

Grounding Requirements for Machinery Instrumentation and Noise Case Studies

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1 Purpose

This document describes recommended grounding practices as applicable to Bently Nevada* vibration monitoring systems. It also defines common terms, identifies potential sources of noise, describes basics of a plant grounding system, explains ground loops, and presents a troubleshooting guide to help locate a noise/ground issue and then eliminate it from the system.

2 Scope

Because issues related to grounding are broad and deep in scope, this document only describes grounding issues as they apply specifically to a Bently Nevada monitoring system.

Disclaimer - This guide presents and describes known and potential grounding issues with Bently Nevada products. It is not intended to replace or supersede any local, national, or international electrical safety standards. Always follow the National Electric Code or equivalent when designing or implementing grounding and bonding schemes.

3 Definitions

0V – True 0 voltage.

Ground – True 0V reference. A ground connection from an instrument is a green wire or green with yellow strip wire connected to earth and will only carry current under fault conditions.

Neutral – A power system conductor that normally carries current and is connected to earth ground at the main electrical panel.

Earth – All grounds are ultimately tied to 0V reference at the planet earth (exceptions are ships, airplanes, and space craft).

Protective Earth (PE) – Central plant ground point to which all equipment will ultimately connect. This serves not only as a system level reference for voltage potential, but also provides the final location for transient electrical currents to travel.

Chassis – The metallic enclosure of a system or piece of electrical gear such as the 3500 Series monitoring system metal enclosure.

Ground Loop – An unwanted electrical current path in a circuit that can cause interference. Ground loops frequently occur when two points that are thought to be at the same potential, but are not, are connected together.

Common – The internal 0V reference point for internal circuits within a system, also known as signal common.

Bonding – The physical low impedance connection between two electrical conductors such as exposed metallic items in a building or instrument. Bonding must be sufficiently robust to carry the maximum electrical fault current to the 0V ground point thus activating protective fuses and/or breakers to protect against electrical shock.

4 Grounding Problem Indicators

Issue/Indicator	Details
Variable Locations, Not Easy to Duplicate	Grounding problems can sometimes appear to move around and may not be easily and consistently duplicated.
Loose Shields, Improper Wiring	Loose or improperly connected shields and improper wiring are leading causes of noise/grounding issues. Each shield wire should be insulated along its length and only make contact to ground at a single point, the monitor.
Grounds and Bonding Jumper Connections	Failure to understand and diagram ALL grounds and bonding jumpers connected to the rack or cabinet can lead to incorrect and duplicate connections. A voltage potential between the ground points will cause any loop that exists to carry current. These ground currents may affect the systems performance.
Multiple Ground Connections	Multiple connections to ground will each carry current and form voltage potentials across parasitic impedances in those connections, unbalancing ground points generally considered equipotential, and thereby often affecting the system as a whole. Similarly, multiple connections to ground can be effected by electromagnetic energy causing a potential difference between the connections, resulting in unintended current flowing through the grounding conductors. The voltage potential difference can also cause system problems, as the reference potential for different parts of the system varies from one point to another. A 60 or 50 Hertz (3600 or 3000 CPM) signal that is unrelated to machine vibration is a common example of an issue that may be caused by a ground loop.

5 Grounding Practices

5.1 Basics

A primary purpose for grounding of electronic equipment is personal safety. A properly installed safety ground on electronic equipment allows faults to be cleared by the fast opening of circuit breakers or fuses and is no different than that of other equipment. Safe grounding results in all exposed metal surfaces on the electrical system and equipment staying below levels that people can safely contact.

System Threats: Electronic systems' circuit components can be sensitive to relatively small transient currents and voltages. The inherent nature of solid-state devices allows them to respond very fast; this means that they can be affected by short duration electrical disturbances that are difficult to capture on analysis instrumentation. Interestingly, lightning is a slow transient compared to the response of almost any electronic device, and lightning impulses often cause a signal response in nearby electronics. Typical threats to proper operation of electronic devices and systems include:

- **Lightning** – Direct strikes, but also induced currents and voltage generated by overhead cloud-to-cloud discharges, and nearby lightning strikes.
- **Switching transients** – From power network operations and power factor capacitor switching, lightning arrestor operation, and fault clearing activities on nearby power circuits.
- **Static electricity** – Directly applied static discharges to the equipment, or static discharges to nearby equipment.
Note: Charges build up on rotating shafts of motors, generators, and steam turbines with resulting ESD discharges.
- **Electrical fast transients** – Typically caused by arcing contacts or collapsing magnetic fields in the coils of contactors in equipment – usually very near the affected equipment **or** field wiring.

Controlling Transient Effects: A Bently Nevada system failing to perform as expected may be due to electrical noise associated with grounding problems. Grounding problems frequently are exposed by the presence of fast electrical transients. Their occurrence may be random in time and frequency of occurrence, making the solving of transient-induced problems very difficult. In general, they have wave shapes that are not easily captured or analyzed. However, the effects of transients can be controlled, or at least reduced, by following the four general rules below:

1. Limit overvoltages (surge voltages) on the AC power conductors with surge protective devices (SPDs).
2. Reduce the chances of electrical noise on the power circuits connected to electronic equipment and the data signal circuit cables that interconnect the units of equipment. This can often be accomplished by observing the requirements for proper routing and grounding of field wiring and branch circuits along with ensuring adequate separation of power and data signal wiring.

3. Enable proper application of signal shielding by grounding at just a single point, on the monitor.
4. Ensure proper grounding through the correct installation of equipment grounding conductors of all types, and neutral terminal grounding and bonding at the service entrance, and for separately derived AC systems.

Vibration Monitoring System Installation: While the above recommendations are all within the scope of the equipment installation contractor's job, GE's Bently Nevada personnel must review and provide expert input regarding the proper installation of the vibration monitoring system. The vibration monitoring system is defined as all the equipment and wiring from the transducer (or probe) to the System 1* server. If errors occur during system installation, extensive effort and expenditures may be required to repair the installation and get the vibration monitoring system operating properly. Even worse, errors may not be detected until after system commissioning, often requiring difficult troubleshooting to determine the source of encountered problems.

Grounding Terminology:

Ground (Earth) – In electrical engineering, ground or earth is the reference point in an electrical circuit from which voltages are measured, a common return path for electric current, or a direct physical connection to the Earth. Electrical circuits may be connected to ground for several reasons.

Ground Bus – A heavy solid copper bar with many locations where ground leads can be terminated. A large conductor is routed from the bus bar to the plant 0V point.

Dirty Ground – A ground bus that carries the large electrical currents from heavy machinery. This ground could be in a Motor Control Center (MCC) where motors are turned on and off where large current and voltage surges are possible. A separate conductor is run from the MCC dirty ground bus to the 0Vearth ground at the power input panel.

Clean Ground – A ground bus separated from all heavy electrical loads with a separate conductor run from the clean ground bus to the 0V plant ground.

I.S. Ground – An Intrinsic Safe (I.S.) Ground is required to assure a single point ground for use with systems that interface with equipment in potentially hazardous areas.

N-E Ground – The ground connection at the power main input panel where the transformer neutral is connected to the plant 0V ground grid.

MCC Ground – The Motor Control Center from which high voltage and current devices are managed. This ground bus can experience voltage spikes due to motor start-ups, contactors opening and closing, relays making and breaking, and so on.

Instrument System Ground – A ground bus where instruments requiring a clean ground are connected with a separate conductor run to the 0V plant ground.

Lighting CC – A control center (CC) similar to the MCC control center. This ground bus is separately connected to the 0V point.

PLC, PLC Systems, Etc. – Ground buses that may be dedicated to a particular group of instrumentation, such as within a Bently Nevada instrument cabinet, and then connected to a clean instrumentation bus.

SE Bar – A bonding of the structural frame of the building that is tied directly to the 0V point.

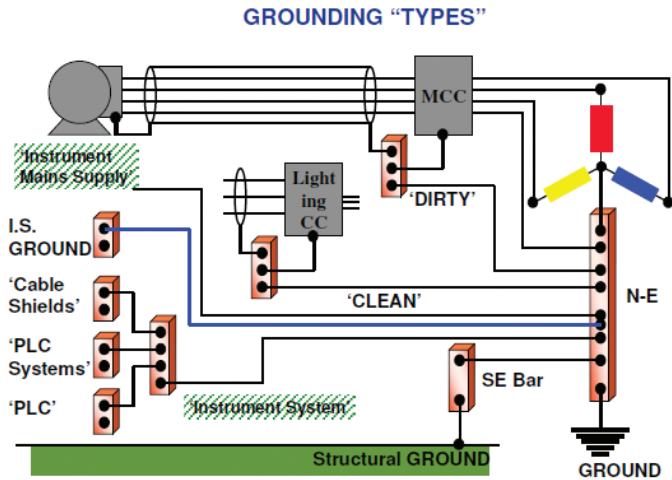


Figure 1. Ideal installation
 Proper Grounding of Instrument and Control Systems
 in Hazardous Locations
 Joe Zullo, Regional Sales Manager: MTL Americas

5.2 Plant Ground Types

Figure 1 shows an ideal, though often atypical, grounding system. When a monitoring system is installed at site and connected to the plant's grounding system, the plant installation does not often conform to the installation depicted in Figure 1. If the monitoring system is installed near the machine being monitored, there may be unintended ground connections between clean and dirty grounds in the plant. If the monitoring system is located in the control room, it is often easier to provide a grounding system similar to Figure 1, with some minor variations, providing a clean ground.

Any discussion on grounding invariably leads to a discussion on the different types of grounds and the corresponding definition of each. However, it is commonly accepted that grounds in the process industry can be broadly classified as either dirty or clean (Refer to Figure 1 for a visual comparison of the different grounds).

Mains Supply and Large Equipment/Dirty Grounds

Dirty grounds inside the facility are typically 120 VAC, 220 VAC, or 480 VAC power grounds that are associated with high current-level switching such as motor control centers (MCC), lighting, power distribution, and/or grounds contaminated by radio frequencies or other electromagnetic interference. Quite often the primary AC power coming into the plant can introduce spikes and surges, or "brownouts" on the mains that can further erode the cleanliness of the AC ground.

Instrument/Clean Grounds

Examples of clean grounds are the DC grounds – usually 24 VDC – that reference the Programmable Logic Controller (PLC), Distributed Control System (DSC), or metering/control system in the plant. Frequently, control systems engineers from the major Supervisory Control and Data Acquisition (SCADA) vendors recommend isolating these grounds from power grounds. Other clean grounds are those associated with data and communication buses that, due to the vulnerability of many electronic devices, must be maintained relatively free of noise interference or risk data/communications losses.

Structural Grounds

The structural grounds physically and electrically tie the facility together and, quite importantly, complete the circuit to the 0V, ground, or earth termination of the power distribution transformer. Structural grounds can take many forms. In a ship, it is the hull of the ship; and on an offshore oil/gas platform, it is the structural steel of the platform. In large petrochemical or pharmaceutical plants, often a ground grid or mat is installed under the plant, or the welded structural steel of the plant itself becomes the 0V electrical power ground.

In the typical plant, the 0V ground reference is most often a heavy gauge copper wire embedded around the base of the building and tied into ground rods at the corners as well as into the AC ground feeds at critical junctures. Not only does this copper ground create the 0V reference for the plant's electrical system, it becomes part of a possible Faraday cage lightning protection system.

STAR POINT GROUNDING

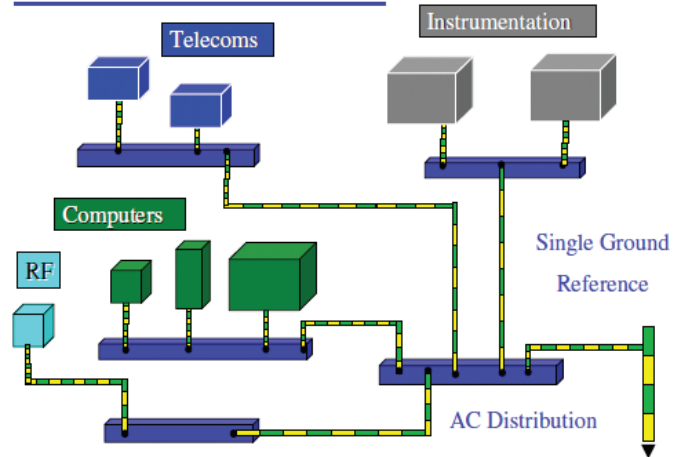


Figure 2: Star/Single Point Grounding Example
 Proper Grounding of Instrument and Control Systems
 in Hazardous Locations
 Joe Zullo, Regional Sales Manager: MTL Americas

Star Point/Single Point Grounding

The AC distribution diagram in Figure 2 shows that all the subsystems in the plant – instrumentation, communication, computers and control, and AC power – are connected to a single point ground system. This is known as “star point” grounding. Properly done, each subsystem ground is kept as short as reasonably possible and is connected to the star point at only one point.

Multiple paths to the ground plane from a subsystem should be avoided, as they can lead to errors within the subsystem. This occurs because each path has inherently different resistance and different resistances to ground produce, and by Ohm’s Law, different voltage potentials within the subsystem

If star point grounding is not used, increased vulnerability to transient surge damage, as well as less-reliable control system operation, can result. This can affect Bently Nevada monitoring system channels by causing errors in readings or causing channels to enter into a NOT OK state. This can lead to false alarms and/or failure to collect valuable machine waveform data. It may also be perceived as ground bounce, which causes some or all channels in the monitor to vary in amplitude unrelated to machine activity, according to the changes on their reference connection.

5.3 Grounding Concerns

All grounds in a plant should be tied together at one point in the plant. Wiring paths to that one point are separated according to the signal level carried by that ground wire.

Ensure Proper Monitoring System Placement: Grounding can often become an issue when the monitoring system is mounted at the machine and away from the control room. Typically, running the grounding conductor back to a clean reference is not considered cost effective and plants may connect the monitoring system ground to the closest ground available, often a dirty ground. This is typically a machinery plant ground that has the potential for more transients and noise. The control room often has its own grounding grid or mat that provides a low noise 0V reference point.

Establish Effective Bonding: Most lightning damage to electronic equipment occurs when a facility employs the use of multiple earthing references that are not intentionally, and effectively, bonded together. Proper bonding between electrode systems can reduce the voltage drops between them and establish an equipotential plane within the facility for enhanced personnel safety. For example, lack of bonding between the electrical system electrode and the communications system electrode may result in damage to modems, telephone answering machines, and other equipment during lightning and system fault conditions. A typical scenario employs a monitoring system in one building that communicates with a DCS in another building.

Building-to-building cabling introduces two risk areas. The first risk occurs when the two buildings are connected to different electrical power sources and have separate ground systems. These separate ground systems can introduce ground loop currents into the cabling with resulting noise and interference problems.

The second risk is that susceptibility to interference or damage from lightning strikes, whether a cloud-to-cloud strike or a ground strike, is greatly increased when signal or data lines exit a building. Within a building, the building’s Faraday cage, structural steel, metal siding, and so on, isolates and protects the equipment located within the shield. Cabling between buildings penetrates the shield and becomes a source of interference or potential damage through the induced voltage in the cabling. Also, if a lightning strike actually hits one of the building’s lightning protection systems, the ground potential of that building can spike to a very high voltage causing a ground current to flow to the other building.

One approach to avoiding the problem is to interconnect the ground grids of the two buildings and install the cabling in grounded metal conduits between the two buildings. However, this is seldom done due to cost of installation.¹ The use of fiber optic cabling for data lines is an effective way to avoid these problems. However, signal lines on copper are used in the great majority of the installations. These lines can be protected through the use of transient overvoltage protector isolators, optical or transformer, and appropriate installation of lightning arresters. The selection of properly rated surge protection, isolators, and/or lightning arresters is beyond the scope of this Application Note.

Proper Shielding Techniques: A floating shield, not grounded at either end, can introduce as much noise in a system as a shield connected at both ends, creating a ground loop. In this ungrounded case, the shield can act as an antenna for switching signals, and these switching signals can capacitively couple to the signal wires. This noise enters the monitor(s), affecting the vibration signal readings.

A shield wire is to be treated in the same manner as the signal wire of a transducer. It needs to be insulated, isolated from other conductors, and only connected to ground at a single point at the monitor side. Experience has shown that improper shielding is likely the largest contributor to grounds loops in a monitoring system.

The only time a grounding conductor (generally a green-insulated wire, often with a yellow stripe) should carry significant current is when a short circuit or lightning strike has happened, and therefore in a fault condition.

Since 2006, Bently Nevada cabinets may no longer connect the shield of the field wiring to the monitor inputs. The shields are often tied to a ground bar just at the cable entry to the cabinet. This allows any noise on the shields to be drained off to the ground system with less potential effect on the monitoring system.

Reduce Unwanted Coupling: Field-installed signal cables should be separated from power cables and conduits to the greatest practical distance. This reduces unwanted coupling between the two circuits. To reduce noise coupling problems where one circuit crosses another, try to route the wires to cross at a right angle.

¹ Handbook of Electrical Installation, page 235

7 Case Studies

7.1 Spurious Noise Experienced on GE's Gas Turbine Power Generation System

Issue – The customer was experiencing random and spurious vibration signals in the 3500 monitoring system used for machine protection and management.

System – GE's eight 7FA gas turbines at the site were controlled by Mark* VI control systems. All vibration transducers were powered from and connected to the Mark VI TVIB card. TVIB cards provided buffered output signals for each transducer that were then connected to the 3500 monitoring system using a standard DB-25 cable for external terminations. The site used one 3500 monitoring system for every two gas turbines. A 3500 monitoring system was located in the Packaged Electronic/Electrical Control Compartment (PEECC) of each odd numbered gas turbine (units 1, 3, 5 and 7). Each PEECC was placed 60 meters (180 feet) apart on center and grounded to the plant ground system.

Discovery – When each gas turbine and PEECC was tied to the overall plant ground system, a ground loop was created. Unit 1's 3500 monitoring system and Mark VI system's grounds were connected at the same point on the plant ground, but Unit 2's Mark VI system was grounded 180 feet from unit 1. Connecting the transducer's common from the buffered output of the TVIB card to the 3500 monitoring system in unit 1 created the ground loop resulting in the spurious vibration signals. The 180 feet between the ground points of unit 1 and resulted in a voltage potential large enough to affect the vibration channel's output.

Solution – Galvanic isolators were installed to isolate the commons for each transducer signal for the even numbered units 2, 4, 6, and 8.

7.2 High Vibration Alarms Experienced on 650 MW Steam Turbine Generator

Issue – The customer was experiencing Velomitor channels on multiple bearings entering alarm states. Proximity probes on the bearings did not indicate a change in vibration levels. It was determined that the alarms occurred when nearby relays, located above and adjacent to the 3500 racks, were cycled to activate the lube oil system.

Tests performed – The testing was started by cycling lube system relays and verified that 5 to 7 mil spikes were present in the 3500 system at the time of the relay cycling. Because spiking was confirmed, the testing was continued.

The installed Velomitor wiring was disconnected from the terminals in the junction box. Spare Velomitor wiring that was available in the junction box was connected to a Velomitor. The spare Velomitor was not mounted to the turbine, but was located in the junction box. Cycling the lube oil relay again showed 5 to 7 mils of noise, and testing was continued.

The Velomitor field wiring was eliminated by installing a spare Velomitor on Channel 5Y (one of the worst channels for spiking) on the external terminal block in the cabinet at the 3500 rack.

Cycling of the lube oil relay resulted in no spike on channel 5Y. This testing indicated the close proximity of relays to the Velomitor field wiring, and that the 3500 was not an issue. However, the field wiring was a factor with the noise problem.

Note: The following additional steps could have been performed to help isolate the issue and show that the Velomitor itself was not at fault. At the junction box, remove the Velomitor from the transducer field wiring and replace with a battery powered function generator with a DC bias. Simulate the transducer using an AC signal with DC bias (refer to the verification section in the manual for frequency and amplitude). Check to see if spiking is observed in the measured signal at the 3500 rack.

Solution – After consulting with the relay design engineer, a properly-sized diode was connected 'backwards' (reverse biased) across the relay coil. **Note:** This diode is not to be sized or installed by Bently Nevada technicians; it must be the customer's responsibility.

Current flowing through a relay coil creates a magnetic field which collapses suddenly when the current is switched off. The sudden collapse of the magnetic field induces a brief high voltage across the relay coil that is very likely to be transmitted to other signal wires. The protection diode allows the induced voltage to drive a brief current through the coil (and diode) so the magnetic field dies away quickly. This prevents the induced voltage from becoming high, reduces some higher-frequency content, and reduces the likelihood of spikes being transmitted into to other nearby systems.

Appendix 1: Testing 120V AC Power on Sites

Always test the site power outlet socket if it is to be used to power line powered test equipment, such as the Bently Nevada ADRE 408 DSPi. The socket must have the proper polarity have a correctly installed ground wire, and be within the voltage limits. Customer sites have been found to have the line and neutral reversed in the power outlet, no ground wire installed, and neutral being used as a ground. This is not only against code, but is a safety hazard for the personnel operating the equipment. It can result in damaged equipment, or even a monitoring system going into alarm when the test instrument is attached.

Complete the following procedure to test the power socket:

1. Confirm that there is a three-hole outlet for the line, neutral and ground wires (Figure A).

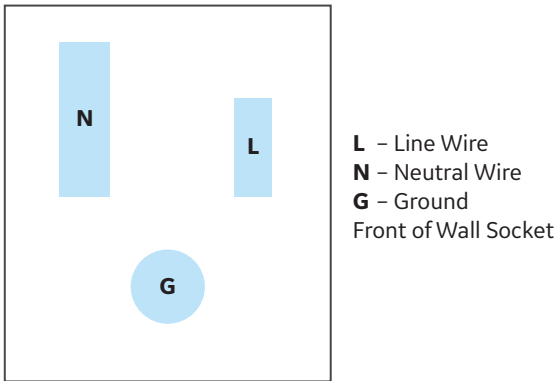


Figure A Typical 3 hole 120V Outlet

2. Check that the outlet has the correct polarity, by either:
 - a. Inserting a polarity tester (Figure B1) into the outlet and confirming the correct polarity by observation of the red, white and yellow lamps on the tester.



Figure B - Gardner Bender polarity tester.

www.gardnerbender.com/en/products/test-instruments

- b. Using a multi-meter, preferably battery powered, to check the polarity and the ground resistance (See step 3)

Warning: Do not use the socket if it fails the test!

3. Use a multi-meter to test for the proper voltage and resistance.
 - The voltage from Line (short slot) to Neutral (long slot) should be 120 V +/-15 Percent RMS.
 - The voltage from Line (short slot) to Ground (round slot) should be 120 V RMS +/- 15percent.
 - The voltage from Neutral (long slot) to Ground (round slot) should be 0 V AC.
 - The resistance between Neutral and Ground should not exceed 1.0 ohms.

Note: The voltage and resistance levels are recommended values. If existing conditions at a particular site do not seem to fit the recommendation, please understand the explanation and use appropriate engineering judgment to determine what is right in an actual field installation. Please provide feedback to the engineering team when this is encountered!

Appendix 2: Suggested Tool Kit

The following items are recommended as useful tools for the verification and troubleshooting of grounding systems in the field:

- Battery powered O-scope 100 MHz (storage-capable, if possible, to capture and store transients)
- Battery powered digital Multi-meter
- Battery powered fluke process calibrator (to simulate AC signal with a DC bias)
- Fluke current clamp similar to i1000s AC Current Probe (best if able to measure signal frequencies between 5 Hz and 10 to 50k Hz)
- 50 feet of 10 AWG braided copper ground wire with clamps
- Clamp on current transformer (CT) able to measure 20 Hz to 500 Hz and voltages from 5 VAC to 500 VAC
- Polarity tester such as Gardner Bender shown above
- Additional potentially useful items for the service kit include:
 - Leaded resistors (with axial leads) such as 10 K Ohm, 1 K Ohm, and 100 Ohm
 - An isolation transformer or UPS supply capable of powering a full 3500 rack and an oscilloscope
 - A Fluke 1630 ground test meter or equivalent
 - Battery powered insulation tester (megger) or equivalent

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BN Document 111M7647 – Evaluation of Grounding Networks for Instrumentation Systems

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