Sensitive Electronic Equipment Grounding:

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Objectives

- Understand the differences between safety and signal grounding.
- Understand and apply NEC requirements for grounding of industrial control rooms and associated sensitive electronic equipment.
- Analyze a recommended grounding method for industrial control rooms based on the Federal Information Processing Standard (FIPS PUB 94), IEEE Std. 142 (Green Book), and IEEE Std. 1100 (Emerald Book) recommendations.
Outline

I. Grounding Basics
II. NEC Requirements
III. Common NEC Grounding Violations
IV. Recommended Grounding Method for Industrial Control Rooms
V. Instrument Circuit Grounding
VI. Summary
I. Grounding Basics
Purposes of Grounding

Grounding of sensitive electronic equipment (i.e. DCS, PLC, computers) is necessary for two reasons:

1. Safety to personnel
2. Operational reliability of system(s)

Grounding can be classified as either safety or signal grounding.
Safety Grounding

- **Touch potential** differences between two conductive objects must be minimized in order to reduce shock to personnel.

- The **ground-fault current return path** to the electrical source must have sufficiently low enough impedance to operate the overcurrent protective device.
Signal Grounding

Simply put, the main objective of signal grounding is to minimize transient voltages and currents (hereinafter referred to as noise).
Types of Noise

1. **Statically coupled.** Capacitive coupled electric fields generated by power circuits and other voltage sources.
2. **Magnetic.** Superimposed currents produced by magnetic fields generated by current carrying conductors or devices.
3. **Common mode.** “The noise voltage that appears equally and in phase from each current-carrying conductor to ground” (IEEE Std. 1100).
Causes of Common Mode Noise

- Different ground potentials at each location in an industrial facility can cause common mode noise.

- An instrument circuit that is grounded in two locations may develop a current flow between them causing noise to be added to the signal.

- Some examples include: short circuits, lightning, power system switching, inadequate wiring and grounding practices, and adjacent and surrounding equipment.
Grounding - Overall Goals

1. The primary goal for grounding of sensitive electronic equipment is safety. **Safety cannot be compromised.**

2. The secondary goal for grounding of sensitive electronic equipment is operational reliability.
II. National Electrical Code Requirements
90.1(A) - Purpose of the Code

“The purpose of this Code is the practical safeguarding of persons and property from the hazards arising from the use of electricity.”

Note: The Code does not address operational reliability and performance.
250.4(A)(2)&(3) - Enclosure Grounding & Bonding

Non-current-carrying conductive materials enclosing electrical conductors or equipment shall be:

- connected to earth, and
- connected to each other, and
- connected to the electrical supply source.
250.4(A)(5) - Effective Ground-Fault Current Path

- The path to ground from equipment, wiring, and other electrically conductive materials shall be installed in manner that creates a low-impedance circuit capable tripping the overcurrent protective device or ground detector for high impedance systems.

- The earth shall not be used as the only equipment grounding conductor or ground-fault return path.
A “separately derived system” is an electrical source other than a “service” that must:

- Have no direct ground connection to circuit conductors of any other electrical source other than those established by grounding and bonding connections.
250.30(A)(1) – System Bonding Jumper

- A system bonding jumper shall connect the grounding electrode (earthing) system with the SDS grounded conductor and the equipment grounding conductors.
- The bonding jumper shall be located at any point between the source and the first disconnecting means.
- The point of connection shall be the same as the grounding electrode conductor.
250.30(A)(1)- System Bonding Jumper

- Two system bonding jumpers may be installed (one at source and one at the 1st disconnect) provided parallel ground paths are not established.
- The earth is not considered as a parallel path.
- To avoid objectionable current, it is recommended to provide a system bonding jumper at one location only.
250.30(A)(5) - Grounding Electrode Conductor

- A grounding electrode conductor shall connect the grounded circuit conductor to the grounding electrode.
- The point of connection shall be the same location as the system bonding jumper.
250.50- Grounding Electrode System

- The grounding electrode system is created when all acceptable grounding electrodes are bonded together.
250.52- Grounding Electrode System

- Metal Underground Water Pipe
- Metal Frame of Building or Structure
- Concrete-Encased Electrodes
- Ground Ring
- Rod and Pipe Electrodes
- Other Listed Electrodes
- Plate Electrodes
- Other Metal Underground Systems or Structures
250.50 - Grounding Electrode System

- If available on a premises, and if any electrodes listed in 250.52(A)(1) through (A)(7) are present at each building or structure served, they must be bonded together.

- This provides electrical continuity and reduces voltage differences between electrodes.

- This is a safety requirement!
250.6 - Objectionable Currents

- The Code does not provide a definition of “objectionable current.”
- Objectionable currents can be caused by unbalanced loads with multiple ground connections.
- Ground-fault currents or noise are not considered objectionable current.
FIGURE 1: OBJECTIONABLE CURRENT CAUSED BY MULTIPLE GROUNDS
250.6(B) - Alterations to Stop Objectionable Currents

- Disconnect one or more but not all of the grounding connections.
- Change the locations of the grounding connections.
- Interrupt the continuity of the conductor or conductive path interconnecting the grounding connections.
- Consult the AHJ for solutions acceptable to solve the problem.
III. Common NEC Grounding Violations
Violation #1: “Quiet” Ground System

- Electronic equipment manufacturers sometime recommend isolating the signal ground system from the plant safety ground system to prevent the entry of unwanted noise generated by the plant safety ground system.

- The signal ground system usually requires a resistance to ground of 1 ohm or less. This can be a difficult value to obtain in some regions.
Violation #1: “Quiet” Ground System

- This “quiet”, “isolated” or “Master Reference” ground systems are not permitted by NEC 250.50 which requires all premises grounding electrodes to be bonded together.

- Additionally, this system violates NEC 250.4(A)(5) which requires a low impedance ground-fault return path. This is necessary to ensure proper operation of the overcurrent protective device.
Violation #1: “Quiet” Ground System

- Ironically, because the quiet ground system usually has a 1 ohm resistance or less, more of the ground-fault current will flow to the quiet ground system when both systems are bonded together.

- Some engineers incorrectly define noise as objectionable current and use the alterations allowed in NEC 250.6(B) as an excuse to isolate the signal ground.
Violation #2: Isolating Bushings

- Installed in power conduits supplying the system in order to provide a “quiet” or isolated ground system.
- Usually this practice meant that the equipment grounding conductor would not be connected.
- This arrangement clearly violates NEC 250.96 which requires electrical continuity of an equipment grounding conductor.
Violation #2: Isolating Bushings

- NEC 250.96(B) allows the use of isolating bushings to reduce noise provided the conduit is not used as the equipment grounding conductor. In this case, an equipment grounding conductor (green wire) is required.
FIGURE 2: ISOLATED SYSTEM WITH HIGH RESISTANCE GROUND FAULT RETURN PATH

\[ I_{SC} = \frac{V}{R} \]

\[ = \frac{120\text{V}}{20\text{ OHMS}} \]

\[ = 6\text{ AMPS} \]

6 AMPS OF CURRENT FLOWING THRU EARTH
Violation #3: Test Point Disconnect Switches

- Some electronics manufacturers recommend installing a disconnect switch usually between the safety ground bus and the signal ground bus. This practice provides a quick and easy isolation of the signal ground system for testing.
- NEC 250.50 requires all premises grounding electrodes to be bonded together.
Violation #3: Test Point Disconnect Switches

- NEC Art. 100 defines “bonding” as “connected to establish electrical continuity and conductivity”.
- Therefore, the use of a disconnect switch violates code by creating a temporary or unreliable connection.
FIGURE 3: GROUND SYSTEM INSTALLATION WITH TEST POINT DISCONNECT
Violation #4: Spark Gap Arresters

- Spark gap arresters are sometimes erroneously installed between the safety ground bus and the signal ground bus.
- The arrester uses a gas-filled gap that acts as an open circuit to low potentials, but becomes ionized and conducts at very high potentials. If the lightning hits the system you are protecting, the gas gap will conduct the current safely to ground.
Violation #4: Spark Gap Arresters

- As mentioned in Violation #3 and for the same reasons, spark gap arresters are not permitted by Code.
FIGURE 4: GROUND SYSTEM INSTALLATION WITH SPARK GAP
IV. Recommended Grounding Method for Industrial Control Rooms
Overview of Control Room Grounding

- Any approach to system grounding must comply with the NEC.
- The following recommendations and suggestions are taken from FIPS PUB 94, IEEE Std. 1100 (Emerald Book), and IEEE Std. 142 (Green Book).
Objective of Control Room Signal Grounding

The objective of signal grounding is to minimize the differences in voltage between each equipment enclosure.

Note: The objective is **not** to minimize the differences in voltage between equipment enclosures and earth.
Separately Derived System

- By creating a separately derived system, a new ground reference point is re-established close to the point of use.
- This significantly reduces common-mode noise through ground-loops or multiple current paths in the ground circuit.
Separately Derived System

- An SDS is typically accomplished through the use of a UPS and a bypass isolation transformer.

Note: the UPS bypass source must be supplied from an isolation transformer to be a separately derived system.
Signal Reference Grid (SRG)

- The SRG is usually an orthogonal grid of parallel wires or copper strips.
- A signal reference grid provides a common signal reference plane of constant voltage over a wide range of frequencies.

Photo courtesy of Erico
Types of SRG’s

1. A grid of #4 AWG copper conductors joined at each intersection on 2’ centers.
2. A grid of copper strips (2” x 26 gauge) joined at each intersection.
3. Floor supporting structure or stringers (not recommended).
4. Continuous sheet steel with good conductivity.
Bonding to Earth Ground

- The SRG should be bonded to the grounding electrode system at multiple points.
- All structural steel within 6 feet of the SRG should be bonded to the SRG.
Bonding to Enclosures

- Each equipment enclosure and cabinet should be bonded to the SRG with a flexible braided copper strap.
- The bonding strap should be kept as short as possible to minimize inductive reactance (5 feet max.).
- The effectiveness of the bonding strap decreases as its reactance increases; therefore, two straps may be required.
Bonding to Raised Floor

- As a minimum, the SRG should be bonded to one out of every six pedestals.

Photo courtesy of Erico
FIGURE 5-1: RECOMMENDED GROUNDING METHOD FOR INDUSTRIAL CONTROL ROOMS

GROUNDING BUILDING STEEL GROUNDING ELECTRODE NEC 250.52(A)(2)

GROUNDING ELECTRODE CONDUCTOR NEC 250.30(A)(5)

PLANT GROUNDING ELECTRODE SYSTEM

NORMAL 480VAC 3Ø SUPPLY

UPS CABINET

SYSTEM BONDING JUMPER NEC 250.30(A)(1)

NEUTRAL BUS

NORMAL POWER OUT

BYPASS POWER IN

N

H

BYPASS 480VAC 3Ø SUPPLY

GND.

L1

L2

H

N

120V PANELBOARD

MAIN BREAKER

NEUTRAL BUS

GROUND BUS

120V PANELBOARD

RAISED FLOOR

CONT. ON FIG. 5-2

SIGNAL REF. GND.
FIGURE 5-2: RECOMMENDED GROUNDING METHOD FOR INDUSTRIAL CONTROL ROOMS

GROUNDED BUILDING STEEL GROUNDING ELECTRODE NEC 250.52(A)(2)

HPM CABINET
EQ. GND BUS
H N
SIGNAL GND BUS
CONT. ON FIG. 5-1
SIGNAL REF. GND.
V. Instrument Circuit Grounding
Shielding - Definition

- A shield is a conductive sheath applied over the length of a conductor with the purpose of intercepting static noise and carrying it off to earth.
- Static noise is caused by capacitively coupled electric fields.
Shielding - Overall & Individual

- According to IEEE Std. 142 (Green Book), overall shields should be grounded at multiple locations and individual shields should be grounded based on the frequency of the signal.
- For signal frequencies up to 1MHz, ground only one end of the inner shield. For signal frequencies above 1MHz, ground both ends of the inner shield.
Shield Ground Location for Signals 1Mhz and Less

- The inner shields should normally be grounded at the source end.
- For most signals, this is at the source inside the control room.
- Thermocouple signals are powered at the thermocouple; therefore, the inner shield should be grounded at the thermocouple.
Twisted Wires

- The effect of twisting wires cancels out most magnetically induced noise.
- Magnetic noise is superimposed current generated by magnetic fields.
VI. Summary
Summary

- Grounding is required for both safety and performance reasons. **Safety** takes top priority, but the sensitive electronic equipment must be simultaneously safe and functionally reliable.

- Industry standards, manufacturer’s recommended methods, and widely accepted design practices sometimes are not in harmony with each other.
Summary

- The system designer should avoid practices that violate the Code and adopt those recommended practices found in FIPS 94, IEEE Std. 142 (Green Book), and IEEE Std. 1100 (Emerald Book) that fit the application.
- Good engineering judgment should always be used.
Discussion?