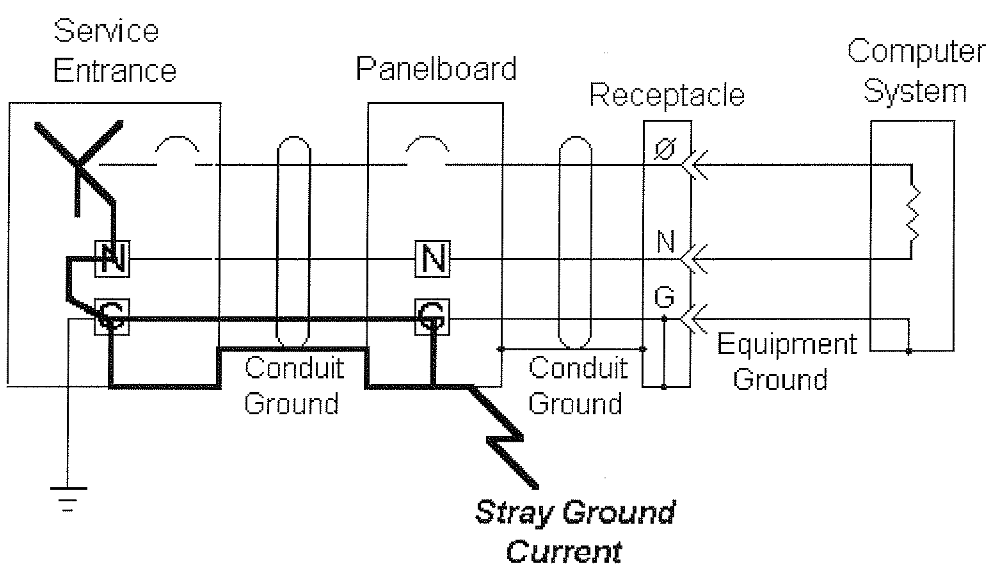

Figure 10
With Standard Ground Configurations,
Stray Ground Currents Affect the Sensitive Load's Ground Reference

The alternative IG configuration is shown in Figure 11. The equipment ground reference for the sensitive load is isolated from the metal conduit and enclosure ground system. Stray ground currents flowing on the conduit and enclosure system cause ground potential changes that are confined to the conduit and enclosure grounding system. Since the stray ground currents do not flow on the IG wiring, they do not affect (upset) the sensitive electronic equipment's ground reference.

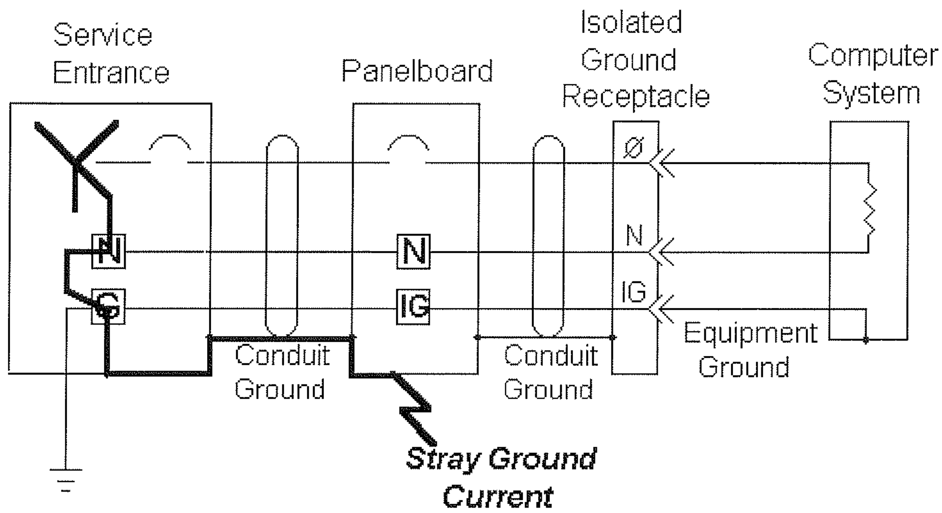

Figure 11
With IG Wiring Configurations,
Stray Ground Currents Do Not Affect the Sensitive Load's Ground Reference

Disadvantages of IG Wiring Techniques

Now that the potential benefits of IG wiring techniques have been stated, a caution concerning the potential disadvantages of IG wiring should also be stated. One potential disadvantage of IG wiring involves induced currents from the power conductors. Consider the relative position of the ground (or IG) conductor to the power conductors in the raceway. Figure 12 shows the cross section of two possible configurations. In most building electrical raceways, the position of the ground conductor is, at best, random relative to the power conductors since multiple individual conductors are normally used (instead of a manufactured cable where the relative position of the conductors is controlled). Whenever the ground conductor is not equally spaced between the power conductors, the magnetic fields associated with the currents flowing in the power conductors will not be balanced in the ground conductor. This net magnetic field, being an AC magnetic field, will induce current into the ground conductor if the ground conductor is part of a complete path for the current to flow (ground loop).

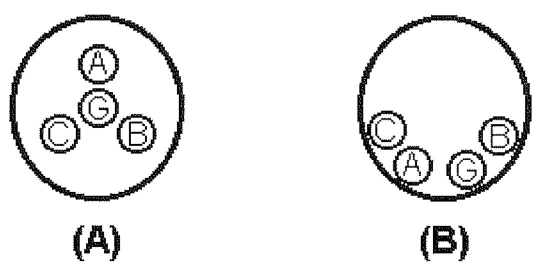

Figure 12
Ground Conductor Position Relative to the Power Conductors Inside a Conduit
(A) Ideal arrangement where the ground conductor is equidistant from the power conductors
(B) One of the usual arrangements where the ground conductor is not equidistant from the power conductors

IG circuits might be considered a solution to the induced ground current problem since the IG conductor is terminated to ground at only one end and does not form a complete loop through which the current can flow. This would be true as long as the load equipment served by the IG receptacle does not have any other connections to the power system ground. For interconnected systems, those having more than one piece of load equipment connected together by way of data, communication, or control cables, the use of IG wiring can actually make the induced current problem worse. Consider the interconnected system shown in Figure 13. A loop for the induced current in the IG conductor is completed by the interconnecting data, communication, or control cable. Currents induced by the power conductors are forced to flow on the interconnecting cables where there is a greater chance of upsetting or damaging the sensitive load. Induced currents on the interconnecting cabling of interconnected systems has lead to the widespread practice of grounding the shield of the interconnecting cable at only one end. While this practice may break up the potentially disruptive ground loop, it allows for the possibility of damaging or unsafe voltages to be developed in the system, particularly during ground fault, lightning, or other surge events.

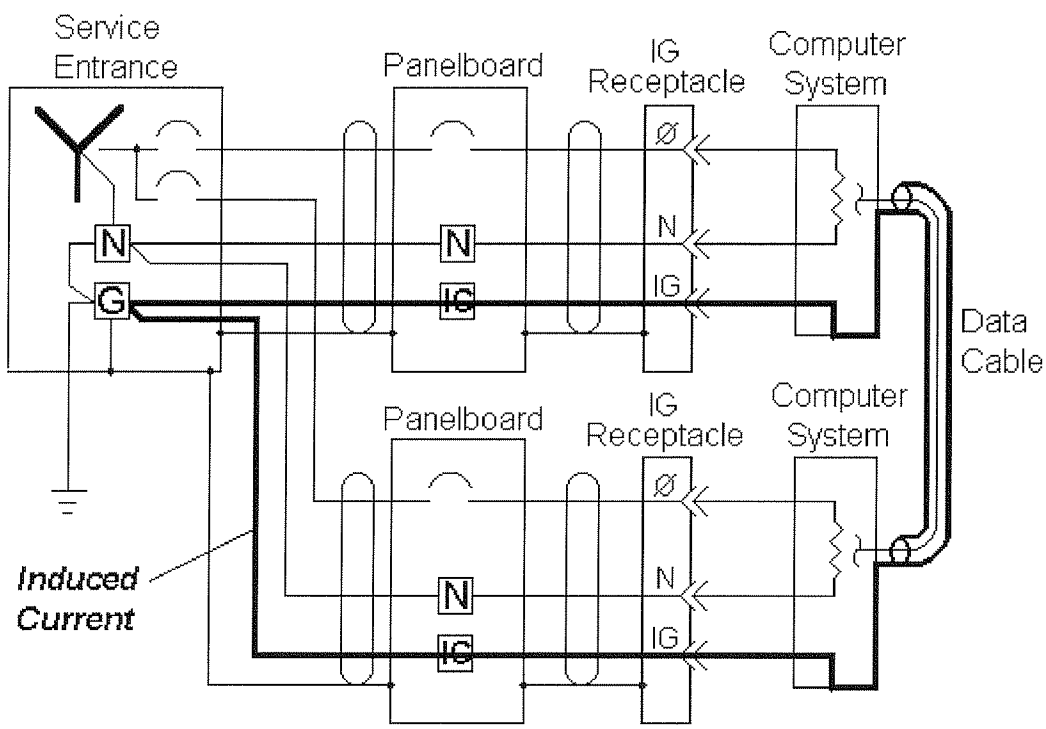

Figure 13
Induced Currents in Interconnected Systems Using IG Wiring Techniques

Induced currents on the interconnecting cables can be particularly troublesome for sensitive electronic systems having signals on the interconnecting cables which can be upset by the power system frequencies (60 Hz and the harmonics of 60 Hz). Examples of systems that have been observed to be sensitive to the power system frequencies include audio equipment, video equipment, and analog signal processors.

Standard grounding techniques, which use an insulated equipment grounding conductor connected to all of the metal enclosures, are less prone to problems with induced ground currents caused by the power conductors. See Figure 14. Whenever an insulated ground conductor is routed with individual power conductors, the resulting net magnetic fields from the power conductors will induce currents into any loop involving the insulated ground conductor. With standard grounding techniques, the metal conduit or raceway is electrically in parallel with the insulated ground conductor. The resulting induced ground current will flow without practical consequence in the ground conductor and conduit system. The induced current is diverted away from and normally will not flow in the typically higher impedance loop involving the interconnecting data, communication, or control cables.

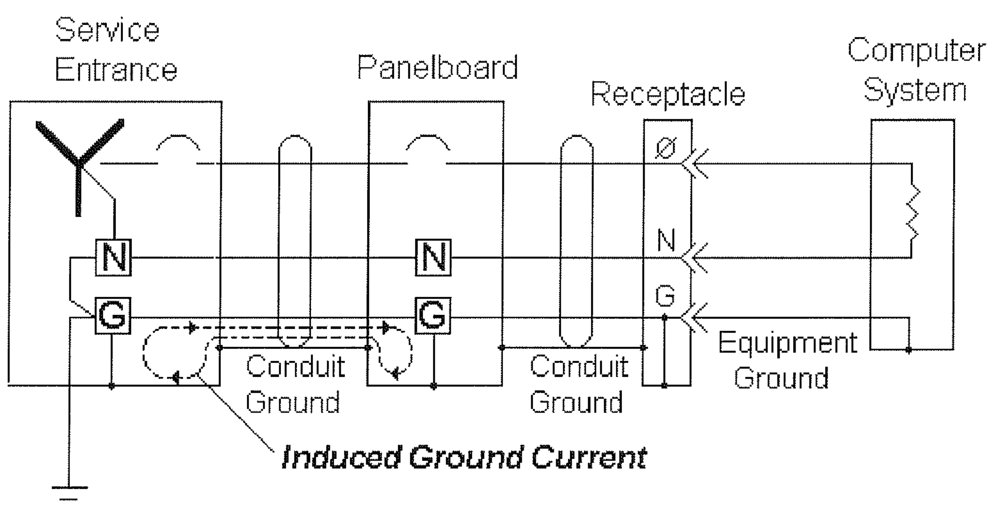

Figure 14
Induced Ground Current Flow with Standard (Non-IG) Wiring Techniques

Sometimes IG wiring techniques are inadvertently implemented. Such is the case when non-metallic conduit or enclosures are used, not because they interrupt the metal conduit system, but for environmental reasons, such as in corrosive environments or because of direct burial in the earth or concrete. Since the raceway does not provide an effective ground path, an insulated ground conductor is used. This non-metallic raceway system shares some of the characteristics of IG wiring since the insulated ground conductors typically have only one connection to the power system ground. The non-metallic raceway system also has the same concerns with induced ground currents and interconnected systems as IG wiring. One significant difference of the non-metallic raceway system from the IG wiring techniques discussed previously is that non-metallic raceway systems do not provide the EMI/RFI shielding of metallic raceway systems.

Summary

IG wiring, as allowed by the NEC, was explained and contrasted to the standard grounding techniques. IG is not *isolated* from the power system grounding. For safety reasons, the IG wire must be connected to the power system ground to ensure effective grounding of the load equipment. A better term for IG would be *insulated* ground, since the intent of IG wiring is insulate the grounding of the sensitive load equipment from the conduit grounding system and to control the connection to the power grounding system.

IG techniques can be useful to reduce the common mode noise appearing at the sensitive load equipment by providing EMI/RFI shielding and by eliminating the ground potential shifts due to stray ground currents flowing in the conduit system. However, with interconnected sensitive equipment, IG wiring can have a detrimental effect due to the induced currents flowing on the interconnecting cabling. Whether IG wiring is beneficial or not depends on the particular noise coupling modes, the sensitive equipment's susceptibility to either ground potential shifts or induced ground currents, and the power system configuration.

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