WHERE IS THE GROUND?

With each code cycle, the code evolves in response to events, practices, and developing technologies. In the discussion herein, I present a case study where past and current code editions are in conflict with each other. Supporting the case study are discussions of code and history that help to shine a light on the potential problems between code editions.

What you will learn: some National Electric Code history, history of power generation, grounding fundamentals, and a solid approach to code review for modernizations of vintage buildings.

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1.0 Introduction

Like many other codes that evolve and develop in response to catastrophic events and evolving technologies, the National Electric Code (NEC) is no different. Prior to the use of electric power in businesses and in homes, the NEC did not exist at all and came into existence in response to the perceived and demonstrated hazards of bringing electric power in contact with humans. I recall early in my career conducting field investigations of existing vintage buildings for modernization projects. While crawling through an attic I came across glass spool like devices with bare wire fastened to them. I could follow the paired wires through the attic. They were the remnants of the first installation of electric power distribution through the building. I marveled at the crude methods of delivering power in the building; fortunately they were abandoned. Bare wire run exposed through attics and void spaces in walls and under floors strapped to glass insulators delivered electricity to homes and buildings. It wasn't until after a plethora of fires and electric shocks followed by a public outcry that code officials responded by revising the code to require wire to be insulated. A reactionary response but appropriate to be true to the codes purpose "*safeguarding of persons and buildings*". The code is a living document and evolves overtime in response to disasters, noted deficiencies and new technology. When working on older buildings and structures we must be aware of the adopted code at the time of construction and the current code we are working under today as we prepare design solutions to modernize these building. In the case study presented in this paper the evolving NEC code section "Grounding and Bonding" is shown to have evolved significantly to the point where the old code is in conflict with the latest code edition.

Photo Courtesy of K. Montross

2.0 History

Photo Courtesy of G. Tuley
Tesla AC Machine

On June 21st, 1891, L.L. Nunn, a Colorado lawyer and manager of the Gold King Mine, signed a contract with Westinghouse to install the Tesla A.C. power system. The plan was to harness a river below the mine and replace the costly coal powered steam generators. This facility became known as the Ames Power Station and was the first power station in the world to transmit alternating current at high voltage for a long distance for power use purposes. The Electric Age had arrived. Not far away, aware of the success of the Ames power station, Smuggler-Union Hydroelectric plant was constructed in 1907, also using a Tesla designed Westinghouse AC generator (pictured at right). The power was used in the Smuggler-Union mine, adjacent residence and cook house. It is believed Tesla stayed at this residence to assist in the installation of the generator and electrical equipment. They diverted a nearby stream that fed a water fall through the basement of the house with the intent of using the falling water to generate electricity. The house was perched precariously on a 400 foot cliff. The flowing water turned an electric generator that produced the electric power. Right from the start it was clear electric power was a marvelous albeit little understood utility capable of making life more convenient for the user. The Ames Power Station is still in operation today with the original generator making it one of the oldest generators still in operation. It currently provides power to approximately one-fourth of the neighboring town of Telluride, or about 2000 average American homes. The birth of the electric code was essential to the safe development of electric power use.

3.0 Code

Within the 1951 National Electric Code introduction is a statement of Purpose and Scope which reads: *"The purpose of this Code is the practical safeguarding of persons and buildings and their contents, from electrical hazards arising from the use of electricity for light, heat, power, radio, signaling and for other purposes."* Considering the continued relatively safe use of electric power in our everyday life, the evolving code has lived up to its stated purpose.

Taken from the 1951 National Electric Code (NEC): *The National Electric Code was originally drawn in 1897 as the result of the united efforts of various insurance, electrical, architectural and allied interests. The original Code was prepared by the National Conference on Standard Electrical Rules, composed of delegates from various interested national associations, including Underwriters' National Electric Association.*

One of the many articles in the NEC is *Grounding and Bonding* originally called *Grounding*. The NEC definition of ground is simply "The Earth." Grounding, when properly implemented will protect the electrical system and equipment from overvoltage and induced energy from indirect lightning strikes by providing the energy pule a path to earth. In general, lightning wants to go to earth. There are several conditions that will cause an overvoltage on the electrical system such as the unintentional contact of higher-voltage lines, line surges, static and others, but the most familiar is lightning. Please note the NEC code is not a lightning protection standard and is not intended to protect the electrical system or equipment from damage by a lightning strike.

4.0 Discussion

Early-on most electrical systems were ungrounded, that is there was no intentional connection to ground. It was discovered that the electrical conductors and equipment of ungrounded systems became damaged during an overvoltage condition because there was no place for the energy to go except into the equipment and conductors served. Ungrounded systems were susceptible to damage and the best solution was to move away from ungrounded systems and to use grounded systems. Most electrical systems today are grounded. Ground connections are made at one location only, at separately derived systems such as transformers and generators. At 3-phase transformers the ground connection is made at the center point of secondary 'Y' connected windings to the grounding electrode. Grounding electrical systems will allow induced energy to travel to ground reducing the risk of damage to the conductor insulation and equipment.

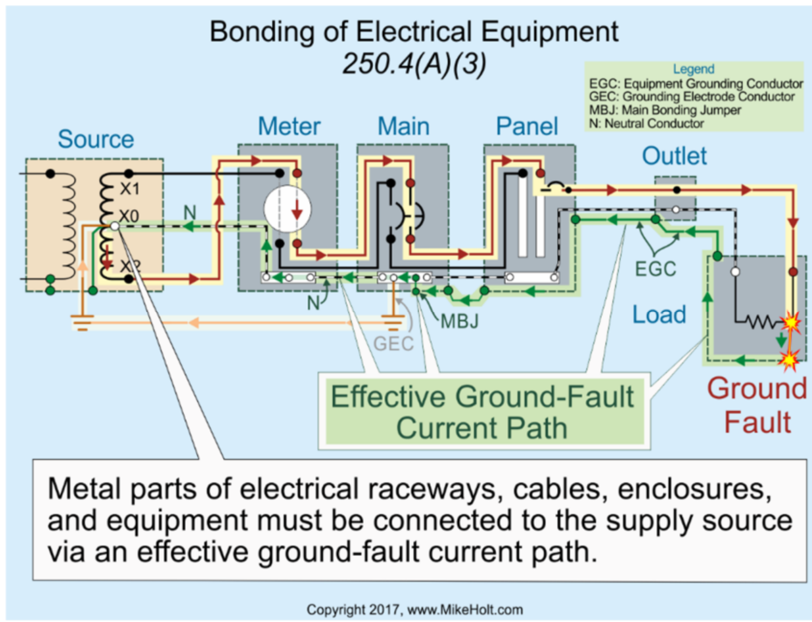
Grounding of the normally non-current-carrying conductive materials (metal) enclosing electrical conductors or equipment, or forming part of such equipment is called electrical equipment grounding. This is required by code. The purpose for equipment grounding is to limit the voltage to ground on these materials and to dissipate any induced energy to ground. Similar to induced energy onto the electrical system, energy can be induced onto the electrical equipment by indirect lightning strikes. If the conduit, equipment, enclosures and conductive parts are not grounded, and the energy of a nearby lightning strike is induced onto the equipment, the energy will seek a path to ground. This path can be through supports or attachments of the equipment to the building, or it could flash over into adjacent piping, building steel or similar path. This arcing or side-flashing can penetrate through building materials like walls or even unsuspecting persons in the wrong place at the wrong time. Arcing through building materials could result in fires. Connecting the electrical equipment to ground will provide a safe path for the induced energy to find its way to earth. The equipment grounding connection is made at one place only, where the electric service enters the premises at the main service switch or transformer.

At this one point at the service, all ground connections are made and are connected to ground by the grounding electrode conductor. The grounding electrode can be comprised of (if available) buried metal water pipe, metal in-ground support structures like building steel in direct contact with earth or that is an extension of a ground connection in the building footing, rebar in the concrete footing, ground rods, and buried copper conductors. Anything making a connection to earth is an electrode, but the code permits only these and a few other items.

Photo courtesy of J. Montross
Ground Bus with grounding connections

Fundamentally there are two types of grounding – system grounding and equipment grounding. System grounding is for the protection of the conductors and is the ground connection at the transformer. Equipment grounding is for the protection of the equipment and is a ground connection at the building service. If the electrical service includes a grounded conductor (also referred to as neutral) this too will be connected at this point.

In every electric circuit, current will flow from the source through a conductor, through the load such as a light or motor, and then back to the source. The current always returns to the source and will take any path available to do so, this is a fact. Unintentional contact of the electrical conductors to the metal enclosures comprising the electrical equipment will cause a short circuit or fault. A short-circuit is still a circuit and fault current still wants to flow back to the source just like in the normal circuit. Turning off the power in this scenario is the only means to clear the fault and protect the system from damage. Devices used to switch off the power are called over current protective device (OCPD), commonly referred to as a fuse or circuit breaker. OCPD's are designed to allow normal operating current to flow through them but will open the circuit when the current exceeds a set value. Additionally OCPD's are designed to open faster with increasing current, like in a fault; the higher the fault current, the faster the device will open. To facilitate the switching off of a faulted circuit we want to create a low impedance path for the fault current to return to the source. The low impedance will ensure the current increases sufficiently to trip or open the OCPD. Per the code, an effective ground-fault current path must be created by installing electrical equipment, wiring and other electrically conductive material likely to be energized in such a manner that creates a low impedance circuit facilitating the operation of the OCPD. The effective ground path must be capable of safely carrying the maximum ground-fault current likely to be imposed on it from any point on the wiring system where a ground fault may occur. Exposed, normally non-current carrying metal parts of fixed equipment supplied by or enclosing conductors or components that are likely to become energized shall be connected to an equipment grounding conductor. The code goes on to list the conditions and structure types for this connection.



Graphic Courtesy of Mike Holt Enterprises

The equipment grounding conductor, usually green in color, provides a safe effective low impedance ground path for fault current to return to the source and switch off the OCPD. In addition to the equipment grounding conductor the normally non-current carrying conductive materials enclosing electrical conductors or equipment or forming part of such equipment, shall be connected together and to the electrical supply source in a manner that establishes an effective ground-fault current path. The connection of all the components is called 'bonding.' Proper grounding and bonding of electrical equipment is paramount to the safe use of the power we command with the touch of a switch. We find electrical grounding conductors in our homes and businesses, evident in wall receptacles seen as the 'third' ground prong of your plug that fits nicely into the receptacle. Connected to that receptacle, if installed properly by code, is an equipment grounding conductor or bonded electrical components that are connected to every other grounding conductor and piece of equipment it passes by on its route through your home or business.

Without an effective ground fault current path, electrical faults will remain on the system, imposing the system voltage on components that may come into contact with people. You may have heard the story of a male dog relieving itself on a light pole and being electrocuted. In this case, the light pole circuit faulted to the metal pole and did not clear. The light pole was then energized by the circuit voltage. This happened because there wasn't an equipment grounding conductor or effective low impedance path to bring the fault current back to the source and open the OCPD. Ultimately all electrical components should be connected together by connection of the equipment grounding conductor(s) and bonding of all electrical equipment. Final connection to the grounding electrode at the service is made by the main bonding jumper. In this way the equipment grounding conductor makes a single point connection to ground at the service entry point, similar to the system ground and equipment ground previously discussed.

In summary: system grounding allows high energy pulses induced on the system conductors to dissipate to ground; equipment grounding provides a connection to earth to dissipate induced energy on the electrical equipment; and low impedance equipment grounding conductors provide an effective ground path to safely turn off the power in a fault condition. Today, Article 250 – *Grounding and Bonding* of the National Electrical Code[1] (NEC) provides the requirements for the grounding of electrical systems and equipment.

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[1] National Fire Protection Association NFPA; 70 National Electrical Code (NEC)

5.0 Case Study of Evolving Code

Recently I was called in to resolve design discrepancies in a modernization project for a high school that required replacement of the main switchboard and campus distribution equipment. School construction was completed in 1955-57 with additional buildings added later. All metering equipment, distribution boards and transformers in the main electric room needed to be upsized and relocated for the modernization project. Construction documents identified all feeder wires to be intercepted and rerouted to the new metering distribution board. Electrical designers called for replacement feeders to include an equipment grounding conductor as required by the adopted 2014 NEC Code, Article 250.32(B). Site plans identified intercept points with pull boxes to facilitate the splice to existing conductors. Pre-design site investigation included visual inspection of all equipment without opening up distribution boards, panels, vaults, etc. Important information of the existing wiring was missed by not opening the equipment. Any electrical designer today will include an equipment grounding conductor in feeders as a matter of practice, automatically. Feeders REQUIRE equipment grounding conductors to remote buildings and structures by code. What the contractor found on this site was troubling; none of the original feeders serving the buildings were provided an equipment grounding conductor. My first thought was the contractor was mistaken, however subsequent inspections of the equipment and in-grade vaults confirmed the contractor's findings, the equipment grounding conductor was missing, "*Where is the Ground*?" What we had before us was a conflict between old and new code editions. We began an analysis to determine our approach in correcting the missing grounding conductor.

First, we considered that the ground path was established by rigid metal conduit which the code allows as long as the ground path is permanent and continuous. Under these conditions, metal conduit is an acceptable substitution for an equipment grounding conductor. Unfortunately, installed conduit was confirmed to be transite pipe, or PVC, not metallic; and the ground was still missing. It is a miracle that the school operated without equipment grounding conductors for 61 years without harm to life or property. Though the school electrical system was code compliant in 1953, an equipment grounding conductor was missing, and if a fault condition did occur, it miraculously cleared without harm to the students or buildings. At each remote building equipment grounding was established with a grounding electrode conductor connected to a buried copper conductor, ground rod and water pipe where present. And the electrode conductor was connected at the building switch. The grounding at each building's main switch protected the equipment within the building from induced energy by nearby lightning strikes. However, the electrical equipment was left without an effective low impedance grounding conductor return path for fault current. Without a low impedance equipment grounding conductor the chances of a fault clearing are unlikely. The fault current will find its way back to the source, most likely through earth between the grounding electrodes at each building. With considerable distance and high contact resistance at the building electrode the fault current will not be sufficient to trip the circuit breaker. This is dangerous! The voltage of the feeder will now be imposed onto the electrical equipment due to the fault, and if contacted by a person it could be fatal. Without the circuit breaker tripping, this condition could remain indefinitely. Equally dangerous is the voltage gradient created by the fault current flowing in the earth back to source, especially around the pool area, gym and showers where students are walking around barefoot. It is a miracle no one was killed on this campus. By the grace above, over the history of the school there wasn't a single fault causing this dangerous condition.

At the time of the original design and construction of the school the 1953 NEC code was employed. Article 250 Grounding, paragraph 2514 states: "*It is <u>recommended</u> that alternating-current systems be grounded as provided in this article where the voltage to ground does not exceed 300 volts. Higher voltage circuits <u>may</u> be grounded.*" The service and downstream distribution at the school is at 480 Volt, 3-phase, delta-connection meaning the voltage to ground is 480 Volts. The system was ungrounded. At the time of original construction, grounding was simply a recommendation or something you 'may' do depending on your design goals or budget. At the time of construction, what was installed at this school was a code compliant electrical system that did not include equipment grounding conductors.

NEC 250.32(B) is the current code section that applies to feeders serving remote buildings or structures. Within the code section there is an exception that if under a previous code edition the neutral conductor was allowed to serve as both the equipment grounding conductor and the grounded conductor (neutral), then the neutral of an existing or modified circuit can continue to serve as both whereas the current code is specific in requiring these to be separate if installed today. This code exception allows for all kinds of problems such as objectionable currents and hazardous conditions beyond the scope of this paper. Suffice it to say, a neutral conductor (grounded conductor) should be connected to ground once at the single point ground at the service and not in multiple locations. Using the neutral conductor as both the "grounded conductor" and "equipment grounding conductor" will result in the neutral being connected to ground at both ends. Our recommendation to the school was to replace all feeders with a new feeder that included both a neutral and equipment grounding conductor. Only this feeder configuration will ensure a safe electrical code compliant system for the campus.

Our next step in the analysis was to investigate how the feeder circuits were terminated at the buildings served. This investigation informed our repair design by identifying any old and obsolete equipment that should not be reused as well as any needed repairs to the grounding electrode systems and connections at the building switch. We expected most feeders to be terminated on a switch that connected directly to a step down transformer and our investigation confirmed this condition. However, the main switch did not accommodate connections for the neutral and the equipment grounding conductor and needed to be replaced.

6.0 Recommendations

The project scope to modernize the campus electrical system at the service needed to be expanded to address existing conditions that were unsafe and/or not compliant with current code. What needed to be considered in the redesign is the existing feeder configuration, points of reconnect, whether the existing feeder needed to be upsized, if anything could be reused to save costs and compliance with current code. The missing equipment grounding conductor expanded this project beyond the original scope into upgrading all feeders throughout the campus. Our recommendations to update the electrical system to meet current code and replace the feeders were as follows:

1. Code section NEC 250.32(B) allows for the reuse of the neutral to serve as both the neutral (grounded conductor) and the equipment grounding conductor. As previously discussed, this will only lead to problems with the distribution system and we recommended not to take this code exception and to replace all combined neutral/grounding wires with dedicated neutrals and equipment grounding conductors for all feeders.
2. Where the existing feeder only contained phase conductors – that is no neutral or equipment grounding conductor, the entire feeder length will need to be replaced from the new main switchboard to the building served. The new feeder included phase (hot) conductors, a neutral (grounded conductor) and equipment grounding conductor wire. The new campus distribution system voltage rating is 480Y/277V 3-phase 4-wire that constitutes a grounded system. Modifications were made to the remote buildings main switch as necessary to accommodate the new feeder conductors, equipment grounding conductor, grounding electrode conductor, and grounded conductor wire terminations.
3. New feeders shall be copper for the entire length. This was recommended as an additive alternate, with the base-bid wire specified as aluminum to match existing aluminum conductors and to minimize cost. Where possible and the existing conduit size is adequate the new feeder will be upsized to maximum conduit fill. Upsizing the feeder wires will allow for future growth. Copper wire has greater current capacity than aluminum for equal size wire therefore using copper wire will increase capacity slightly.
4. If load capacity was increased, the feeder breaker – OCPD would be upsized as required.

7.0 Lessons Learned

Every project is unique and offers different challenges for us to solve. These challenges are what adds excitement and interest to our work. I find most challenges are discovered in modernization projects where new design objectives may conflict with existing conditions and possibly previous code versions as we found here. Dealing with older buildings and facilities is particularly challenging because as-built documentation is typically sparse or non-existent. Field inspections and observations can only reveal so much, leaving much unknown going into your design. It isn't until demolition of existing work is underway when unforeseen conditions materialize and need to be addressed. Unfortunately the electrical designers that worked on the modernization of this high school had moved on and direct one-on-one teaching moments were lost. Nevertheless, there are lessons to be learned from this challenge:

1. When modernizing an older building the original code requirements must be understood and how they differ from current code. How will the new design bridge the gap to deliver a completely code compliant system? There may be components of the system that will be "grandfathered-in" and a code update will not be required. However, the grandfathered components may allow for unsafe conditions and the designers must be wary of this.
2. The Authority having Jurisdiction may need to be consulted for an interpretation of the code in cases of code conflict. It is always best to design for the safest condition recognizing the code is a minimum requirement and as designers public safety is our first concern.
3. Obtain and study all available 'as-built' documents. In this case study, the designers ignored the as-built drawings and assumed the original feeders were installed per current code. The reality was the new code compliant feeders were called to connect to existing feeders that had become non-compliant by code evolution.

4. Once a full understanding of the building's electrical system is obtained through study of available drawings a thorough field investigation must be completed to verify the existing conditions. Information gathered in the field survey must be used to inform and adjust the design approach to address all building components that may have become non-code compliant by code changes and evolution.
5. Field investigation should include opening of electrical equipment to study connections and number and type of conductors in use.
6. Owners and operators of buildings will need to be educated prior to beginning any modernization project that code changes may impact the design and ultimately the construction budget. Budgets will need to be augmented and contingencies created to ensure a successful project outcome.

Photo Courtesy of K. Montross
IEEE Plaque below Ames Power Station Sign

Special thanks to Mike Holt, www.MikeHolt.com, for his invaluable contribution to this paper.
To better understand the relationship between grounding and the effective ground-fault current path, watch this video **https://www.youtube.com/embed/mpgAVE4UwFw.**