



# CONTROL ENGINEERING



## Control System Power and Grounding

● Better Practice

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By

*David Brown,*

*David Harrold,*

*and Roger Hope*



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Control System Power and Grounding Better Practice

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David Brown, David Harrold, and Roger Hope



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ENGINEERING®**



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# Contents

<b>Introduction</b> .....	<b>xi</b>
CE Statement .....	xi
Warnings, Cautions, and Notes .....	xii
Liability .....	xii
<b>Chapter 1 Site Preparation Overview</b> .....	<b>1-1</b>
System Availability .....	1-1
Impact of New Technologies on System Availability .....	1-2
Importance of Mean Time to Repair .....	1-2
Electrical Noise Influences .....	1-3
Minimizing Influences .....	1-3
AC Power Considerations .....	1-4
Voltage Regulation .....	1-4
Electrical Noise Isolation .....	1-4
Backup Power .....	1-4
System Ground .....	1-5
Earth Ground .....	1-5
Signal Wiring for Traditional I/O Systems .....	1-6
Selecting Analog Current or Voltage Signals .....	1-6
Separating Signal Lines From Power Lines .....	1-6
Multi-Conductor Cables .....	1-6
Signal Wiring for I/O Bus Systems .....	1-7
Intrinsically Safe I/O Systems .....	1-7
Lightning Protection .....	1-8
<b>Chapter 2 AC Power Distribution</b> .....	<b>2-1</b>
AC Power Considerations .....	2-1
Maintaining Power Quality .....	2-1
Primary Power Requirements .....	2-2
Primary Power Calculation .....	2-3
Recommended Wire Sizes .....	2-3
Power Cable Run Alternatives .....	2-4
AC Distribution System .....	2-4
AC Power Supply Connections .....	2-11
Workstations and Peripheral Equipment .....	2-14
Auxiliary Equipment .....	2-15

---

<b>Chapter 3 DC Power Distribution .....</b>	<b>3-1</b>
DC Power Considerations .....	3-1
DC Power Connections .....	3-1
Bussed Field Power .....	3-3
Barrier Strips .....	3-4
Carrier Connections .....	3-4
Resistor-Capacitor Snubbers .....	3-6
Intrinsic Safety Considerations .....	3-6
<b>Chapter 4 System Grounding .....</b>	<b>4-1</b>
Single-Point Ground Techniques .....	4-1
Enclosure Ground Considerations .....	4-6
Effective Grounding .....	4-7
Using Existing Ground Systems .....	4-7
Separating AC and DC Grounds .....	4-8
AC Ground Network .....	4-8
DC Ground Network .....	4-8
Special Cases .....	4-8
Ground Wiring .....	4-10
Local and Isolated Common Reference Points .....	4-10
DC Return Ground Wiring .....	4-12
Marking Grounds .....	4-12
Ground Impedance .....	4-12
Shield Grounds .....	4-13
Workstations and Peripheral Devices .....	4-14
AC/DC Controller and I/O Power Supply .....	4-14
DC/DC Controller and I/O Power Supplies .....	4-16
Bulk Power Supplies .....	4-17
Redundant Power Connections .....	4-17
Intrinsic Safety Installation Grounding .....	4-20
<b>Chapter 5 Signal Wiring .....</b>	<b>5-1</b>
Signal Wiring Practices .....	5-1
Electromagnetic Interference (EMI) Reduction .....	5-2
Protection from AC Power Line Noise .....	5-4
Direct Cable Runs .....	5-5
Multi-Pair Cable Runs In Junction Boxes .....	5-5
Low-Level Signal Cable Runs in Junction Boxes .....	5-8
Class 1 Division 2 Recommendations .....	5-9
AS-Interface Considerations .....	5-10
DeviceNet Considerations .....	5-12

FOUNDATION Fieldbus Considerations .....	5-14
Profibus Considerations .....	5-16
<b>Chapter 6 Alarm Wiring .....</b>	<b>6-1</b>
<b>Chapter 7 Earth Ground .....</b>	<b>7-1</b>
Designing an Earth Ground .....	7-1
Testing an Earth Ground .....	7-7
Annual Inspection .....	7-10
<b>Chapter 8 Lightning Protection .....</b>	<b>8-1</b>
Reference Documents .....	8-1
Lightning Risk Determination .....	8-1
Lightning Protection Systems .....	8-2
Lightning Rods .....	8-2
Conductor System .....	8-3
Ground System .....	8-4
Lightning Arrestors and Surge Protectors .....	8-5
Implementing Lightning Protection .....	8-5
Inspection of Lightning Protection Systems .....	8-6
<b>Appendix A Variable Speed Drive Considerations .....</b>	<b>A-1</b>
Recommendations .....	A-1
Electrical Noise Examples .....	A-3
Ground Considerations .....	A-4
Motor Ground Connections .....	A-6
VSD Cable Specifications .....	A-8
Critical Cable Lengths .....	A-8
<b>Appendix B Testing with an Oscilloscope .....</b>	<b>B-1</b>
General Monitoring .....	B-1
Fieldbus Segment Monitoring .....	B-2
<b>Appendix C Wire Size and Color Codes .....</b>	<b>C-1</b>
<b>Index .....</b>	<b>Index-1</b>



## Figures

Figure 2-1	Single-Phase, Separately Derived, AC Power Input System . . . . .	2-5
Figure 2-2	Single-Phase, Separately Derived, Reverse Transfer Uninterruptible Power Supply (UPS) with a Manual Transfer Switch . . . . .	2-6
Figure 2-3	Three-Phase, Separately Derived, AC Power Input System . . . . .	2-7
Figure 2-4	Three-Phase, Separately Derived, Reverse Transfer Uninterruptible Power Supply (UPS) with a Manual Transfer Switch . . . . .	2-8
Figure 2-5	AC Distribution System Grounding . . . . .	2-9
Figure 2-6	Single Circuit Breaker Panel Wiring for Isolated Ground Receptacles	2-10
Figure 2-7	AC to DC Controller and I/O Power Supply Input Connections . . . . .	2-11
Figure 2-8	Connections for Single Bulk Power Supply, Including Ground . . . . .	2-12
Figure 2-9	Connections for Multiple, Grouped Bulk Power Supplies, Including Ground . . . . .	2-13
Figure 2-10	Isolated Ground Receptacle Details . . . . .	2-14
Figure 2-11	AC Power to Receptacles in Enclosures . . . . .	2-15
Figure 3-1	DC to DC Controller and I/O Power Supply Connections . . . . .	3-2
Figure 3-2	DC/DC Dual Power Supply Input Connections . . . . .	3-2
Figure 3-3	Bussed Field Power Connections . . . . .	3-3
Figure 3-4	I/O Carrier Bussed Field Power Terminal Block . . . . .	3-4
Figure 3-5	Bussed Field Power Wiring (Non-Extended Power) . . . . .	3-5
Figure 3-6	Bussed Field Power Wiring (Extended Power) . . . . .	3-5
Figure 4-1	Typical, Single-Point Ground Network for a Control System Housed in a Single-Enclosure . . . . .	4-1
Figure 4-2	Typical, Single-Point Ground Network for Control System Housed in Multiple Enclosures . . . . .	4-3
Figure 4-3	Single-Point Ground When One Field Transmitter Connects to Two Points in Separate Enclosures . . . . .	4-4
Figure 4-4	Single-Point Ground When Output From a Device in an Enclosure is Used as an Input to a Device in Another Enclosure in a Single-Ended Mode . . . . .	4-5
Figure 4-5	Single-Point Ground When Distant Enclosures are Powered from a Single Isolation Transformer . . . . .	4-6
Figure 4-6	Details of AC and DC Ground System for Transformer-Isolated Area with Multiple Cabinets with All Grounds Tied to a Single Point	4-9
Figure 4-7	Typical Reference Point Ground Bars . . . . .	4-11
Figure 4-8	Proper Length for Stripped Shield Ground Wire and Proper Wrapping	4-14
Figure 4-9	Ground Connections for AC to DC Controller and I/O Power Supply	4-15
Figure 4-10	Ground Connections for DC/DC Controller and I/O Power Supplies .	4-16
Figure 4-11	Power and Ground Connections for a Bulk AC to 12 VDC or 24 VDC Power Supply . . . . .	4-17
Figure 4-12	Power and Ground Connections for Primary and Backup Controller and I/O Power Supplies with Load-Sharing Bulk Power Supplies . . . . .	4-18
Figure 4-13	Power and Ground Connections for Primary and Backup Controller and I/O Power Supplies with Non-Load-Sharing Bulk Power Supplies . .	4-19

Figure 4-14	Typical Grounding Requirements for a Control System Using an Intrinsically Safe (IS) I/O System . . . . .	4-20
Figure 5-1	Instrument Ground Bond Connections for 4–20 mA Transmitters . . .	5-3
Figure 5-2	Instrument Ground Bond Connections for Digital Valve Controller . .	5-3
Figure 5-3	Typical Wiring and Ground Connections for Direct Cable Runs . . . .	5-6
Figure 5-4	Typical Wiring and Ground Connections for Multiple-Pair Cable Runs Using Junction Boxes or Marshalling Panels . . . . .	5-7
Figure 5-5	Typical Wiring and Ground Connections for Low-Level Signal Cable Runs Using Junction Boxes and Marshalling Panels . . . . .	5-8
Figure 5-6	Typical Power and Ground Connections for an AS-Interface Network	5-11
Figure 5-7	Typical Power and Ground System for DeviceNet . . . . .	5-13
Figure 5-8	Typical Ground Wiring for FOUNDATION Fieldbus . . . . .	5-15
Figure 5-9	Typical Power and Ground Connections for Profibus System . . . . .	5-17
Figure 6-1	Example of Grouped Controller and I/O Power Supplies with One Alarm Output . . . . .	6-1
Figure 6-2	Example of Single Controller and I/O Power Supply Alarm through a DI Card . . . . .	6-2
Figure 7-1	Example of Plant Ground Grid System . . . . .	7-2
Figure 7-2	UFER Ground System Example . . . . .	7-3
Figure 7-3	Example Using Existing Ground Rods . . . . .	7-4
Figure 7-4	Example Using Existing Counterpoise System . . . . .	7-4
Figure 7-5	Example Using Existing Ground Grid System . . . . .	7-5
Figure 7-6	Example Using UFER Ground Connections . . . . .	7-5
Figure 7-7	Example Using Existing Buried Steel Plate Ground . . . . .	7-6
Figure 7-8	Three-Point Method Setup for Testing an Earth Ground System . . . .	7-8
Figure 7-9	Two-Point Method Setup for Testing an Earth Ground System . . . . .	7-9
Figure 8-1	Minimum Conductor Bend Radius Requirements . . . . .	8-3
Figure 8-2	Typical Lightning Protection System . . . . .	8-4
Figure A-1	Common Mode Noise on an Analog Signal (Display A) . . . . .	A-3
Figure A-2	Common Mode Noise on an Analog Signal (Display B) . . . . .	A-4
Figure A-3	Voltage Output Inverter Signal with Superimposed Noise . . . . .	A-5
Figure A-4	Ground Wiring for Adequate Noise Protection with IGBT Inverters . .	A-6
Figure A-5	Ground Connections at Motor Power Cable Ends . . . . .	A-7
Figure A-6	Dropouts from Cable Tray to VSD Motor . . . . .	A-7

## Tables

Table 5-1.	Recommended Separation Distances .....	5-4
Table 7-1.	Typical Distances for Three-Point Method .....	7-8
Table A-1.	Cable Shield Properties .....	A-2
Table A-2.	VSD Cable Specifications .....	A-8
Table A-3.	Critical Cable Lengths by Pulse Rise Time .....	A-8
Table A-4.	Critical Cable Lengths by Switching Type .....	A-9
Table A-5.	Critical Cable Lengths by Switching Frequency for an IGBT Drive .	A-9
Table C-1.	Wiring Specifications .....	C-1
Table C-2.	Ground Wire Sizing Chart .....	C-2

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## Introduction

Because of inadequate installation practices, control system reliability is often jeopardized before power is applied. Frequently, causes of poor control system reliability are unexamined with the result of the control system receiving a “black eye” in the judgement of the end–user. When causes of poor control system reliability are examined, poor power and grounding practices are often the root cause.

When control systems were proprietary, hardware designs remained unique for each control system. The unique, proprietary designs required manufacturers to develop complete and detailed documentation for every aspect of the system, including installation.

Open, hybrid systems make use of commercial off-the-shelf devices, such as power supplies, carriers, mounting methods, etc., almost to the point where it’s difficult to identify a control system manufacturer without first looking at the logos and markings.

Most control system manufacturers still develop and distribute documentation, however the detail and clarity is often missing. *Control Engineering*, working in conjunction with several control system manufacturers and recognized power and grounding experts, has developed this single control system power and grounding resource.

When this resource is used with control system manufacturer installation documentation, users can expect robust, reliable control system installation; one that remains free of “phantom” problems caused by power and grounding glitches.

## CE Mark Statement



*If you intend to have your control system certified for compliance to appropriate European Union directives, you must carefully consider the installation procedures described in the control system manufacturer’s installation manual. Normally, products must be installed in accordance with the procedures to obtain certification.*

## Warnings, Cautions, and Notes

Warnings, Cautions, and Notes attract attention to essential or critical information in this manual. The types of information included in each are explained in the following:

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**Warning...** All warnings have this form and symbol. Do not disregard warnings. They are installation, operation, or maintenance procedures, practices, conditions, statements, and so forth, which if not strictly observed, may result in personal injury or loss of life.

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**Caution...** All cautions have this form and symbol. Do not disregard cautions. They are installation, operation, or maintenance procedures, practices, conditions, statements, and so forth, which if not strictly observed, may result in damage to, or destruction of, equipment or may cause long term health hazards.

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**Note ...** *Notes have this form and symbol. Notes contain installation, operation, or maintenance procedures, practices, conditions, statements, and so forth, that alert you to important information which may make your task easier or increase your understanding.*

## Liability

Every effort has been made to ensure the information here provides appropriate guidance. However, applications, standards, and equipment change regularly. Therefore, Reed Business Information does not assume and hereby disclaims any liability to any person for any loss or damage caused by errors or omissions in the material contained herein, regardless of whether such errors results from negligence, accident, or other cause whatsoever.

## Chapter 1 Site Preparation Overview

Before you install your control system, your site must be adequately prepared to accept the system. Such preparation is of prime importance for personnel safety and system availability. Preparation includes proper power and grounding and satisfactory signal shielding to maximize reliable and efficient operation of your control system.

This guide provides information you need to help adequately prepare your site. It is believed that the recommendations and guidelines in this manual meet or exceed applicable local electrical codes and regulations. If differences occur between this guide and local codes and regulations, then the local codes and regulations should be given preference.

While the recommendations and guidelines in this guide cover most situations, there will, no doubt, be peculiarities at some installations that require alternate approaches. In these cases, it is recommended that you contact your control system manufacturer for assistance.

### System Availability

Basic requirements exist to assure system availability at levels you require, and include single-point grounding, clean AC and DC power, and other considerations as described below. Beyond these, you may be able to make tradeoffs between system availability required by your process and economic concerns.

If a process is critical to plant operation and process interruptions must be minimized, secondary power sources, signal redundancy, and other forms of backup controls should be considered. If less stringent requirements are acceptable, you can make certain cost control decisions. However, basic requirements cannot be compromised. This guide provides basic requirements and ideas on backup controls.

## Impact of New Technologies on System Availability

Control system availability means that a system is available to perform its intended function. System availability can be defined mathematically as the percent of time that the system is available (operating as intended) compared to the total time that the system is in use.

The percent of time of a system's availability is expressed as Mean Time Between Failures (MTBF) divided by the sum of the MTBF and the Mean Time to Repair (MTTR) times 100. In equation form:

$$\text{Percent available time} = \text{MTBF}/(\text{MTBF}+\text{MTTR})*100$$

System "Boundary" and "Operational" conditions make the availability definition specific to a system. Typically, boundary conditions are determined by operator consoles, system communications, AC and DC power equipment, controllers, and I/O assemblies.

Operational conditions traditionally limit the unavailability of display or control to one loop. Operational conditions are based on historical analysis, and assumes that a final control element has the highest component failure rate. By definition, control strategies that can survive a final control element failure are available if no more than one final control element fails.

However, the use of new technologies may impact these definitions. Fieldbus technologies, which can connect multiple final control elements on a single bus, may extend the system boundary conditions from only an I/O assembly to include multi-drop fieldbus segments. Examples of conditions which can change boundary conditions are: loss of power in a bus-powered fieldbus (which may cause the loss of multiple instruments) and loss of a fieldbus intrinsic safety barrier (which may cause loss of multiple elements).

## Importance of Mean Time to Repair

Mean time to repair (MTTR) is an important consideration for system availability; the shorter the MTTR, the more the system is available. MTTR includes identifying a fault after its first indication, location of the fault, and the time required to correct the fault. For information about methods to minimize MTTR, refer to ANSI/ISA-84.01-1996, *Application of Safety Instrumented Systems for the Process Industries*.

## Electrical Noise Influences

The reliability of a control system can be reduced when it is subjected to unusually high amounts of electrical noise, but proper power and grounding can minimize the effects.

Various components of a system can be affected to different degrees. The following observations have been made during system troubleshooting:

- Properly installed, standard, non-communicating (called traditional or classic) I/O products that use 4–20 mA analog I/O signals only are typically not affected by electrical noise, except high frequency noise.
- High frequency electromagnetic noise generated by AC drives, insulated gate bipolar transistor (IGBT) power switching devices, and other sources can affect all control products without bias to a particular vendor.
- Digital data signals used in bus communication systems are susceptible to electrical noise.

## Minimizing Influences

These effects can be minimized by:

- Using isolated AC power sources
- Grounding at single points
- Minimizing undue influence on signal wiring from stray magnetic fields
- Selecting appropriate cables and pathways, including adequate cable separation.



## AC Power Considerations

Good AC power installation practices can improve the operation of control systems.

### Voltage Regulation

Typically, primary AC power is supplied to a control system through an isolation transformer or other filtering means from the commercial AC source to obtain adequate voltage regulation. The source and its power distribution network should be able to handle initial inrush currents (lasting at least ten cycles) and still maintain voltage regulation within the operating specifications of the control system.

### Electrical Noise Isolation

For isolation from source electrical noise, it is recommended that the control system be supplied from an isolation transformer or power source that is separate from sources used for room lighting and other power loads. Ideally, this separate power source should be supplied from the highest primary source voltage available.

### Backup Power

Often, the process being controlled requires backup power to achieve defined levels of reliability and availability. Backup power should be considered if the following conditions exist:

- The primary power source has a history of failure or of fluctuations beyond the specified tolerance of equipment input power.
- The process requires electrical power for control, and there are no non-electrical means available for control.
- Loss of power requires manual setting of relays or solenoids.
- Loss of power can cause the process to enter an uncontrollable cycle.
- Loss of power causes a process reaction that creates a hazardous condition or an extensive loss of product.

You may want to use power backup of the source only, or you may prefer power backup of every power supply in the control system, such as backup power for every controller. The extent of backup affects system availability and, therefore, is a consideration when determining the level of system availability required.

## System Ground

The ground network for a control system is a vital consideration. Proper ground networks can eliminate the affects of potential deficiencies in the power source and distribution network that affect personnel safety and control system operation.

Poor or faulty grounds are among the most common causes of control system faults. For example, improper grounding of AC neutrals at two or more points can cause stray currents that, in turn, can induce noise and operational errors into the system.

Many times, glitches in systems are traced to electrical ground faults only after hours are spent checking the system itself. The extra time and effort spent in laying out a good ground network is rewarded by easier startup and more reliable operation. It is suggested that you review IEEE Standard 1100-1992, *Recommended Practice for Power and Grounding Sensitive Electronic Equipment*, for industry-accepted methods to obtain good power and grounding.

## Earth Ground

Proper earth grounding is also important to user safety and efficient operation of a control system. A good earth grounding system safely conducts stray electrical currents into the ground. It can also considerably reduce electrical noise caused by static discharge, lightning charges, and electrical components of electro-mechanical devices.

Building steel must be part of a good earth ground system. For protection from both lightning and electrical noise caused by plant equipment, the steel and earth must form a conductive network and equal voltage potential ground system. For example, electric motor frame grounds are normally connected to building steel as supplemental grounding. Therefore, the steel must contain a good, low impedance, electrical path to earth to provide adequate electrical noise protection for control systems.

## Signal Wiring for Traditional I/O Systems

To achieve optimum I/O subsystem operation, the system should use industry-prescribed cables (as described below) that are properly installed to negate electromagnetic interference (EMI) and other electrical noise that can adversely affect the instruments controlling the process.

### Selecting Analog Current or Voltage Signals

Among analog signals, current signals generally have higher noise immunity than voltage signals. It is recommended that two-wire current transmission be used whenever possible.

### Separating Signal Lines From Power Lines

Signal cabling should be kept away from AC power lines, transformers, rotating electrical equipment, or other high power machinery to reduce the possibility of electromagnetic interference being induced on analog and discrete signals. Normally, power lines and signal cables should be carried in separate cable trays. If necessary, power lines and signal cables can be carried in the same tray if separated by a tray divider. Some national electric codes may also require separation. Table 5-1 lists recommended distances between signal cables and power lines.

### Multi-Conductor Cables

Signal circuits rarely contain enough power to generate noise in adjacent circuits. Typically, if your plant design practices allow, traditional I/O signals can be run through multi-pair cables without generating interfering noise. Using multi-pair cables instead of individual wires or pairs usually reduces installation costs and provides adequate noise immunity. Multi-pair cables should use color-coding, numbering, and so forth to identify pairs of twisted wires for each signal.

For added protection from electrical noise, standard, 4–20 mA, 1–5 VDC, and 24 VDC discrete signals may use multi-pair cable in which each twisted pair contains a metallic shield and drain wire plus an overall metallic shield and drain wire for the cable. Normally specified cable is shielded, twisted pair per National Electric Code (NEC) Type tray cable (TC), instrumentation tray cable (ITC), power limited tray cable (PLTC), or metal clad (MC). Multi-core cable with a single, overall shield is generally accepted for wiring 120 VAC discrete signals and is often used for 240 VDC discrete signals.

Protection from electrical noise must be given to low amplitude signals, such as those derived from millivolt, thermocouple, and resistance-temperature devices. Commercially available, individually shielded, single-pair or multi-pair cables should be used for such devices. However, even with their use, the cables should be kept away from AC circuits, especially those containing motor or generator control solenoids, similar types of circuits with relatively high inrush currents, and solid-state switching circuits.

Various industry standards, such as IEEE 518-1982, *IEEE Guide for the Installation of Electrical Equipment to Minimize Noise Inputs to Controllers from External Sources*, describe noise identification and classification as well as recommended wiring practices. It is recommended that you obtain appropriate standards.

## Signal Wiring for I/O Bus Systems

To achieve optimum system operation, digital I/O bus systems, such as AS-Interface, DeviceNet, FOUNDATION Fieldbus, and Profibus, must be properly installed. Otherwise, electromagnetic interference (EMI) and other electrical noise can adversely affect the capabilities of the instruments controlling the process.

When using digital I/O systems, cable types, lengths, and sizes; grounding requirements; power; and other factors must be considered. Information about these factors is usually available from the control system manufacturer. Once a digital I/O system is installed, its operation should be verified before it is commissioned.

For most digital I/O systems, important design information is available on the manufacturer's web sites. Sites for commonly used digital I/O systems are listed in Chapter 5 of this manual.

## Intrinsically Safe I/O Systems

Most control system manufacturers offer a selection of intrinsically safe I/O systems, including I/O cards, isolating power supplies, and local bus isolators. When using the control system manufacturers intrinsically safe devices, consult the manufacturers installation documentation.

Most control systems can be used with intrinsically safe I/O systems from third-party manufacturers. When using intrinsically safe devices from multiple manufacturers, it is suggested that you review intrinsic safety information in ANSI/ISA-RP12.6-1995, *Wiring Practices for Hazardous (Classified) Locations — Instrumentation Part 1: Intrinsic Safety*.

## Lightning Protection

In an area where damage from electrical storms may occur, a lightning protection system should be installed to protect both personnel and equipment. The protection system should include buildings, the power distribution system, copper wire LAN systems, and any cables that run outdoors to other locations.

For detailed information, refer to:

- *National Fire Protection Association Inc. (NFPA) Lightning Protection Codes NFPA-78*
- *IEEE Recommended Practices for Grounding of Industrial and Commercial Power Systems IEEE Standard 142-1991*

## Chapter 2 AC Power Distribution

This chapter provides recommendations for powering control systems from AC sources, including information on single-phase power, three-phase power, transformer isolation, distribution, power supply connections, and AC connections to workstations.

### AC Power Considerations

Commercial AC power utilities normally provide power that meets the voltage and frequency requirements of the control system. However, plant distribution networks may drop 5 percent or more of the input AC power between the plant's service entrance point and the final power connection to various portions of the control system.

Additionally, power disturbances can be introduced on power lines by starting transients induced from large motors and other loads connected to the distribution system. These disturbances can cause momentary line-voltage reductions as well as possible waveshape distortions. For example, starting large motors may momentarily drop line voltage as much as 15%. Therefore, assessing AC power requirements for a control system and then designing a plant AC distribution system that meets the requirements is critical to reliable, efficient control system operation.

### Maintaining Power Quality

To maintain good AC power quality, items such as power loss, intermittent noise, low voltage, transients, and surges on power lines must be designed around or otherwise controlled. Process application and process availability are critical factors for determining the amount of noise protection desired.

It is recommended that AC power supplied to a control system be taken from an AC power distribution system isolated from the AC power supplied to all other functions in the plant area. As a minimum, an isolation transformer should be installed between the commercial power source and the main AC power distribution panel for the control system. The power source should be as close to the system as possible.

**Note ...** *Isolation transformers are recommended because they inherently provide good line regulation and transient filtering. In addition, each building or site containing control system devices should have a separate power source or backup power source, or both.*

A separate distribution system is recommended for each building containing control system devices. In addition, if system devices are located in the same building, but in different rooms that are more than 200 cable feet from the AC power source, an isolation transformer for the devices in each room is generally beneficial.

Loads, such as AC drives and solid-state switching electronics, on AC power systems other than the control system cannot be ignored. These loads can induce electrical noise on nearby power systems. Protection for electrical noise generated by these loads may be required.

To suppress electrical noise, a dedicated feeder between the main distribution panel and the control system branch panel is recommended. Other devices that may be used to provide protection, either alone or in combination, include:

- Noise filters
- Line conditioners
- Voltage regulating power sources
- Motor-generator sets
- Uninterruptible power supply (UPS)

If loss of power from a commercial power source is a probability, a backup power source, such as an uninterruptible power supply for critical portions of the control system, is recommended.

## Primary Power Requirements

Most control systems use single-phase power in a voltage range of 85 to 264 Volts and a frequency range of 47 to 63 Hz. These ranges allow for AC input power from normal 120 VAC and 240 VAC sources. Frequently, a plant uses three-phase power. If it is, the load between phases should be balanced at each power panel, minimizing any voltage differentials between the AC neutral and the ground conductors. Typically, one phase powers control system devices, another powers associated field devices, and the other powers associated support equipment.

The power source and its power distribution network should be sized to handle initial inrush currents that can last up to 10 cycles and still be able to regulate the voltage to the control system.

**Note ...** *The primary power source must be free of non-repeating power interruptions greater than 20 milliseconds. A power interruption greater than 20 milliseconds can cause loss of control, system configuration data, and process data in a control system.*

If your existing plant power does not meet the 20-millisecond requirement, uninterruptible power supplies (UPS) are available from a variety of sources. Small supplies are available to provide backup to selected plant areas. Large supplies can be used for a single common unit to back up an entire system. If a common unit is used, each plant area should be isolated in a manner duplicating the primary source isolation method.

When using isolation transformers, the input power to the transformers should be supplied from the highest line voltage available from the commercial source. Using the highest power makes distribution easier. In addition, an isolation transformer should be dedicated to the control system. Other systems, such as emergency shutdown (ESD) systems and programmable logic controllers (PLCs), should have their own source or sources and also should be isolated.

## Primary Power Calculation

Manufacturer product data sheets usually list the power input requirements. Review these sheets and add the individual power requirements to obtain the total power required for control systems.

## Recommended Wire Sizes

The wiring from a power source to equipment should be large enough to maintain the specified voltage range at equipment input terminals when all equipment is energized. Wiring must conform to NFPA and NEC as well as applicable local, regional (state, province), and national codes to ensure that it can conduct the current load safely and without overheating.

Recommended wire sizes for various load currents and run lengths are usually determined from formulas that take into account ampacity, temperature, power factor (for switching loads), and allowable voltage drop limits. Formulas and further wiring recommendations are found in appropriate NEC, CSA, and European standards. Refer to these standards to determine proper wiring lengths and sizes for your plant.



## Power Cable Run Alternatives

Power cables may be run underground or above ground. Each method offers advantages. Underground runs are generally better physically protected than above ground runs and are safer from fire. However, underground runs can be subject to faults caused by moisture and are difficult to repair or modify unless underground cable vaults are installed. In addition, if the control system is being installed into an existing plant, adding underground cable may be impossible. If you choose above-ground runs, cables should be physically supported in conduits or on cable trays.

## AC Distribution System

Input AC power is supplied through an isolation transformer or UPS, and the AC ground point for the control system is established at or near the transformer or UPS. The AC circuit conductors are routed through the main distribution panel (containing the main disconnect switch) into the circuit breaker panel or panels.

This design meets or exceeds the requirements for grounding of the NEC. For large control systems, multiple circuit breaker panels should be used. Separate panels are dedicated to system enclosures and to control system workstations.

Figure 2-1 provides details for single-phase wiring between an isolation transformer and the main distribution panel.

Figure 2-2 shows an uninterruptible power supply (UPS) used in a single-phase system with an isolation transformer.

Figure 2-3 provides details for three-phase wiring between an isolation transformer and the main distribution panel.

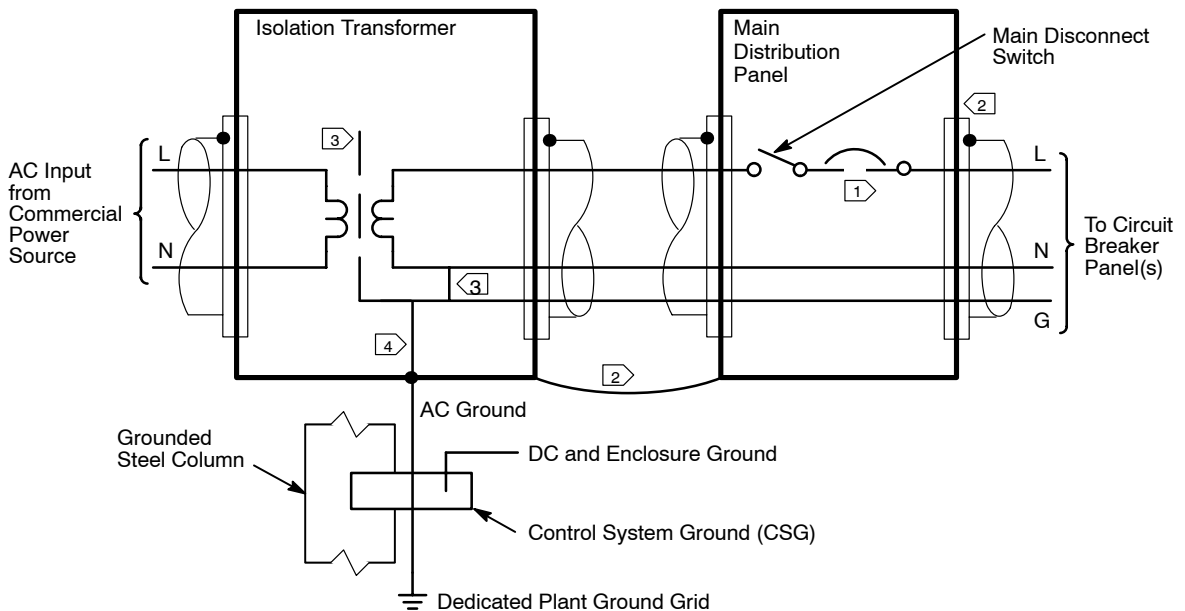
Figure 2-4 shows an uninterruptible power supply (UPS) used in a three-phase system with an isolation transformer.

Figure 2-5 provides an overview of an adequate grounding network for an AC distribution system.

Figure 2-6 shows a method of wiring grounded type AC receptacles through a circuit breaker panel to obtain a good ground system.

In Figure 2-6, the neutral and ground conductors are shown bonded to separate bus bars inside the circuit breaker panel. The bus bars are electrically isolated from the panel and from each other. Throughout the distribution system, all AC circuit conductors (line, neutral, and ground) are electrically isolated from their conduits and circuit breaker panels.

This conductor isolation is maintained from the isolation transformer or UPS to the point of final connection at the instrumentation. The only connection between neutral, isolated ground, and earth ground is at the main bonding jumper. The insulated ground conductor should be the same size or larger than the phase and neutral conductors. The connection should never be made to building steel, but building steel can be connected to the control system ground (CSG), as shown in Figure 2-1.



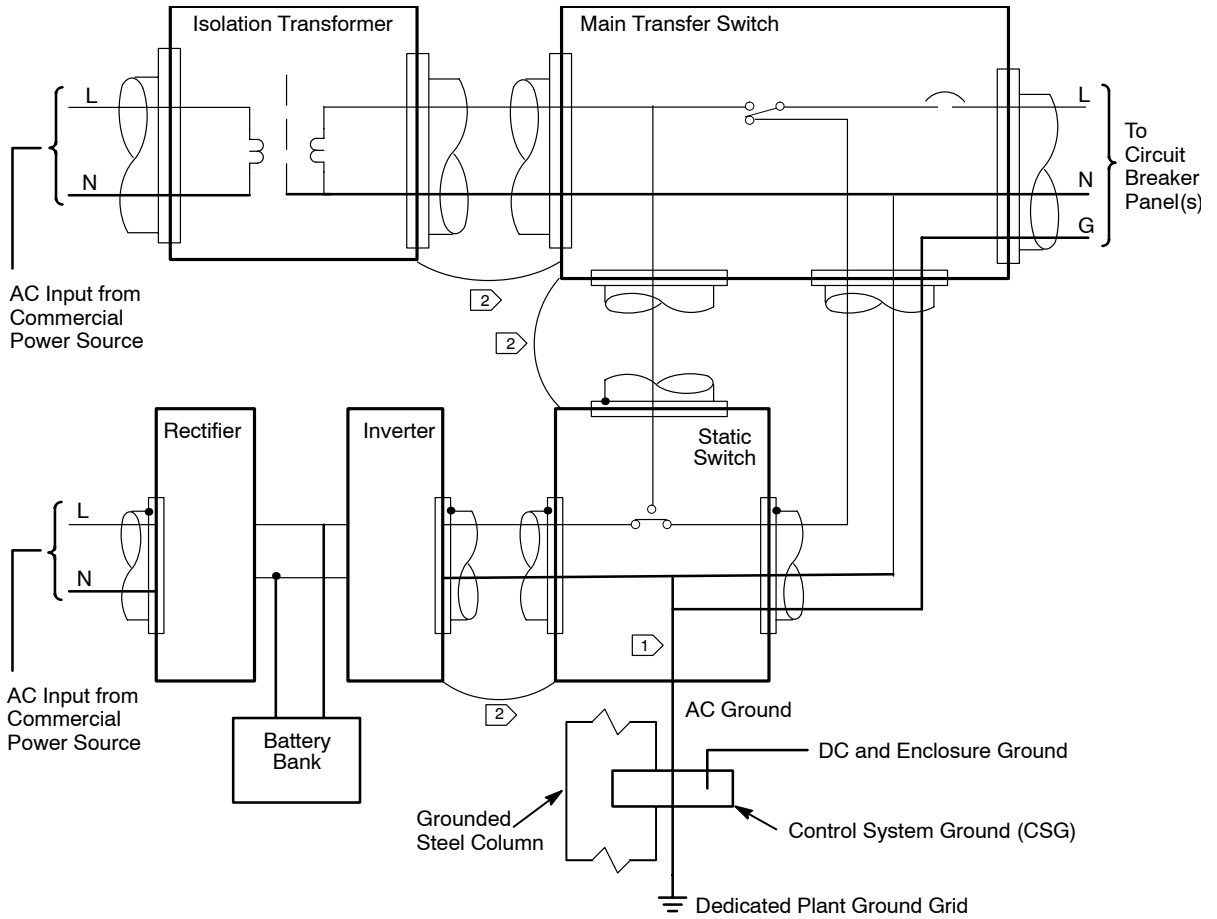
**Notes:**

- ① Circuit breaker, as required by national codes and regulations
- ② Conduit provides a safety ground connection for individual equipment housings. If no conduit or non-metallic conduit is used, bond housings together with cable. See NEC table 250-122.
- ③ All isolation transformers should be shielded.
- ④ The conductor between the neutral and ground leads and the dedicated AC ground should be as short as physically possible.

**Legend:**

- L Line
- N Neutral
- G Ground

**Figure 2-1 Single Phase, Separately Derived, AC Power Input System**



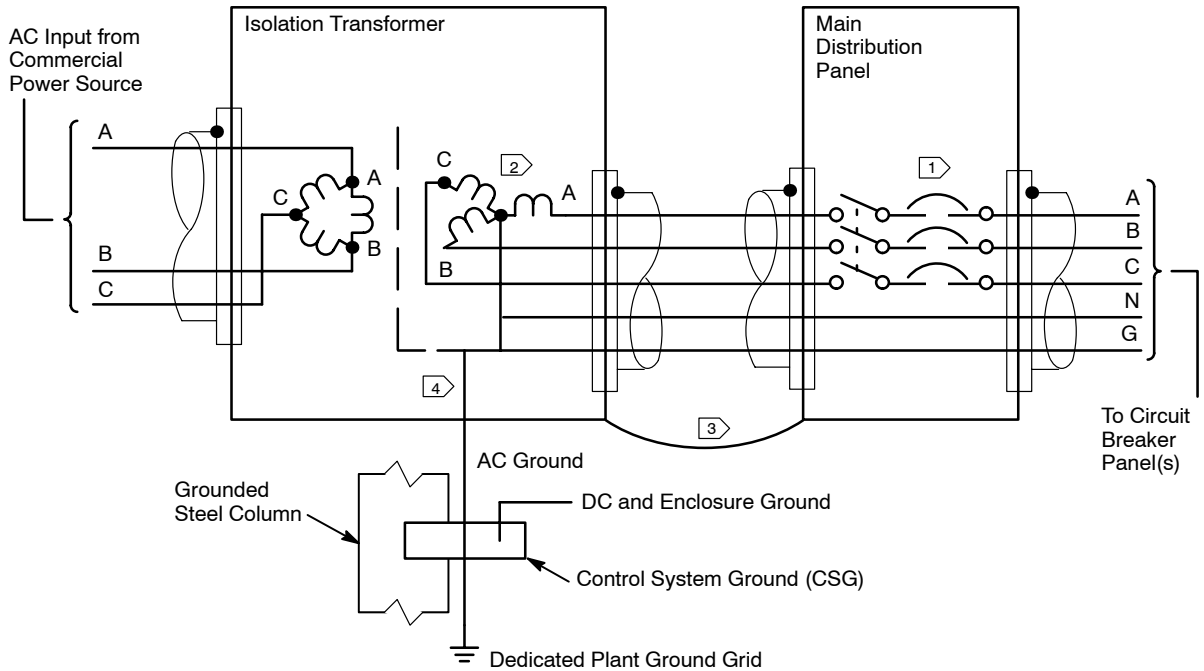
**Notes:**

- ① The conductor between the neutral and ground leads and the dedicated AC ground should be as short as physically possible.
- ② Conduit provides a safety ground connection for individual equipment housings. If no conduit or non-metallic conduit is used, bond housings together with cable. See NEC table 250-122.

**Legend:**

- L Line
- N Neutral
- G Ground

**Figure 2-2 Single-Phase, Separately Derived, Reverse Transfer Uninterruptible Power Supply (UPS) with a Manual Transfer Switch**

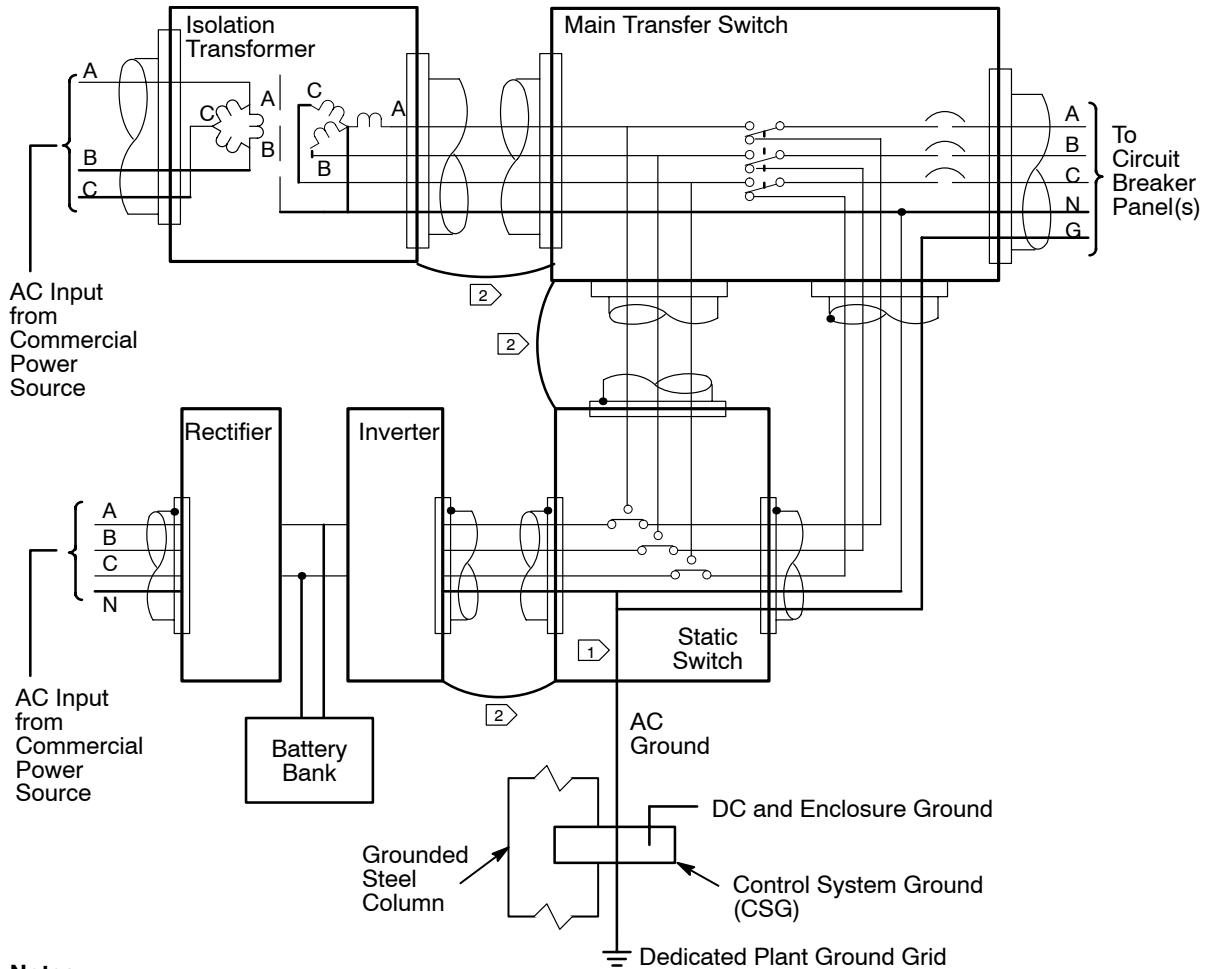
**Notes:**

- ① Circuit breaker, as required by local codes and regulations
- ② The isolation transformer secondary can be a 208Y/120 Volt, 120 Volt, 120/240 Volt, or European 230/240 Volt output.
- ③ Conduit provides a safety ground connection for individual equipment housings. If no conduit or non-metallic conduit is used, bond housings together with cable. See NEC table 250-122.
- ④ The conductor between the neutral and ground leads and the dedicated AC ground should be as short as physically possible.

**Legend:**

- L Line
- N Neutral
- G Ground

**Figure 2-3 Three Phase, Separately Derived, AC Power Input System**

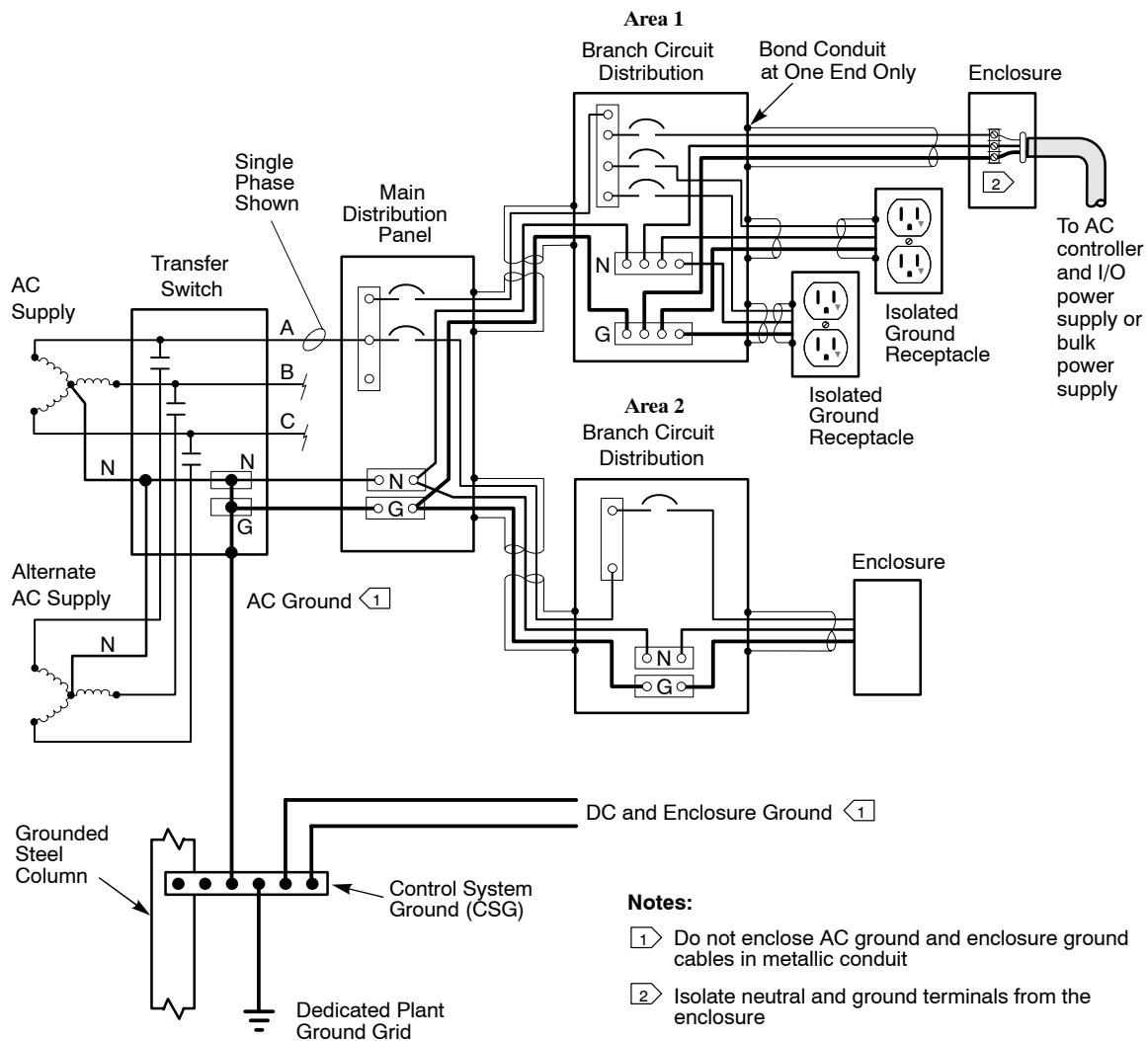


**Notes:**

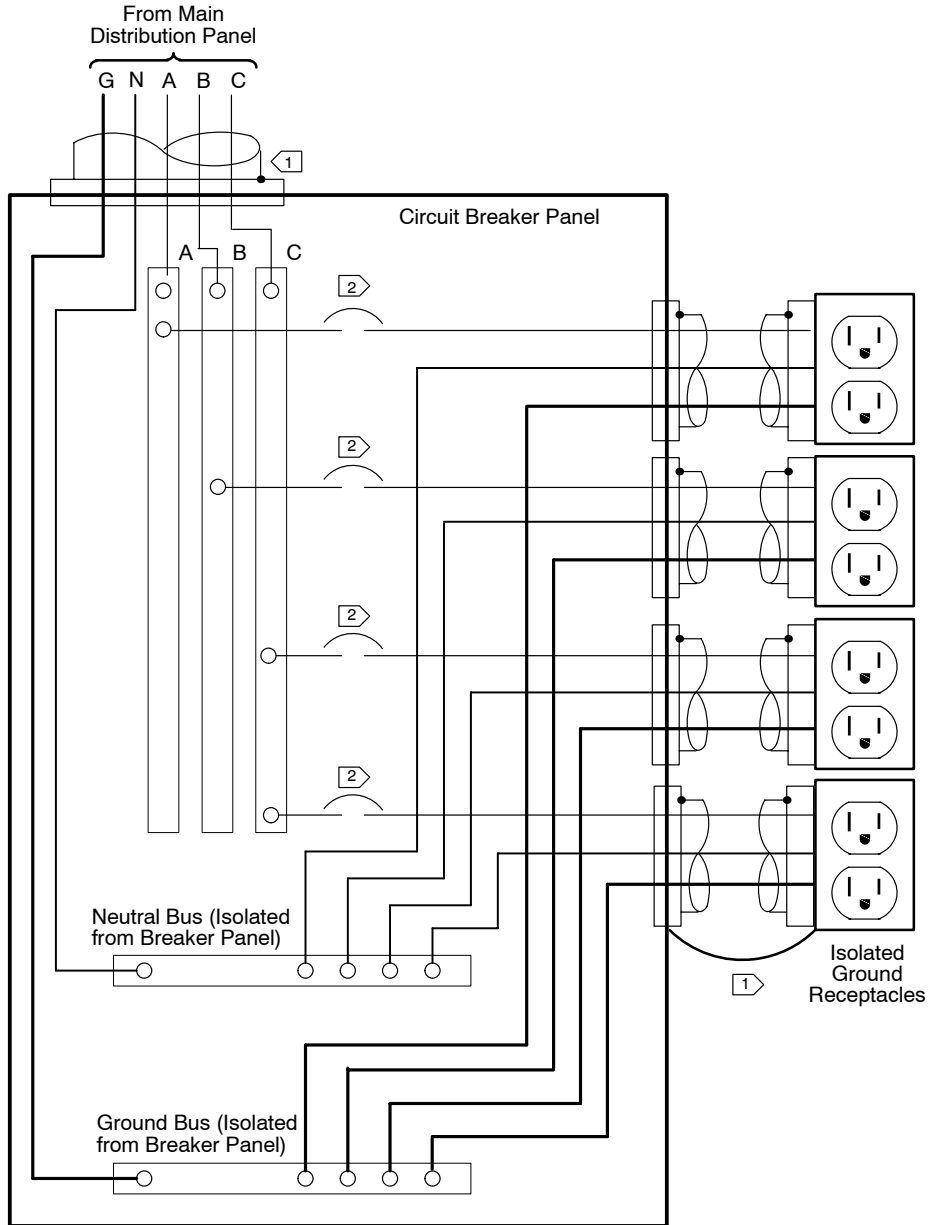
- ① The conductor between the neutral and ground leads and the dedicated AC ground should be as short as physically possible. Table C-2 provides length and size information.
- ② Conduit provides a safety ground connection for individual equipment housings. If no conduit or non-metallic conduit is used, bond housings together with cable. See NEC table 250-122.

**Legend:**  
 L Line  
 N Neutral  
 G Ground

**Figure 2-4 Three-Phase, Separately Derived, Reverse Transfer Uninterruptible Power Supply (UPS) with a Manual Transfer Switch**



**Figure 2-5 AC Distribution System Grounding**



**Notes:**

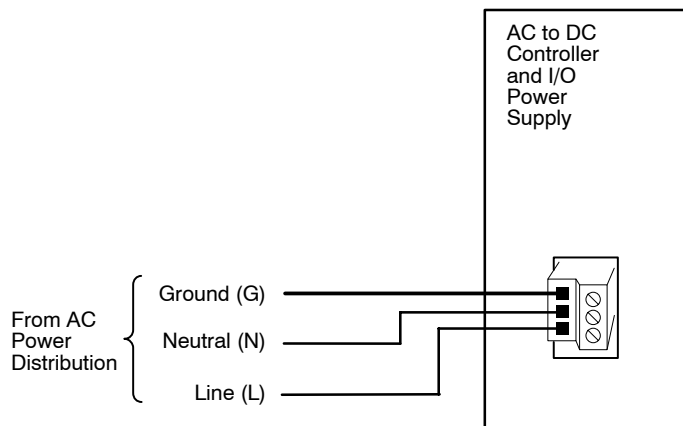
- 1) Conduit provides a safety ground connection for individual panels. If no conduit or non-metallic conduit is used, bond panels together with cable. See NEC table 250-122.
- 2) Circuit breaker as required by national codes and regulations.

**Figure 2-6 Single Circuit Breaker Panel Wiring for Isolated Ground Recept**

## AC Power Supply Connections

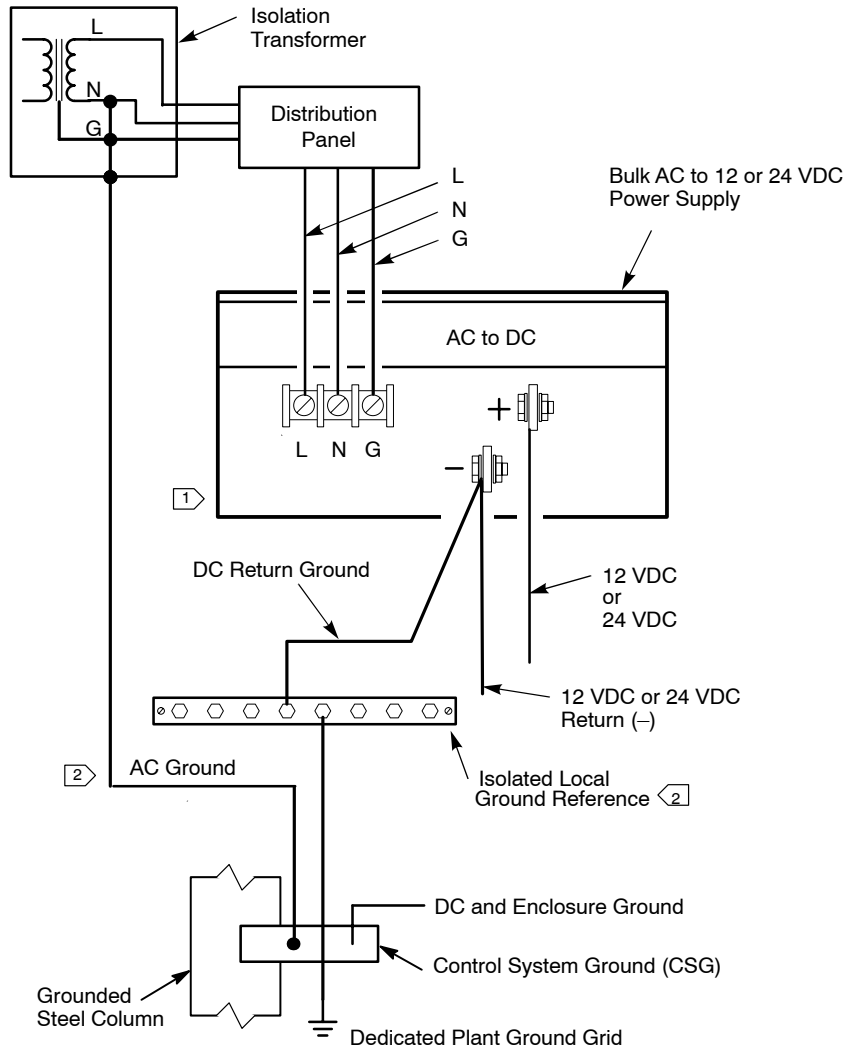
It is recommended that AC power from a breaker be connected to a terminal block inside the enclosure, as illustrated in Figure 2-5. AC power for control system power supplies is connected from the enclosure terminal blocks to terminals on the supplies.

Figure 2-7 shows the line, neutral, and ground connections for a control system AC to DC controller and I/O power supply. Figure 2-8 shows line, neutral, and ground connections for a single bulk power supplies. Figure 2-9 shows line, neutral, and ground connections for multiple, grouped, bulk power supplies.



**Figure 2-7 AC to DC Controller and I/O Power Supply Input Connections**



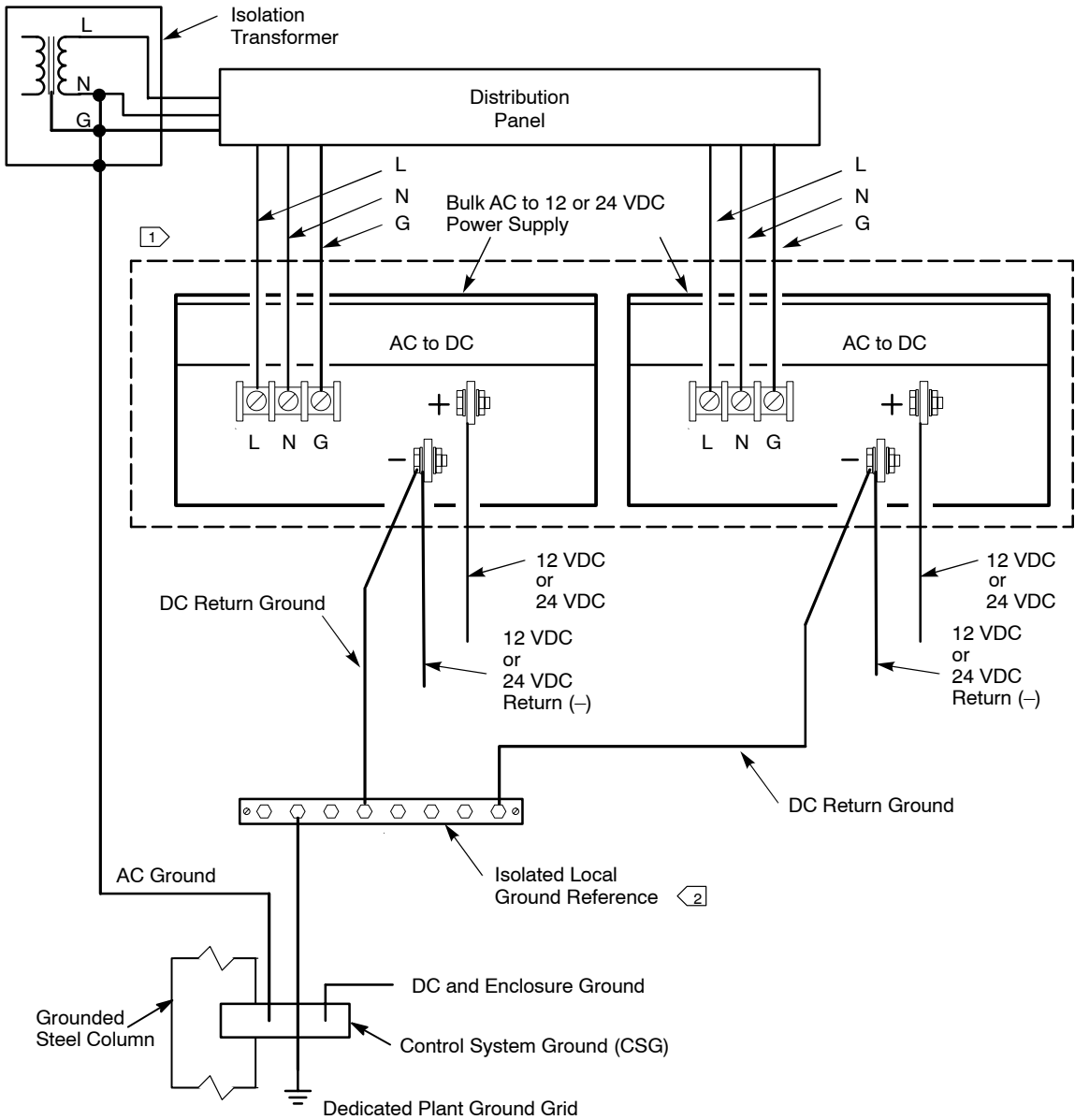


**Notes:**

- ① Power supply chassis is grounded through the mounting enclosure.
- ② See Figure 4-1 and Figure 4-2 for ground connection details.

**Legend:**  
 L Line  
 N Neutral  
 G Ground

**Figure 2-8 Connections for Single Bulk Power Supply, Including Ground**



**Notes:**

- ① Dashed line indicates that bulk power supplies are grouped in an enclosure or plant area.
- ② See Figure 4-1 and Figure 4-2 for ground connection details.

**Legend:**

- L Line
- N Neutral
- G Ground

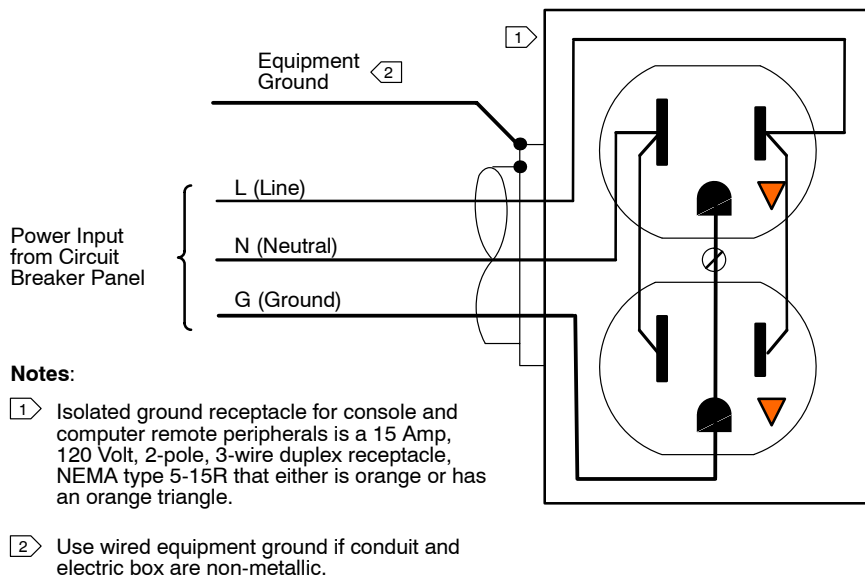
**Figure 2-9 Connections for Multiple, Grouped Bulk Power Supplies, Including Ground**

## Workstations and Peripheral Equipment

All AC power for control system workstations should be routed from a circuit breaker panel to dedicated isolated AC receptacles. The panel can be the same one that is used for equipment in enclosures, as shown in Figure 2-5 and Figure 2-6. These figures illustrate a good safety ground setup, using isolated ground receptacles.

Peripheral equipment can sometimes be plugged into nearby receptacles, depending on the equipment power isolation and the integrity of the safety ground wire. To assure proper equipment power and ground connections, it is recommended that isolated ground receptacles be used and that they are connected as shown in Figure 2-5 and Figure 2-6.

Isolated ground receptacles are detailed in Figure 2-10. They must be constructed and installed so that the ground terminal is electrically isolated from the conduit and the box in which the receptacle is mounted. If non-isolated communications or signal wiring is used, connected peripheral units and electronic units must receive AC power from the same circuit breaker panel.



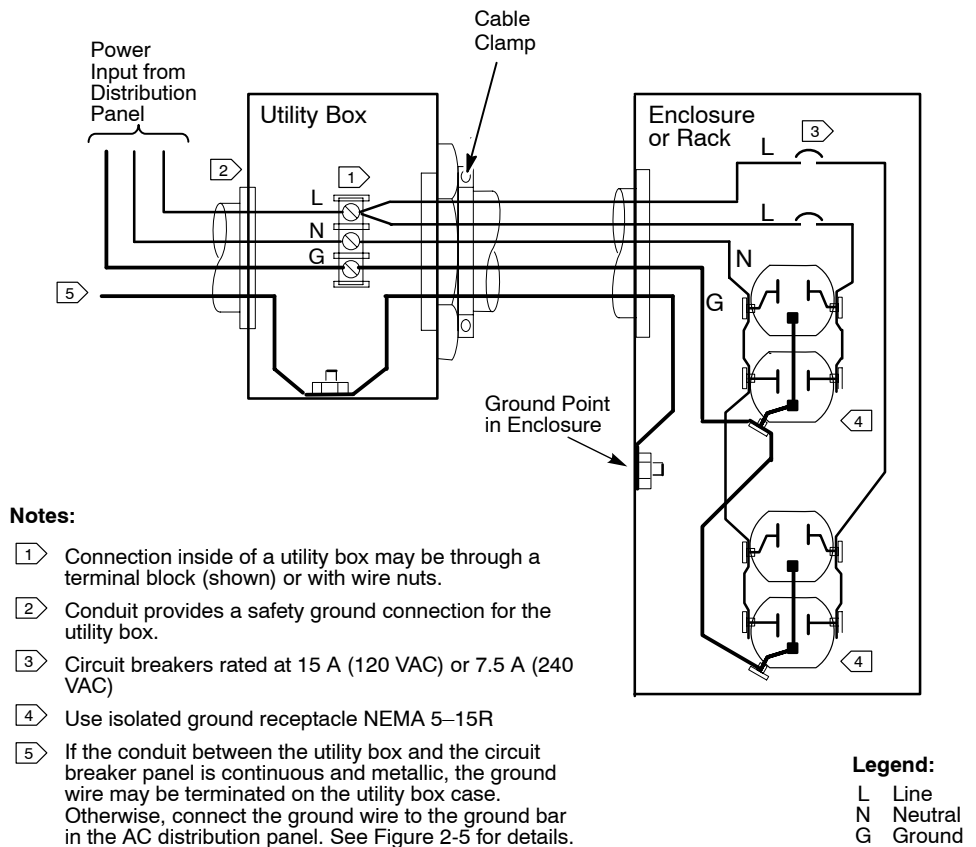
**Figure 2-10 Isolated Ground Receptacle Details**

## Auxiliary Equipment

You may want to use auxiliary equipment, such as fans, modems, and other small AC loads in your enclosures. AC power for such equipment is typically routed through a 1-pole, 15-ampere circuit breaker to AC receptacles. You may use circuit breakers capable of handling current up to the required load.

However, do not use breakers greater than 30 Amperes. Most NEC codes limit these circuits to 30 Amperes and most wiring used for auxiliary equipment is not rated for current greater than 30 Amperes.

Be sure to use circuit breakers for auxiliary equipment so that faults in the auxiliary equipment do not cause the main breaker to trip. Figure 2-11 shows a possible design, including receptacles for the primary and redundant power supplies. A typical North American receptacle is shown; use receptacles appropriate for each world area.



**Figure 2-11 AC Power to Receptacles in Enclosures**

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## Chapter 3 DC Power Distribution

Control system controllers and I/O systems are usually powered by controller and I/O power supplies, providing a variety of DC voltages such as 12 VDC, 5 VDC, and others for controllers and I/O cards. This section describes distribution requirements for DC supplies.

### DC Power Considerations

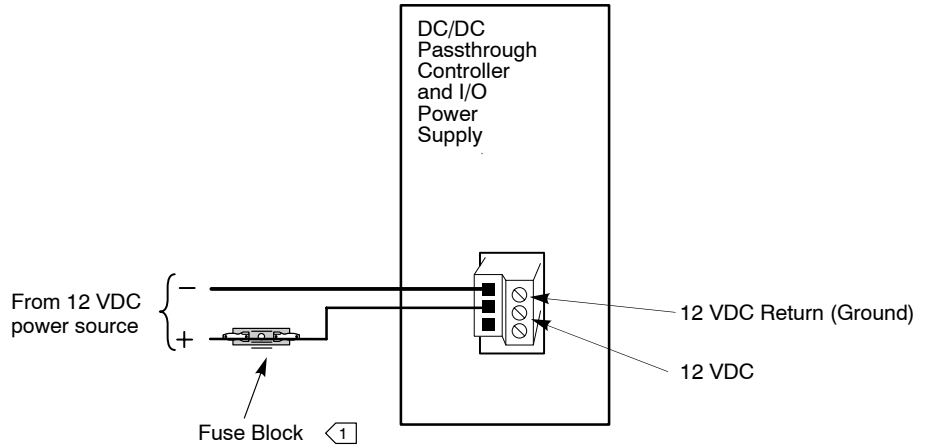
When designing DC power distribution system, the design should be reviewed to ensure that the DC distribution system can sustain the required reliability. A good review reveals whether or not DC power redundancy is required. Backup of both bulk power supplies and DC to DC controller and I/O supplies can be applied.

If a backup bulk supply is used, the backup supply must be connected to the same local ground point as the associated primary supply. A backup supply can back up a primary supply in a separate enclosure.

### DC Power Connections

Many control systems use DC/DC passthrough power supplies for controllers and I/O. The supplies receive DC power from bulk power supplies or from other in-plant DC sources. Often, DC/DC passthrough supplies accept 12 VDC input. Figure 3-1 shows typical connections.

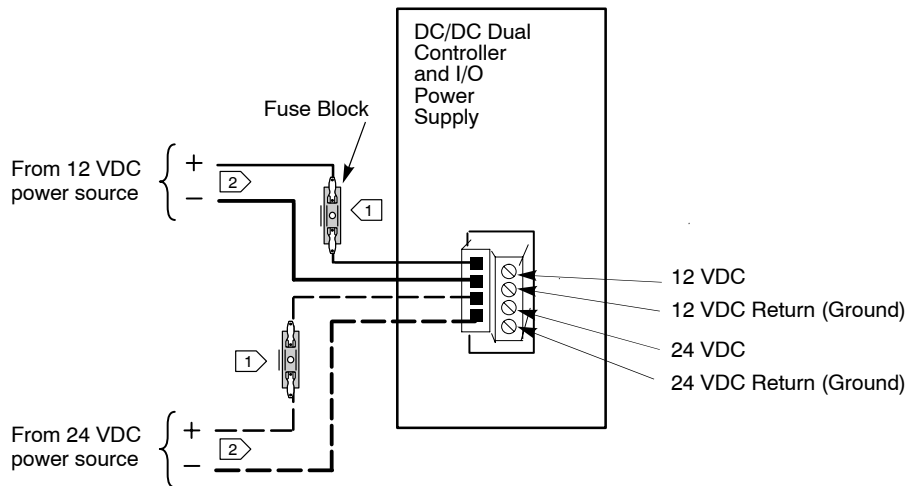
Some systems include dual DC/DC supplies. These supplies can accept both 12 VDC and 24 VDC voltages, depending on input terminal connections. Figure 3-2 shows these connections. Usually, the connections are made between source and supply with stranded wire of a minimum size of 8 AWG (8.4 mm<sup>2</sup>). The size and length of wire must be chosen to minimize the voltage drop to 2% or less.



**Note:**

1 A fuse block and fuse are optional. If you are providing bulk DC power to several DC/DC passthrough controller and I/O power supplies, it is recommended that you fuse the line to each supply.

**Figure 3-1 DC to DC Controller and I/O Power Supply Connections**



**Note:**

1 A fuse block and fuse are optional. If you are providing bulk DC power to several DC to DC controller and I/O supplies, it is recommended that you fuse the line to each supply.

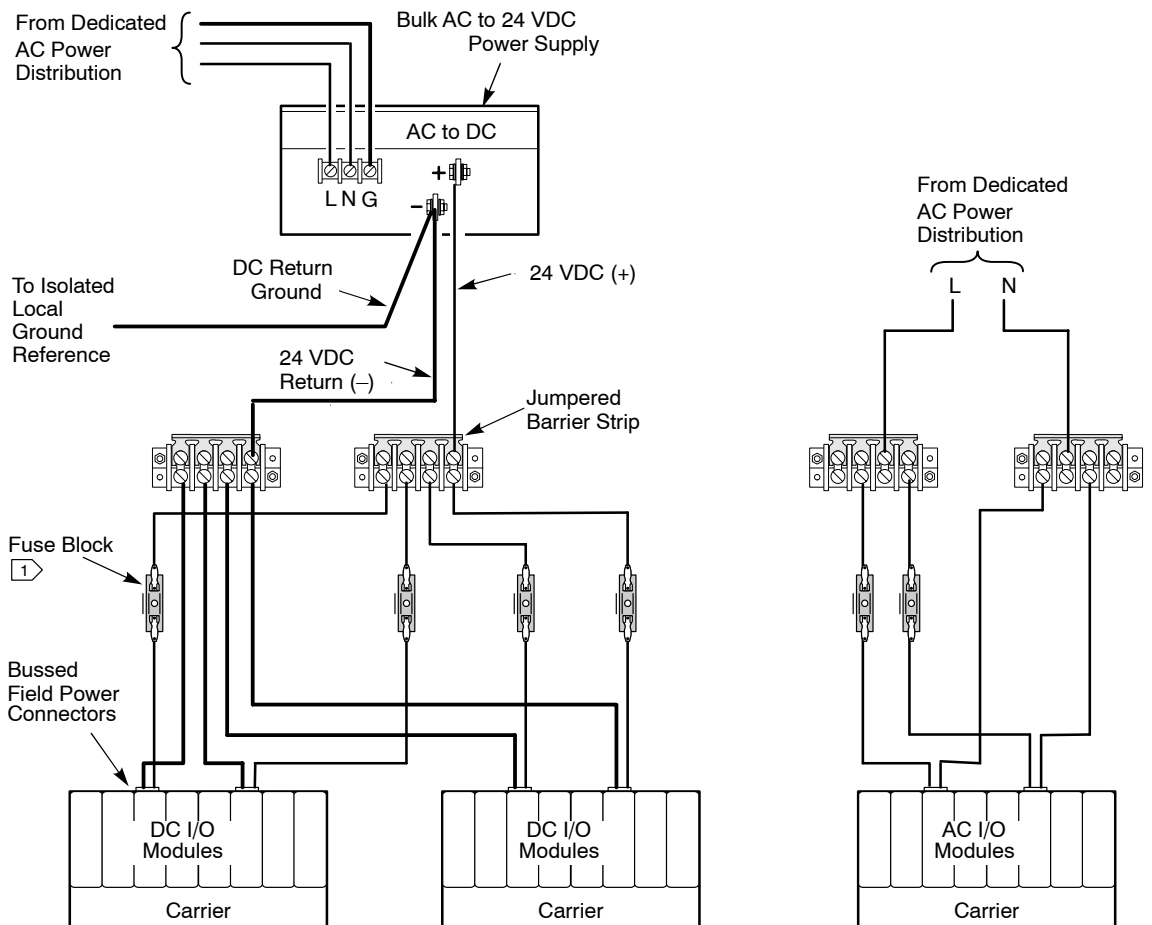
2 Use either 12 VDC or 24 VDC. Only one input voltage is used; not both simultaneously.

**Figure 3-2 DC/DC Dual Power Supply Input Connections**

## Bussed Field Power

Bussed field power is connected directly to the I/O interface carrier, as shown in Figure 3-3. For 24 VDC field devices, either bulk DC power supplies or DC plant power can be used. For 120 VAC or 240 VAC field devices, power from the AC power distribution system can be used.

The AC distribution system used for bussed field power should not be the same one as used for the control system. Using a separate system isolates electrical noise from the control system. The noise can be fed back on field power lines from heavy switching relays and other loads that typically cause spikes.



**Note:**

① A fuse block and fuse are optional. If you are providing bussed field power to several carriers from one power supply, it is recommended that you fuse the line to each carrier.

**Legend**

L Line  
N Neutral  
G Ground

**Figure 3-3 Bussed Field Power Connections**

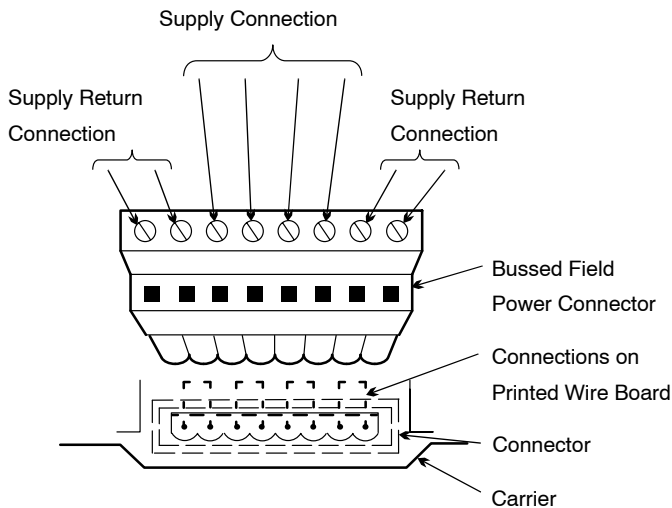


## Barrier Strips

I/O interface carriers contain bussed field power connections. Figure 3-3 shows a connection being powered through a barrier strip. When connecting field device power to several I/O interface carriers, barrier strips should be used. Carriers should not be daisy chained together because it is very difficult to remove power from one carrier without affecting all other carriers in a daisy chain. You may daisy chain the connectors on the same carrier if you wish, but separate connections, as shown in Figure 3-3, are recommended.

## Carrier Connections

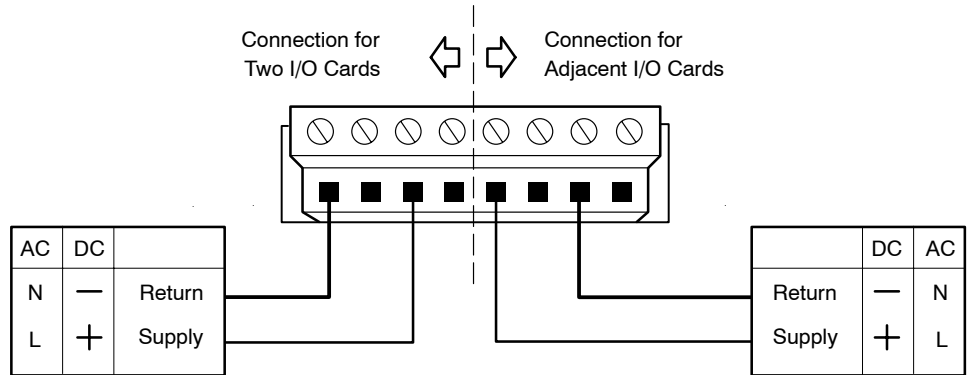
Figure 3-4 shows connector details for power connections on typical bussed field power connectors of I/O carriers.



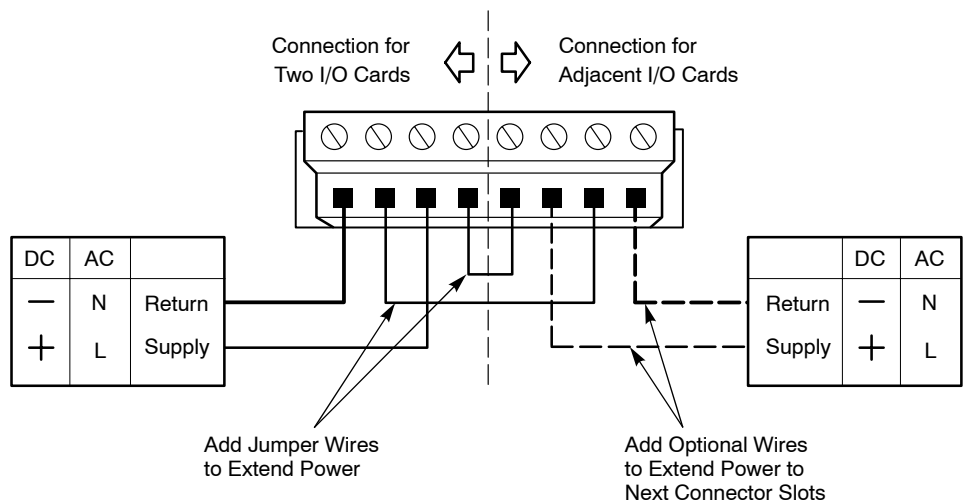
**Figure 3-4 I/O Carrier Bussed Field Power Terminal Block**

As shown in Figure 3-4, two terminals provide supply connections, and two terminals provide return connections. The connections route power to two adjacent I/O cards. Cards 1 and 2 are paired and must use the same field voltage level. Similarly, cards 3 and 4 must use the same voltage level, although the level can differ from that of cards 1 and 2. However, it is recommended to supply the same field voltage to all cards on the same carrier.

Figure 3-5 illustrates typical connections for adjacent I/O cards. Figure 3-6 illustrates typical connections for extending power from power supplies used for adjacent I/O cards.



**Figure 3-5 Bussed Field Power Wiring (Non-Extended Power)**



**Figure 3-6 Bussed Field Power Wiring (Extended Power)**

**Note ...** *It is neither recommended, nor is it good engineering practice, to connect both AC and DC power to the same connector.*

If AC and DC power are connected to the same block, the block must be marked with a warning label to indicate that 120 VAC or 240 VAC and 24 VDC are found on the block. In addition, precaution must be taken that both AC and DC power are disconnected when the block is removed.

The bussed field power connector provides power to the field through the I/O cards only. Extending power from this connection to additional field devices is not supported or appropriate.

## Resistor-Capacitor Snubbers

For discrete inputs and outputs, resistor-capacitor (R-C) snubbers may be necessary to suppress electrical arcing. Refer to the control system manufacturers manual for descriptions of snubbers you can use for suppression.

## Intrinsic Safety Considerations

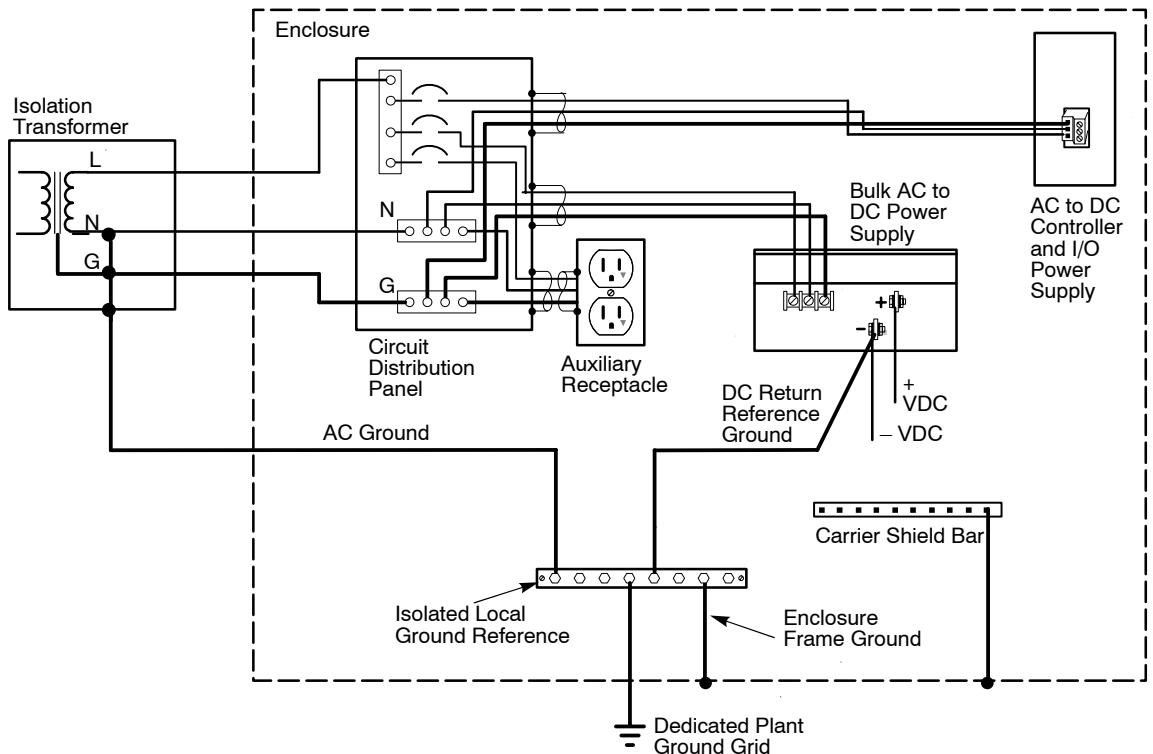
Most control systems do not require special or additional DC power supplies to power Intrinsic Safety (IS) I/O cards. The DC output for the control system intrinsic safety power supply connects directly to the IS I/O cards through the backplane. The local bus isolator electrically isolates intrinsic safety I/O cards from non-IS I/O cards. See Figure 4-14 for the location of the power supply and isolator on the IS I/O carrier.

## Chapter 4 System Grounding

To ensure best performance and reliability of your control system, an adequate electrical ground network must be installed. Poor or faulty grounds are among the most common causes of control system faults. The extra time and effort spent in installing a good ground network is rewarded by easier system startup and more reliable system operation.

### Single-Point Ground Techniques

The ground network is an organized system of ground wiring that terminates in a single, dedicated point on the plant ground grid. With single-point ground, you can achieve a clean reference for the control signals in your control system, thereby ensuring increased system reliability over systems with poorly designed ground networks. Figure 4-1 illustrates a typical, single-point ground network for a small control system.



**Figure 4-1** Typical, Single-Point Ground Network for a Control System Housed in a Single-Enclosure

The system illustrated in Figure 4-1 usually consists of a single enclosure with the isolation transformer included on the enclosure. For heat control purposes, the transformer is usually mounted outside of the enclosure. The transformer only provides power for the equipment in the enclosure. Its AC ground is connected to the control system ground (CSG).

Figure 4-2 illustrates a typical, single-point ground network for either a large control system housed in several adjacent enclosures or for a system spread over a local area. It is important that the term “local area” is well understood in relationship to power and grounding.

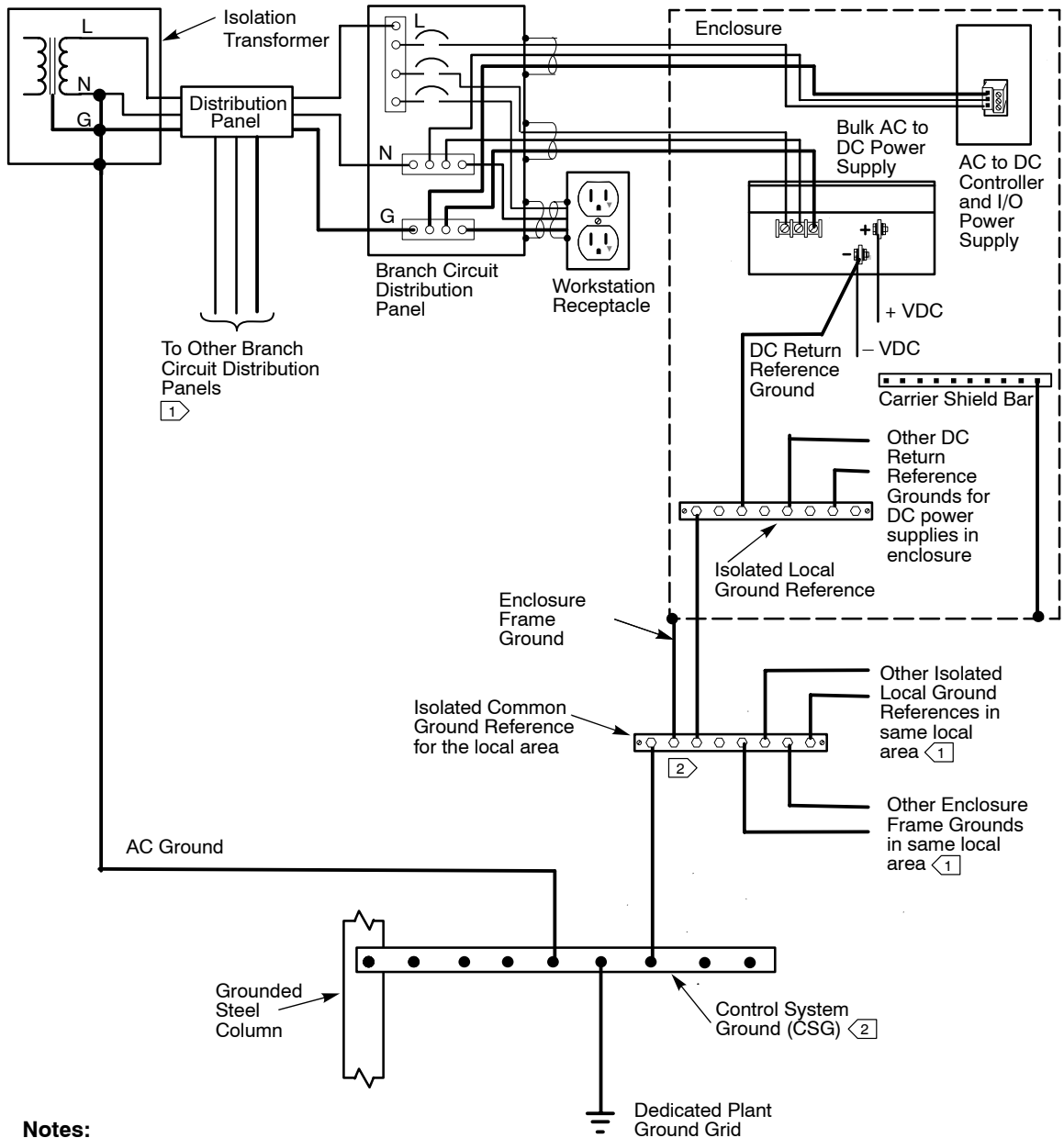
Each local area is defined as having one isolation transformer, a ground reference for the area, and cable-foot limitations. By this definition, all instruments powered by the transformer are located in the same local area, whether the instruments are located in one enclosure, in multiple adjacent enclosures, or spread in remote enclosures. All instrumentation and enclosure grounds, and the transformer ground, terminate at one ground reference for the area. Additionally, each power and ground path is typically limited to 200 cable-feet.

By using a separate isolation transformer, an isolated common ground reference for each area, and cable length limitations, each local area is electrically isolated from other areas. Therefore, ground loops between areas are eliminated, electrical noise is minimized, and common reference voltage is maintained.

Using Figure 4-2 as an example, there is one isolation transformer for the area. All control system instruments powered by the transformer are grounded to the same common ground reference through the local ground reference in each enclosure. The isolation transformer is connected to the same control system ground (CSG) as the common ground reference. The AC Ground is 200 cable-feet and the path from any isolated local ground reference to the CSG is 200 cable-feet.

The same isolated local ground reference can be used as follows:

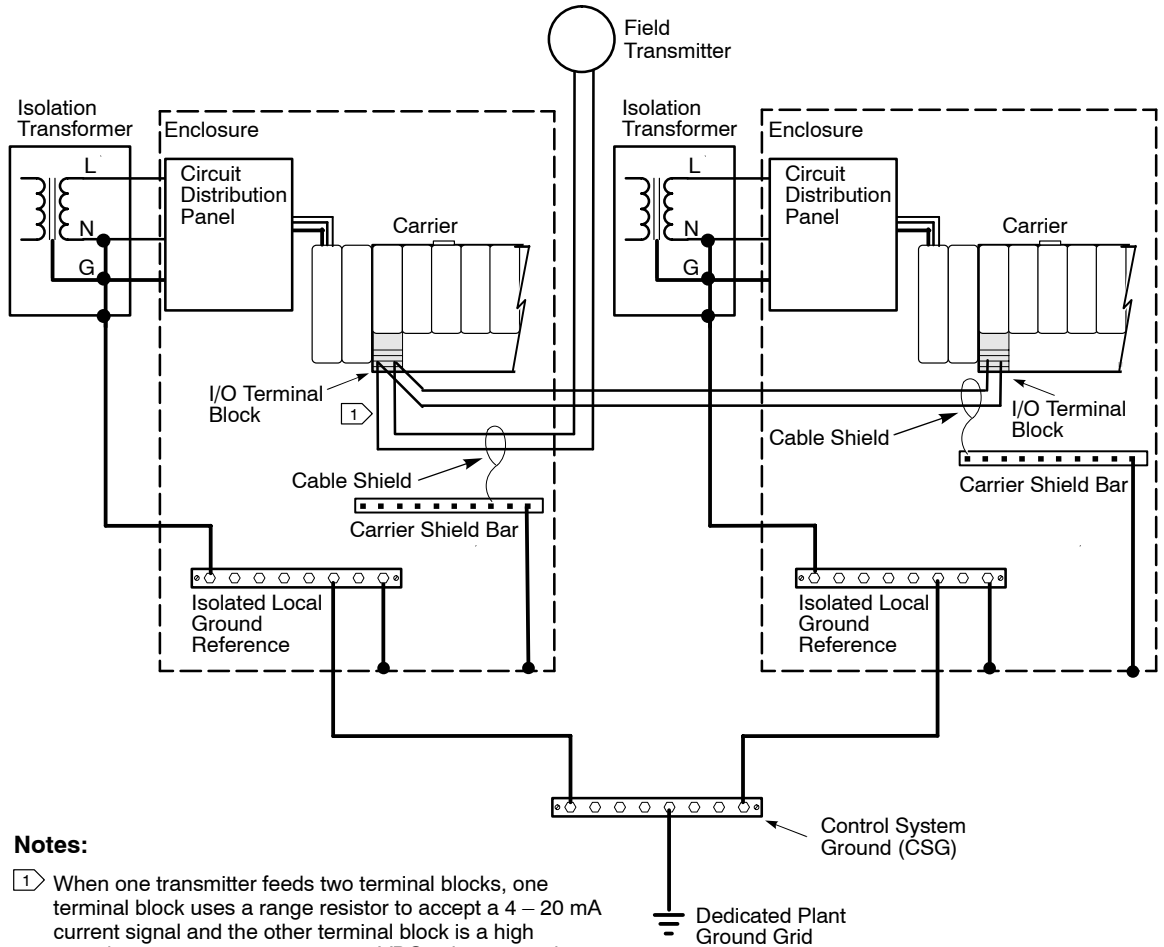
- Enclosures are located in the same local area.
- Enclosures are bolted together to form one continuous unit.
- Separate enclosures share the same single-ended signal. This case occurs if one field transmitter is connected to two points in separate enclosures (Figure 4-3) or an output from a device is used as an input for a device in another enclosure (Figure 4-4).
- Enclosures are located in separate buildings or at distant from one another, but the AC power to the enclosures is taken from the same power source where transformer isolation is not used at both locations (Figure 4-5).



**Notes:**

- 1 Applicable for 200 cable-feet or less, other branch distribution panels located in the same room, and having a common isolation transformer (same AC source)
- 2 If space and distance permit, the Isolated Common Ground Reference bar and the Common System Ground may be the same bar.

**Figure 4-2 Typical, Single-Point Ground Network for Control System Housed in Multiple Enclosures**

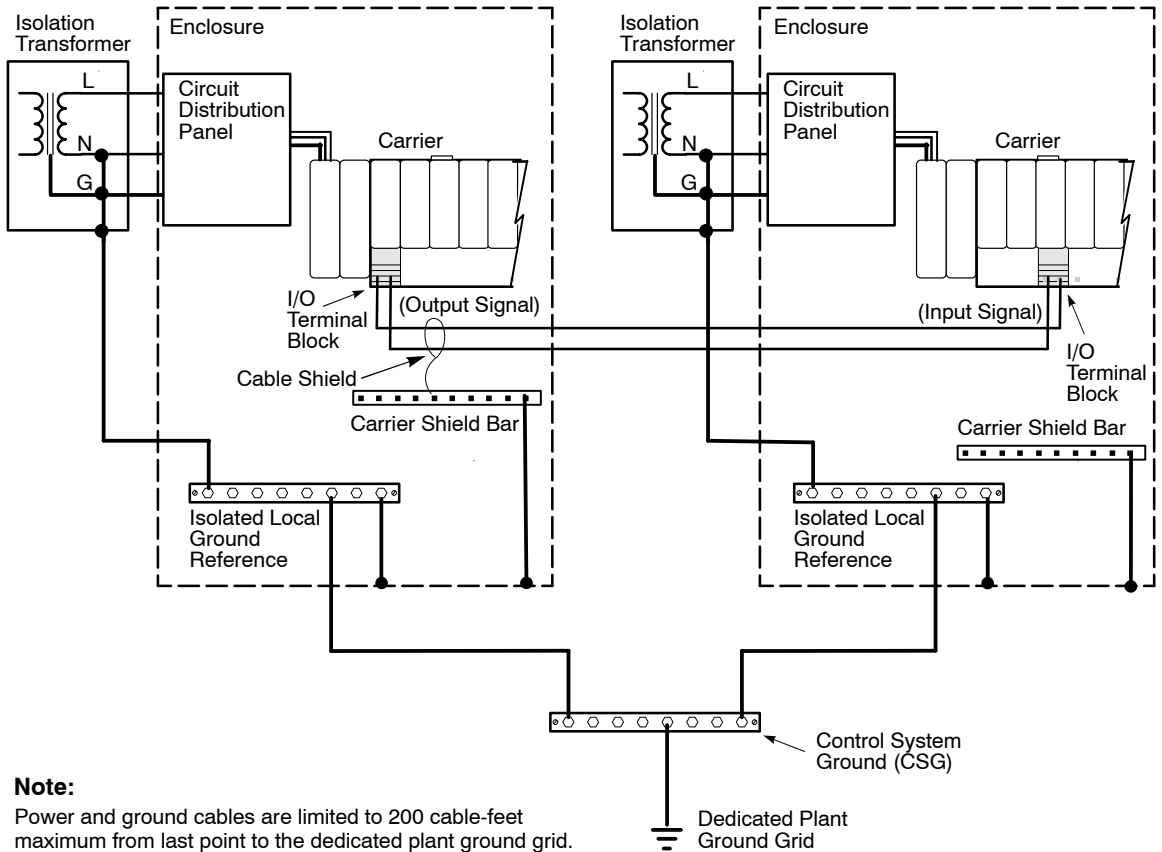


**Notes:**

- ① When one transmitter feeds two terminal blocks, one terminal block uses a range resistor to accept a 4 – 20 mA current signal and the other terminal block is a high impedance input to accept a 1 – 5 VDC voltage signal.

Power and ground cables are limited to 200 cable-feet maximum from last point to the dedicated plant ground grid.

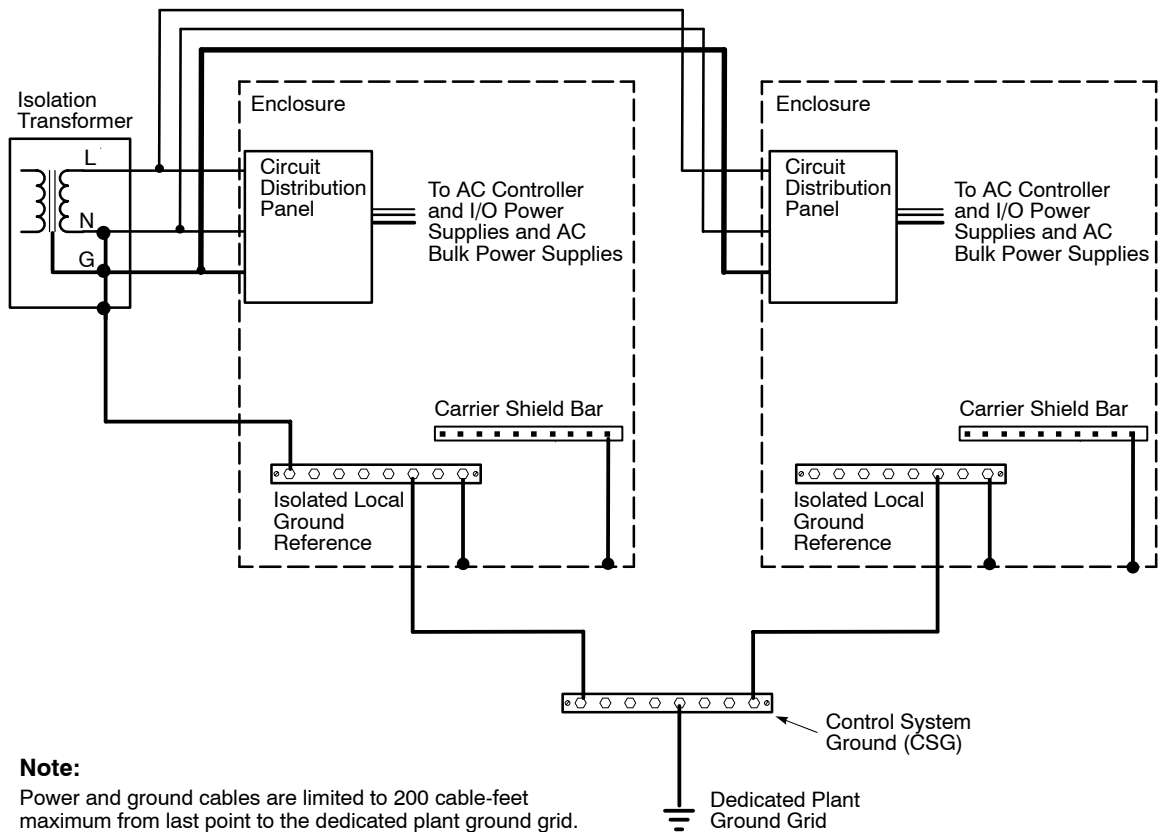
**Figure 4-3 Single-Point Ground When One Field Transmitter Connects to Two Points in Separate Enclosures**



**Figure 4-4 Single-Point Ground When Output From a Device in an Enclosure is Used as an Input to a Device in Another Enclosure in a Single-Ended Mode**

Devices connected **only** by a control system communication network (e.g., Ethernet) normally do not require connection to the same ground system because the network usually provides isolation between devices. Systems isolated in this manner may have separate power sources.





**Figure 4-5 Single-Point Ground When Distant Enclosures are Powered from a Single Isolation Transformer**

## Enclosure Ground Considerations

An enclosure ground provides protection to equipment by minimizing effects from electromagnetic interference (EMI) and ground loops and to personnel by minimizing accidental shock hazards. Enclosures may be isolated from building steel and grounded by cable to the local ground reference point, or they may be grounded to building steel if it provides a low impedance path to true earth ground.

If enclosures are grounded to building steel, an isolation transformer that is closely located to the enclosures (preferably mounted on them) should be used. By using a transformer, possible ground loops between the transformer AC ground and the enclosure ground has a negligible effect on the control system. By keeping power and ground cables to within 200 cable-feet, EMI noise coupling is normally kept within adequate levels for proper system operation.

An enclosure ground must remain separate from all other DC ground connections. Figure 4-6 shows enclosure and DC grounds that retain the proper separation. In a group of enclosures, grounds are routed to the center enclosure.

## Effective Grounding

The following guidelines help you provide effective grounding for your control system:

- Provide a ground network dedicated to the control system. Do not share a ground network with other plant systems.
- Design the ground network so that it is accessible for testing.
- Ground enclosures through the single-point ground network.
- Connect all enclosures within a group to the same ground point.
- Provide a single-point ground for all enclosures interconnected by non-isolated signals. Also, provide a single-point ground for all enclosures sharing a backup power supply.
- Ground workstations by the ground conductor that is included in their AC power circuits.
- Provide a low impedance, high integrity, ground path between all instrumentation and control system plant ground connections.
- Keep ground wiring as short as possible.

Explanations of the guidelines are included in following subsections.

## Using Existing Ground Systems

With the installation of a new control system, an effective ground network can be installed at the beginning. However, the expansion of an older system often uses existing ground networks. If the existing network does not meet the criteria of a single-point ground scheme, it may be more cost effective to install a new ground network to ensure proper control system operation. In all cases, care must be taken so that ground loops are not created through signal connections or metal chassis connections.

## Separating AC and DC Grounds

Separate ground networks are used for AC power and DC power to provide a safety return path to earth to protect from faults occurring in the control system and to isolate noise between AC and DC circuits. Figure 4-6 shows the separate ground networks. Both networks terminate at a single point on the control system ground (CSG).

Figure 4-6 shows a primary and secondary source with isolation transformer. If the desired level of system availability permits, you may use a single source. If you use two sources, both sources must use a separate AC ground connection to the control system ground, as shown.

### AC Ground Network

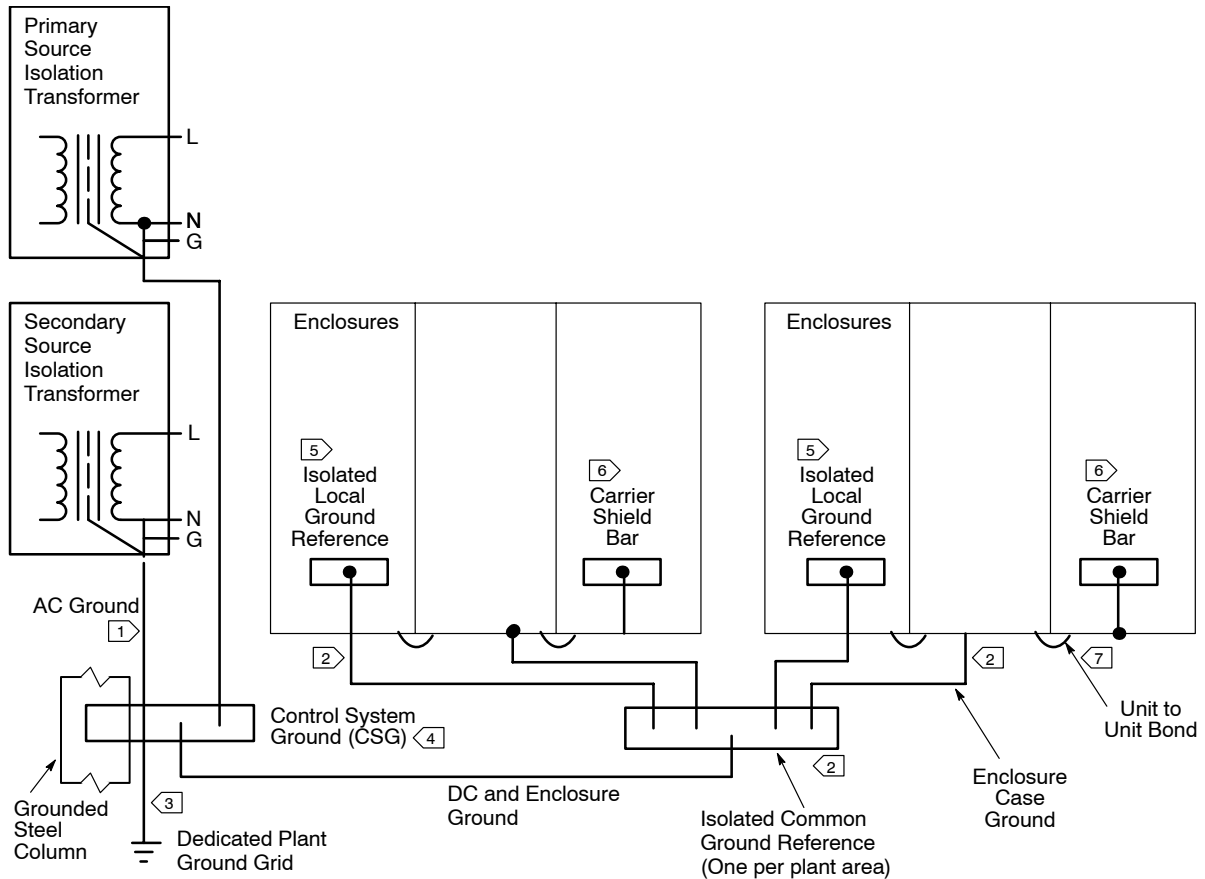
The single-point termination shown in Figure 4-6 provides the AC ground for AC powered devices in the control system. The transformer shield and case as well as the AC neutral and ground are connected to AC ground. The AC ground must conform to all applicable local, state, and federal electrical code requirements.

### DC Ground Network

Figure 4-6 also shows the DC ground network for DC power and I/O signals in the control system. The DC ground serves as the final termination point for all signal common and power supply common wiring. The power supply common is the power return for all DC power connections in the system. Note that the I/O cable shield grounds are connected to the enclosure frame, from which the shield grounds are connected with the enclosure case ground to the common ground reference for the plant area.

### Special Cases

In special cases, such as on oil and gas platforms, floating 24 VDC power may be used to power the control system. To obtain proper electrical ground for the system, a single-point of ground on the platform is needed for controller power supplies, enclosure mounted power supplies, signal commons, shield grounds, case grounds, and so forth. This need means that some type of isolating device, such as an inverter-rectifier, must be used with the isolated 24 VDC power to maintain its floating design.

**Notes:**

- 1 Stranded, insulated AWG 1/0 to 4/0 cable — Conductor used to connect the grounding electrode to the neutral ground bond at the source of a separately derived instrumentation power system [per NEC 250-30(a)(2)] (CSA C22.1 Section 10)
- 2 Stranded, insulated AWG 1/0 to 4/0 cable — Conductors used to provide a low impedance ground reference for the DC power system (Logic, Transmitter, Output) and enclosure ground for EMI/RFI noise protection of the enclosures, carriers, and field wiring shields
- 3 Supplemental conductor used to connect the grounding electrode for the source of a separately derived instrumentation power system directly to the plant ground grid system. This conductor is used to provide low impedance ground reference to EMI/RFI noise [per NEC 250-54-Supplemental Grounding Electrode 250-50(a)(2)].
- 4 The DIG must be effectively bonded to building steel [NEC 250-50(b)], and building steel must be properly grounded to earth ground. Refer to Chapter 7 for earth ground information.
- 5 Isolated local ground reference is used when several devices in the enclosure grouping require ground reference. Use stranded, insulated AWG 1/0 to 4/0 cable between isolated local ground reference and isolated common ground reference.
- 6 Use stranded, insulated AWG 1/0 to 4/0 cable between carrier shield bar and enclosure frame.
- 7 Be sure to strap (not bolt) all grouped enclosures. Half-inch (12 mm) wide, braided, ground strap can be used up to six inches (15 cm). For longer bonding, use insulated 10 AWG wire. Refer to NEC Table 250-122 and Article 250-119.

**Figure 4-6 Details of AC and DC Ground System for Transformer-Isolated Area with Multiple Cabinets with All Grounds Tied to a Single Point**

## Ground Wiring

Proper connections, wire sizing, and overall ground impedance are important to effective grounding.

### Local and Isolated Common Reference Points

An organized ground system includes reference points that are local to an enclosure (or groups of enclosures) and also an isolated common reference point for the plant area. A local reference point provides a central termination point for all power supply common connections within an enclosure. The isolated common reference point ties together the local reference points.

#### **Note ...**

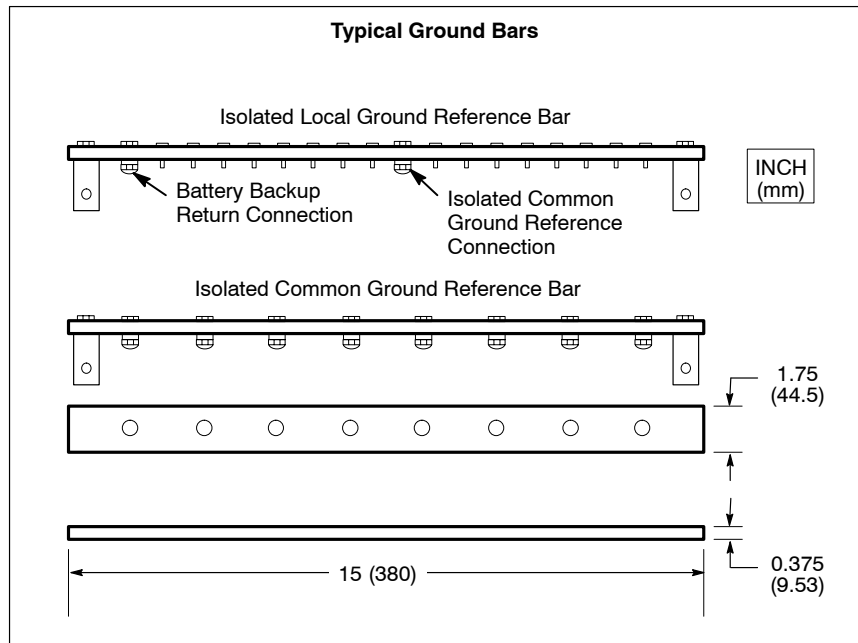
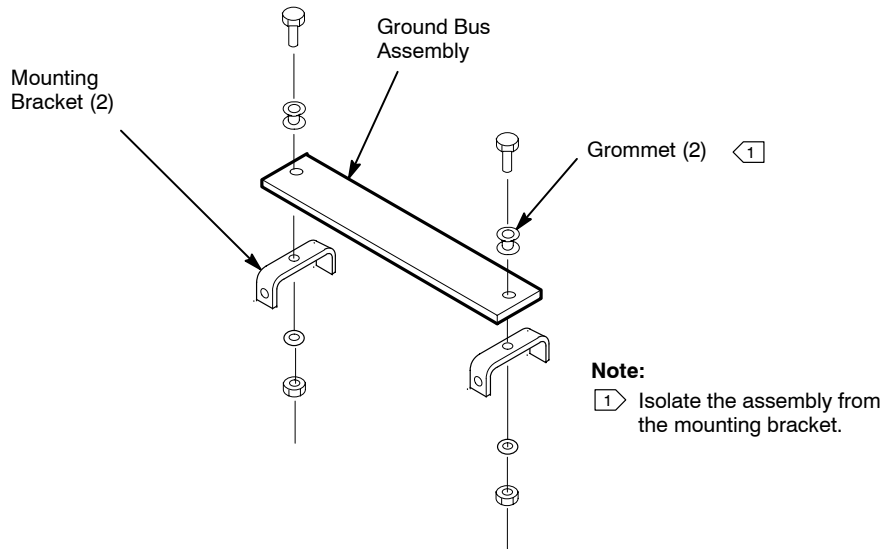
*Some figures in this manual show DC Return Reference Grounds connected directly to an isolated common ground reference. This scheme is applicable when there are only a few reference ground returns. Where many reference grounds exist, as in the case of grouped enclosures, use an isolated local ground reference in each group and connect these to the isolated common ground reference for the area.*

Good reference points should be highly conductive, copper, copper-clad, or brass bars. Such bars are available from local industrial electronics suppliers, or you can fabricate your own ground bars. The bars mount on isolated brackets inside an enclosure. Bars normally allow screw connections for wiring lugs. Use lugs that accept wire sizes of AWG 1/0 to 4/0 (53.5 to 107.2 mm<sup>2</sup>).

Figure 4-7 shows the details of a typical ground bar. Table C-2 lists recommended wire sizes based on cable length. If you fabricate your own ground bars, ensure that the following conditions are met:

- Copper/copper clad steel or hard brass (B16)
- Minimum of 3/8 inch (9.5 mm) thick and 1-3/4 (44.5 mm) inch wide
- Holes for lugs
- Double-bolted lugs
- Bus isolated from mounting bracket with standoffs

**Isolated Mounting for Ground Bars**



**Figure 4-7 Typical Reference Point Ground Bars**

## DC Return Ground Wiring

Ensure that DC return grounds are on separate wires from each power supply to the enclosure local ground reference point. The DC return ground connection at the power supply is the negative (–) DC terminal. Where bulk power supplies feed a DC-to-DC controller and I/O power supply, the DC return is placed between the carrier ground terminal and ground reference.

The recommended wiring for these ground points is AWG 8 (8.4 mm<sup>2</sup>) copper, stranded, insulated with the lengths being as short as possible. The return ground wiring should be insulated to avoid unintentional ground loops that can occur if bare wires touch the metal enclosure frame, or each other. Proper isolation from metal should be verified by electrical measurement after installation.

## Marking Grounds

To aid in ground identification, identifiable insulation colors (green or green with a yellow stripe) or some labeling method should be used that meets U.L.-listed connections. All system ground points should be labeled as follows:

<p>FOR CONTROL SYSTEM GROUND ONLY. DO NOT USE FOR ELECTRIC ARC WELDER CONNECTION OR OTHER ELECTRICAL OR ELECTRONIC CIRCUITS.</p>
------------------------------------------------------------------------------------------------------------------------------------------

## Ground Impedance

A high quality control system ground should provide a ground point that measures one ohm or less to true earth. In some cases, three ohms may be acceptable. In an area where soil does not provide a good ground, it may be necessary to select the best ground impedance available.

There are several methods that can be used to obtain a high quality earth ground system; these methods vary, depending on the soil type and moisture content at the individual location. Refer to Chapter 7 for information about soils and earth grounds. Testing an earth ground per the procedure described in Chapter 7 is highly recommended.

## Shield Grounds

Proper field-wiring shield grounds help ensure proper system operation by reducing electromagnetic interference in signal wiring. A proper shield ground path is to ground the shield at one end only. Grounding at both ends can cause ground loops. The preferred end is at the carrier shield bar. If field transmitters or final control elements are well-grounded four-wire units, shield wires can be grounded to the units instead of the carrier shield bar.

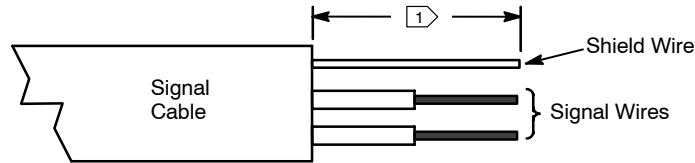
**Note ...**

*The carrier shield bar is connected to the enclosure frame unless the control system occupies only one enclosure, in which case, the shield bar may be connected directly to the isolated common ground reference.*

The recommended wiring between the shield bar and its ground termination on the enclosure frame, or the isolated common ground reference, is AWG 8 (8.3 mm<sup>2</sup>), copper, stranded with length as short as possible. The wiring should be insulated to avoid unintentional ground loops that can occur if bare wires touch the metal enclosure frame, or each other. Proper isolation from metal should be verified by electrical measurement after installation.

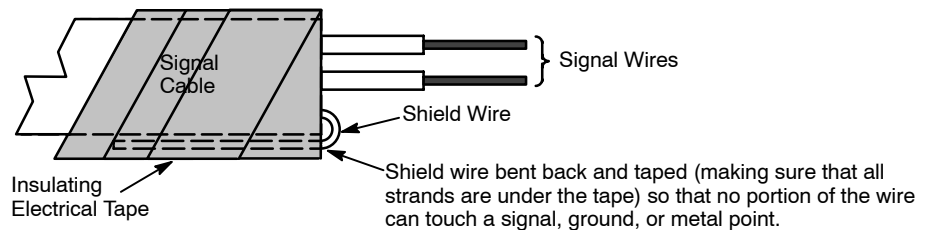
To obtain the intended electromagnetic interference (EMI) protection, it is important that the insulation on shield wiring be properly stripped at the ground end and that it is properly wrapped at the ungrounded end. Figure 4-8 illustrates proper insulation stripping and wrapping.





- ① Preferred length of non-insulated portion of shield wire is 1 inch (25 mm); 2 inch (50 mm) may be used if needed to reach terminations on the carrier shield bar.

#### Stripped Insulation Length on Grounded End of Shield Wire



#### Wrapped Insulation on Non-Grounded End of Shield Wire

**Figure 4-8 Proper Length for Stripped Shield Ground Wire and Proper Wrapping**

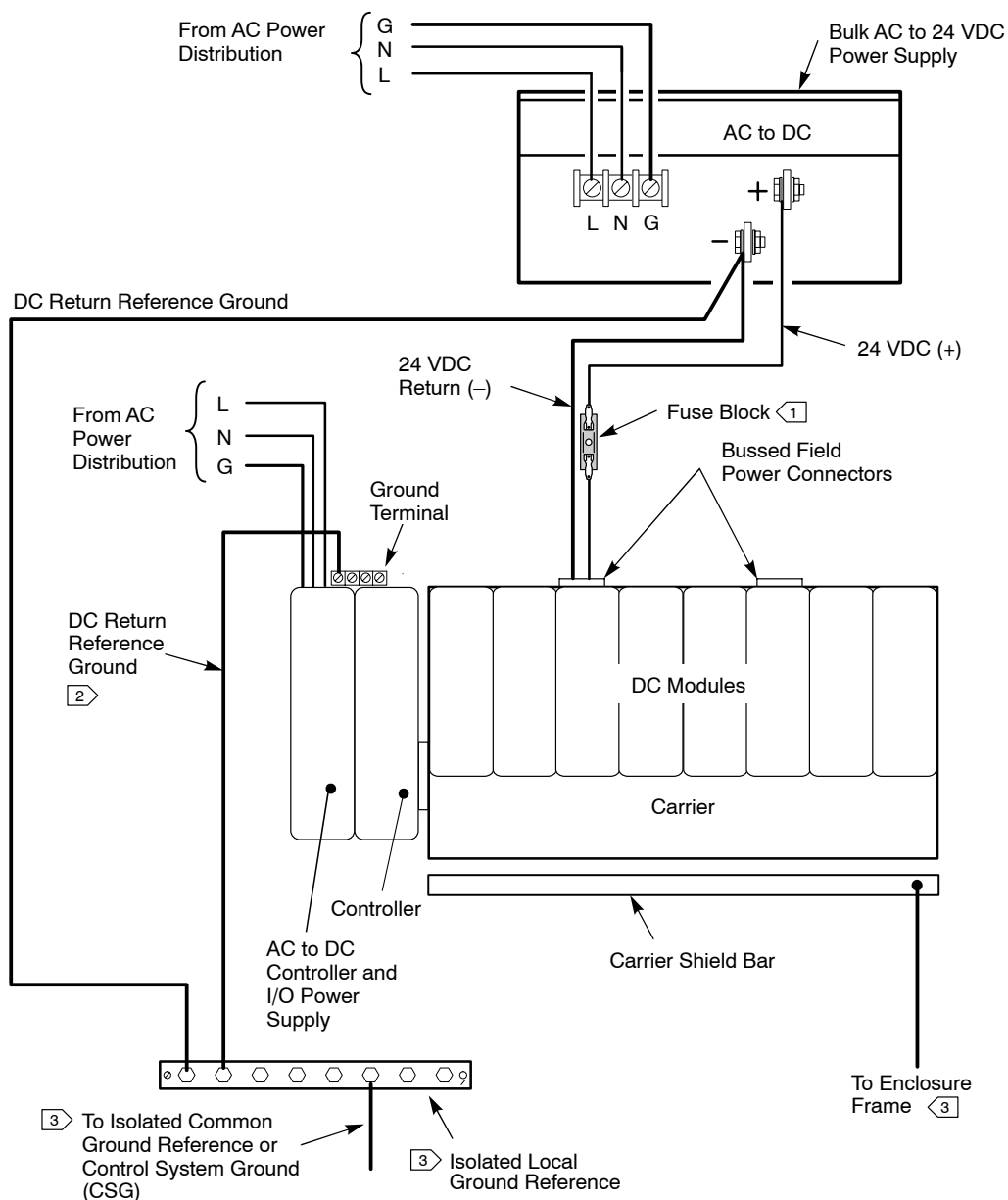
## Workstations and Peripheral Devices

Workstations and peripheral devices, such as network hubs, switches, and printers are grounded to the control system AC ground through the neutral wire and the safety ground wire in the AC power cord. The conduit carrying the AC power conductors to the workstations and peripheral devices must be electrically isolated from the workstations, but it must be bonded at the power supply. The best way to isolate the conduit is to install an isolated AC ground receptacle (NEMA Type 5-15R) near the equipment and run the conduit to the receptacle [per NEC 250-146(d)].

The AC ground wire in the AC conductors should be the same size or one size larger than the current-carrying conductors. For example, the line and neutral lines should be AWG 12 (3.3 mm<sup>2</sup>), copper, stranded wire, and the AC ground should be AWG 10 (5.3 mm<sup>2</sup>), copper, stranded wire. For best noise control, use AC ground wire made of a large number of small strands rather than coarse, stranded wire.

## AC/DC Controller and I/O Power Supply

Figure 4-9 shows how ground connections should be made with a control system which uses an AC to DC controller and I/O power supply.

**Notes:**

- 1 A fuse block and fuse is optional. If you are providing bussed-field power to several carriers from one power supply, it is recommended that you fuse the line to each carrier.
- 2 When AC-DC controller and I/O power supplies are used, a DC Return Reference Ground should always be connected at the carrier ground terminal.
- 3 Refer to Figure 4-1 and Figure 4-2 for ground connection details.

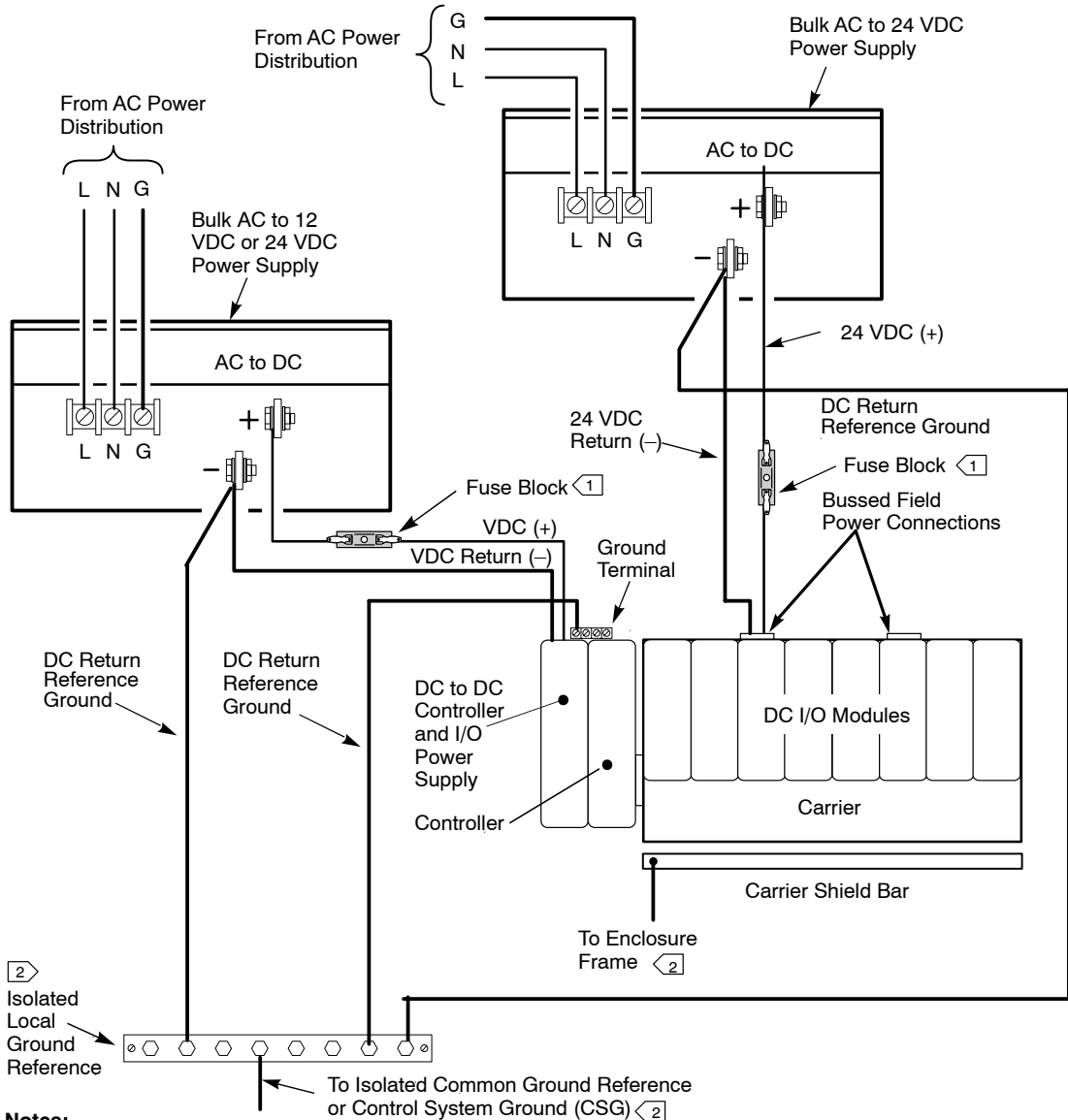
**Legend:**

L Line  
N Neutral  
G Ground

**Figure 4-9 Ground Connections for AC to DC Controller and I/O Power Supply**

## DC/DC Controller and I/O Power Supplies

A DC/DC passthrough controller and I/O power supply accepts 12 VDC input, and a DC/DC dual controller and I/O power supply accepts either 12 VDC or 24 VDC input. Figure 4-10 shows ground connections for either of these supplies.



**Notes:**

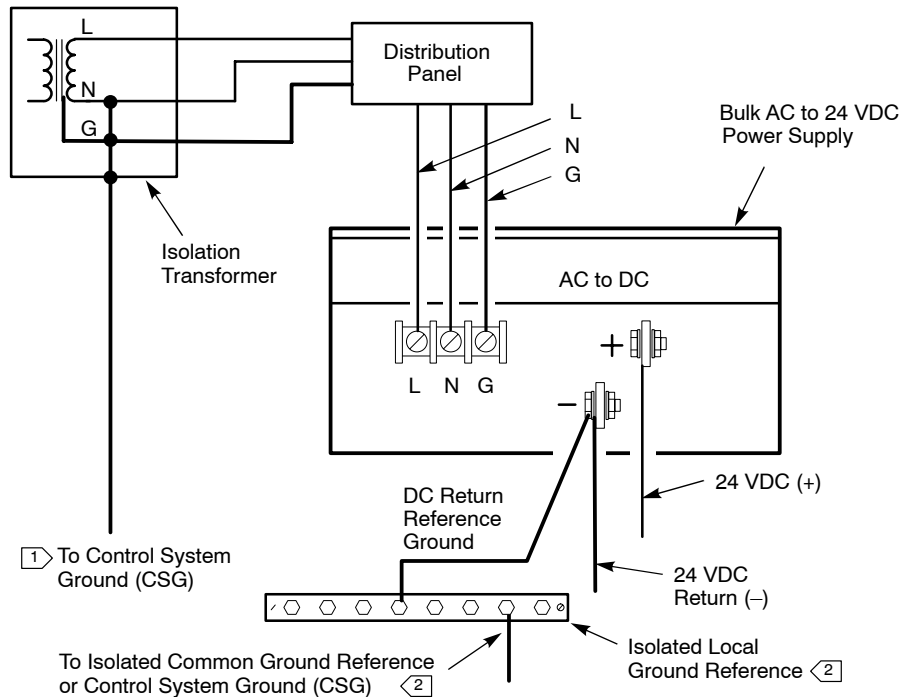
- ① A fuse block and fuse is optional. If you are providing bussed-field power to several carriers from one power supply, it is recommended that you fuse the line to each carrier.
- ② Refer to Figure 4-1 and Figure 4-2 for ground connection details.

**Legend:**  
 L Line  
 N Neutral  
 G Ground

**Figure 4-10 Ground Connections for DC/DC Controller and I/O Power Supplies**

## Bulk Power Supplies

When using a bulk power supply, it is recommended that an isolated ground be used for DC reference. Figure 4-11 shows the recommended connections for all bulk power supplies. For ground connections when several bulk supplies are grouped in an enclosure, refer to Figure 2-9.



### Notes:

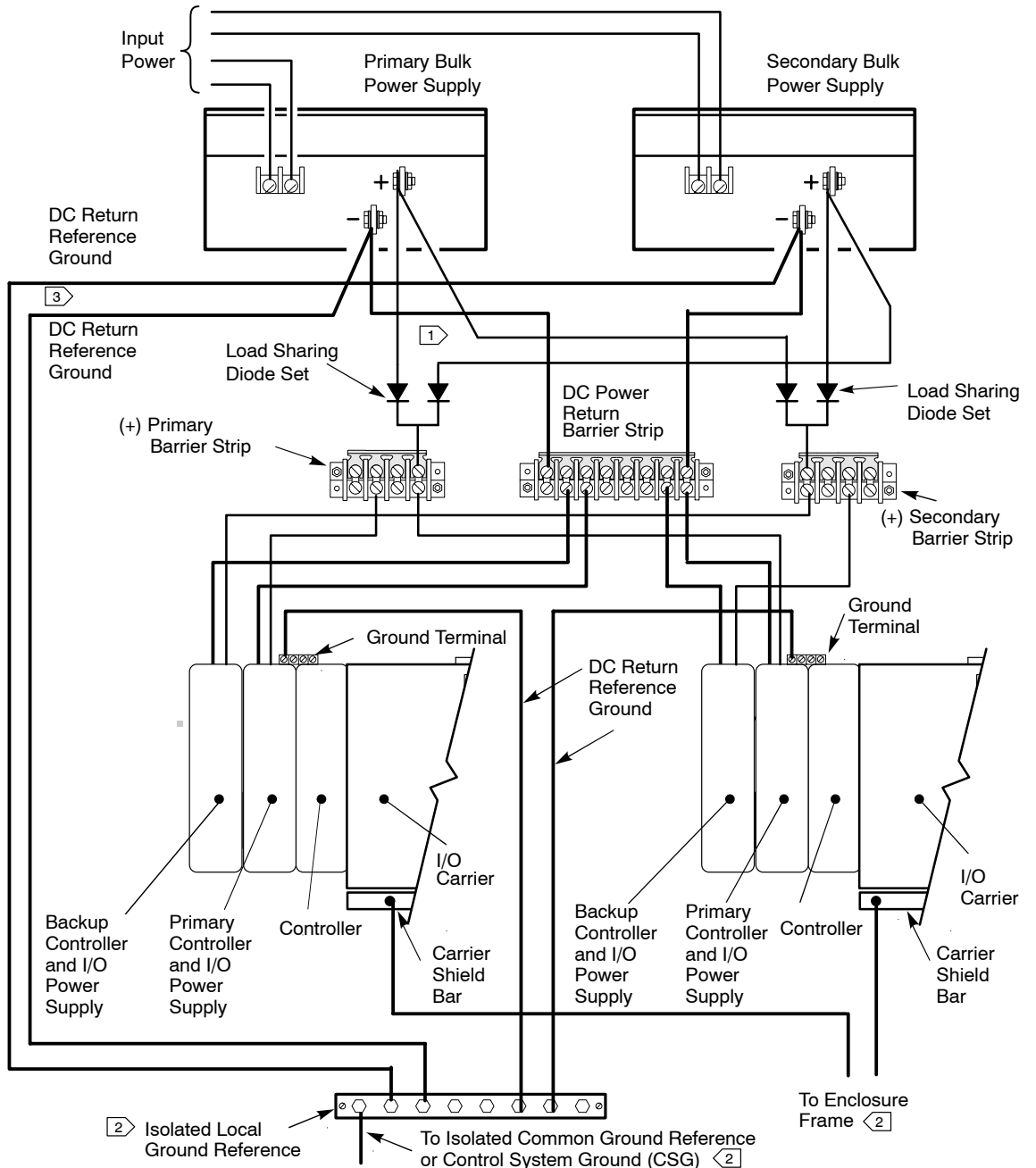
- ① If the power supply is not located in an enclosure, the DC Return Reference Ground may be connected directly to the Control System Ground.
- ② Refer to Figure 4-1 and Figure 4-2 for ground connection details.

**Legend:**  
 L Line  
 N Neutral  
 G Ground

**Figure 4-11 Power and Ground Connections for a Bulk AC to 12 VDC or 24 VDC Power Supply**

## Redundant Power Connections

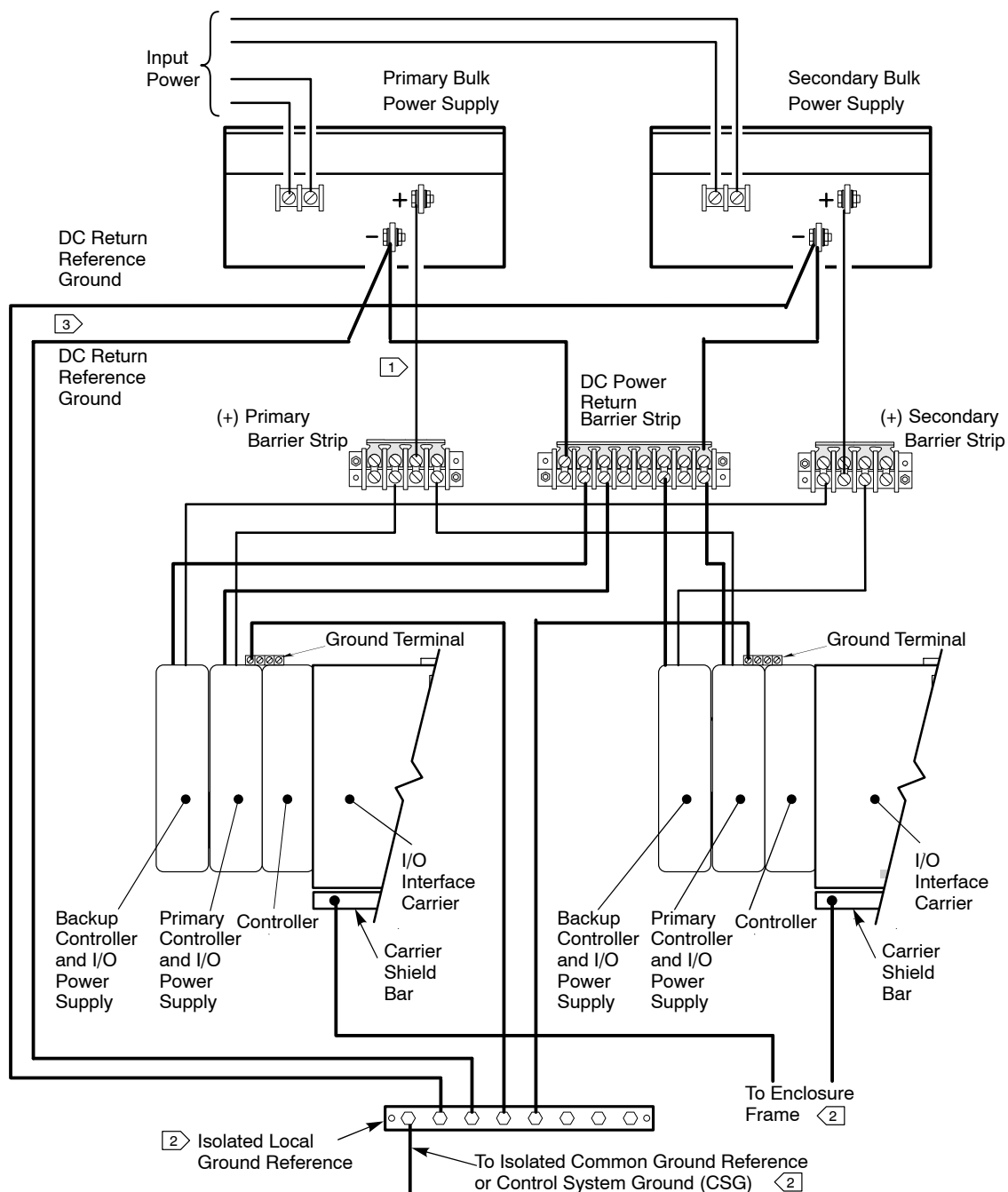
Figure 4-12 (load-sharing bulk supplies) and Figure 4-13 (non-load-sharing bulk supplies) show power and ground connections when primary and backup power supplies are used. Barrier strips include shorting bars across the top set of terminals. One barrier strip is used for each source and another barrier strip is used to consolidate ground wiring before making a ground connection to the isolated common ground reference.



**Notes:**

- 1 Size power and ground wiring large enough to carry the total current drawn from all loads.
- 2 Refer to Figure 4-1 and Figure 4-2 for ground connection details.
- 3 DC Return Reference Grounds should be as short as possible and as close to each other as possible.

**Figure 4-12 Power and Ground Connections for Primary and Backup Controller and I/O Power Supplies with Load-Sharing Bulk Power Supplies**

**Notes:**

- 1 Size power and ground wiring large enough to carry the total current drawn from all loads.
- 2 Refer to Figure 4-1 and Figure 4-2 for ground connection details.
- 3 DC Return Reference Grounds should be as short as possible and as close to each other as possible.

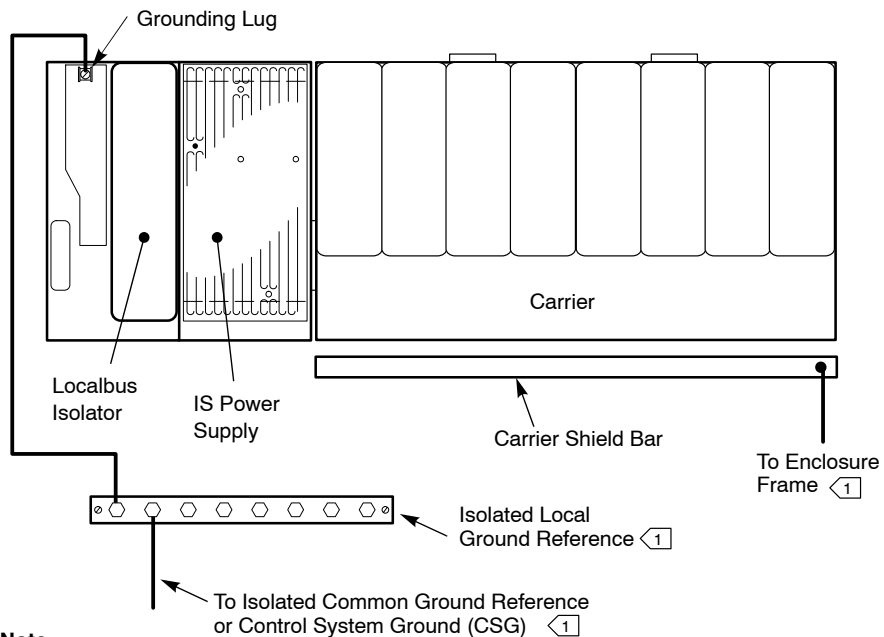
**Figure 4-13 Power and Ground Connections for Primary and Backup Controller and I/O Power Supplies with Non-Load-Sharing Bulk Power Supplies**

## Intrinsic Safety Installation Grounding

In some applications where hazardous gases are present, special wiring practices or other special handling must be used. Conformity with local codes and regulations is essential. Several industry documents are available that describe the requirements for hazardous area instrumentation use or code guidelines.

Figure 4-14 shows typical grounding requirements for a control system using an intrinsically safe (IS) I/O system. The shield bar is connected to the enclosure frame. The carrier is connected to either an isolated local reference point or the isolated common reference point (shown). These grounds provide the electrical ground required for the I/O cards and the IS power supply. Power leads to the supply are connected from a 24 VDC bulk power supply. The negative (–) output terminal is grounded at the bulk power supply output (as shown in Figure 4-11).

For complete I/O system grounding, refer to the intrinsic safety barrier manufacturer's manuals. For additional information, refer to the intrinsic safety information in ANSI/ISA-RP12.6-1995, *Wiring Practices for Hazardous (Classified) Locations — Instrumentation Part 1: Intrinsic Safety*, and in NEC Section 504 for grounding and installation practices. (Note that RP12.6 requires earth ground resistance to be one ohm or less).



**Note:**

① Refer to Figure 4-1 and Figure 4-2 for ground connection details.

**Figure 4-14 Typical Grounding Requirements for a Control System Using an Intrinsically Safe (IS) I/O System**

## Chapter 5 Signal Wiring

This chapter describes methods to minimize electrical interference in signal and ground wiring and properly install and terminate signal wiring.

### Signal Wiring Practices

The following recommendations can help you install reliable signal wiring:

- Field termination connectors on I/O subsystems generally accept up to AWG 12 (3 mm<sup>2</sup>) stranded or solid wire. Wire sizes between AWG 14 and AWG 18 (2 mm<sup>2</sup> and 0.8 mm<sup>2</sup>) are typically used. AWG 18 is recommended. To select wire, determine the maximum current expected or the maximum voltage drop permissible, and the wire length. Then, use local wiring codes to determine the appropriate wire size.
- To terminate field wiring cable shields, it is recommended that shield bars be used with I/O carriers.
- Multi-pair cables should contain at least one spare set twisted-pair wires. It is recommended that each cable contain at least 20 percent spares.
- For a digital I/O system (for example, FOUNDATION Fieldbus, DeviceNet, Profibus, AS-Interface), use only cables specified by the system.
- On external terminal blocks, leave a test point for connecting test equipment. Leaving a little extra exposed wire at a terminal or using terminal lugs are ways to provide test points.
- Use ring tongue or flanged spade tongue connectors on terminal blocks to hold wires in place.
- Avoid stray strands at stripped-back multi-strand wire that can short signals to other terminals.
- Inspect all solder joints for proper solder connections.
- Inspect wires at terminals to ensure that wire insulation is stripped back cleanly and that no insulation is under a wire connection at a terminal block or terminal strip.
- Ensure that cables are run so that sharp metal edges cannot cut through cable insulation.



- Shield ends that are not grounded should be tape-wrapped so there is no possibility that a shield can touch any wires or metal objects. Heat-shrink tubing may also be used to isolate the shield from wires or metal objects.

## Electromagnetic Interference (EMI) Reduction

Electromagnetic interference (EMI), sometimes called radio frequency interference (RFI), can be caused by such devices as radios, intercoms, AC power lines, motors, and high capacity switches. Most modern control system products are fully compliant with electromagnetic standards for European Union countries. The equipment is shielded to reduce EMI to acceptable levels in normal operating conditions.

To minimize EMI introduced by sources external to your control system, you should take the following precautions:

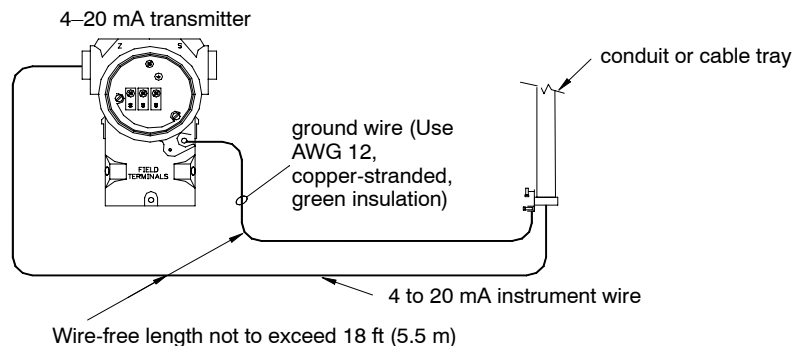
- Use fiber-optic cable as much as possible in network communications systems, especially between buildings. Fiber-optic cable provides optimum protection from EMI and nearby lightning strikes.
- Route network cables as far away from EMI sources (large motors, generators, transformers, and so on) as practical.
- To minimize electrically induced noise on millivolt signals from thermocouples, resistance temperature detectors (RTDs), strain gauges, and pH electrodes, use individually shielded, twisted-pair cables specified for these devices.
- Use multiple-pair, shielded, twisted-pair cables for 4–20 mA and 1–5 V field signals.
- Because pulse count signals contain fast rise-time components that make them both noisy and susceptible to external noise, route them in individually shielded, twisted-pair cables.
- Run a digital control network through grounded conduit to add mechanical protection and electrical noise attenuation. For best attenuation with copper cable, use shielded Category 5 twisted-pair cable. For maximum protection in high EMC noise areas, use fiber-optic cable. Avoid cable splices in conduit. If splices are necessary, ensure that the connector is completely insulated from the conduit.
- Electrostatic coupling usually occurs when long signal cable runs are very close together. It is especially severe when wires that carry different types of signals and have different energy levels run closely together. Shield these

wires from one another with metal conduit, covered tray, metal trough, or shielded cable. An overlapping, multiple-folded, foil-shielded cable with a continuous drain wire in contact with the shield is recommended.

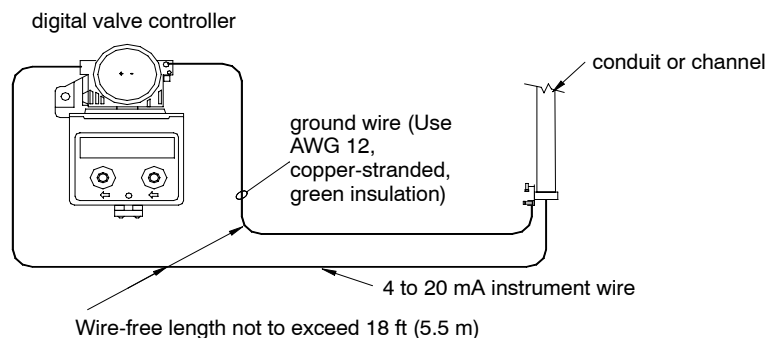
- Individually connect carrier shield bars to isolated ground references.
- Terminate unused conductors and shields to ground on one end only.

**Note ...** *To avoid ground loops, ensure that all shield wires are connected to ground at one end only. It is recommended that measurements be made and documented to ensure single-ended grounding.*

- Always ground field device cases. Field devices can be grounded to metal conduits, pipes, cable trays, and so forth, if these items are electrically grounded. (Refer to Figure 5-1 and Figure 5-2 for examples.) Use case-ground studs with star washers to cut through protective coatings.



**Figure 5-1 Instrument Ground Bond Connections for 4–20 mA Transmitters**



**Figure 5-2 Instrument Ground Bond Connections for Digital Valve Controller**

## Protection from AC Power Line Noise

Inductive coupling interference can occur when signal wiring leads are routed close to power lines or other high current leads. It also can occur when other equipment is not sufficiently separated from power lines, transformers, rotating equipment, or other high power machinery.

Long runs of adjacent cables have a greater potential for noise coupling than short ones. Therefore, the longer the adjacent run, the greater the amount of spacing and shielding required. Redundant shielding can be used to provide noise protection in situations where the recommended distances cannot be met. However, these situations must be evaluated on a case-by-case basis.

In some cases, different cable constructions can provide added shielding. For example, the cable recommended in Appendix A for variable speed drive (VSD) applications provides excellent shielding for power cables (verified by testing). Instrument cables can be provided with a metallic outer armor, but adds cost.

- Table 5-1, based on IEEE 518-1982, *IEEE Guide for the Installation of Electrical Equipment to Minimize Noise Inputs to Controllers from External Sources*, provides the recommended minimum separation distances between twisted-pair signal cables and AC power lines.

**Table 5-1. Recommended Separation Distances**

Voltage	Current	Minimum Distance Between Signal Cable and AC Power Cable
0 to 125 volts	0 to 10 amps	12 inches (30 cm)
125 to 250 volts	1 to 50 amps	15 inches (38 cm)
250 to 440 volts	0 to 200 amps	18 inches (46 cm)
<b>Note:</b> Signal wiring and AC power cable separated by the recommended distances should not be run parallel for more than 20 ft (6 m). If longer parallel runs are needed, increase the separation distance by 12 in. (30 cm) for each additional 30 ft (10 m) in length.		

- Signal cable should be separated from devices that generate magnetic fields by a minimum of 5 ft (1.5 m). Ten to fifteen ft (3 to 4.5 m) of separation is recommended. Shielded, twisted-pair cable with approximately eight crossovers per ft (26 crossovers per meter) is five to six times more effective in reducing noise coupling than shielded cable alone.
- Separate cable trays should be used for signal cables and power cables. Where separate cable trays cannot be used, cable tray dividers must be installed. Dividers must be solid, fixed barriers, and minimum separation distances must be maintained. Signal wiring needs to be completely shielded when AC fields are present.

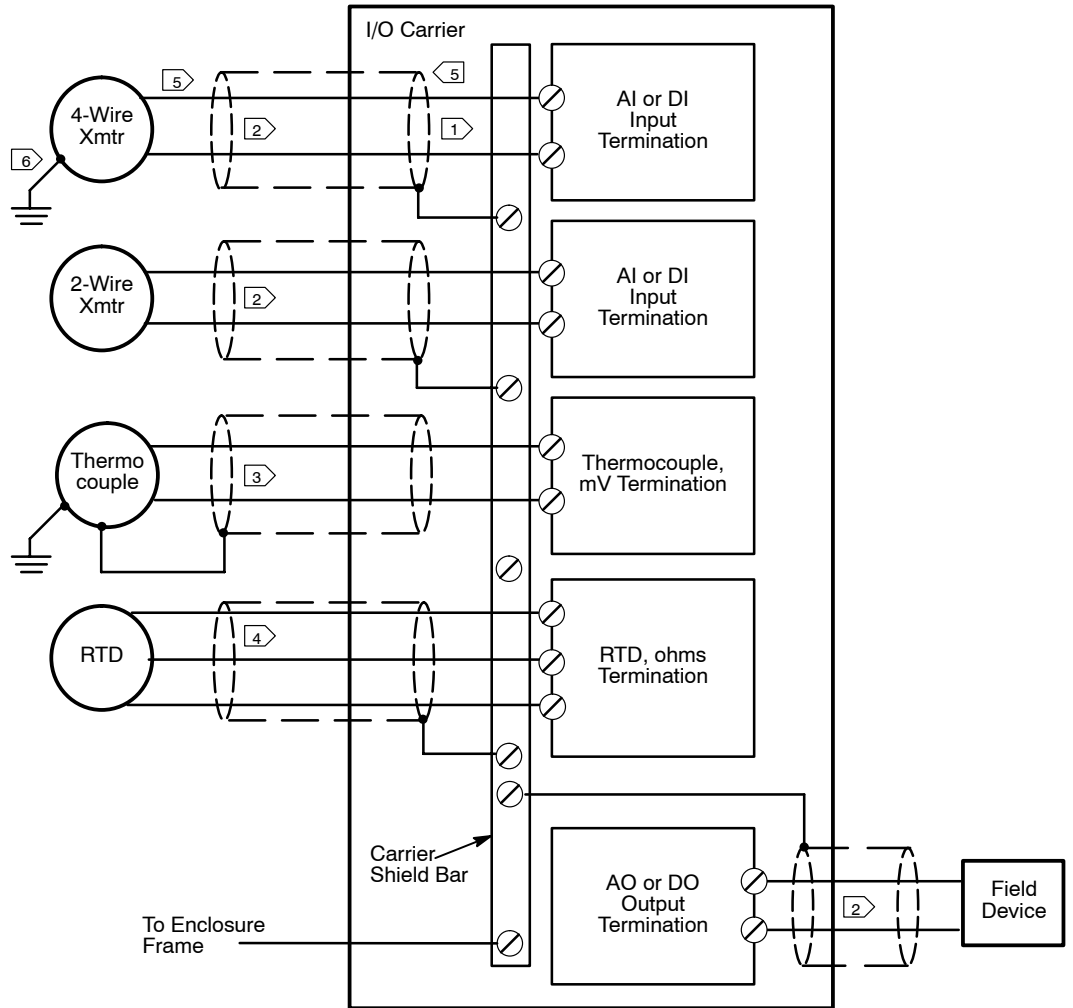
- Assuming the installation does not use intrinsic safe barriers, low-level signal lines should be continuous from signal source to receiver. The signal lines should not run parallel to high-current or high-voltage lines.
- If a magnetic field from AC power leads are a source of interference, the leads can be twisted to reduce field strength. When signal leads and power leads must cross, they should do so at right angles. Both signal wiring and power wiring should be twisted on both sides of the crossing for, at least, the recommended distances given in Table 5-1.
- Metal conduit is mainly used for physical support, and can add some magnetic field protection if the conduit is not carrying significant ground currents. Metallic conduit should not be buried beneath high-voltage power transmission lines or in known ground currents because it can become a conductor of induced voltages.
- Generally, aluminum conduit, cable trays, and enclosures provide better shielding at higher frequencies than steel. Steel provides better magnetic shielding at AC power frequencies.
- If signal cable is individually shielded (and grounded at one end per cable-shield guidelines), armored cable grounded at both ends may be used in place of conduit.

## Direct Cable Runs

Figure 5-3 illustrates typical wiring and ground connections for directly connecting signal wiring between field devices and an I/O carrier.

## Multi-Pair Cable Runs In Junction Boxes

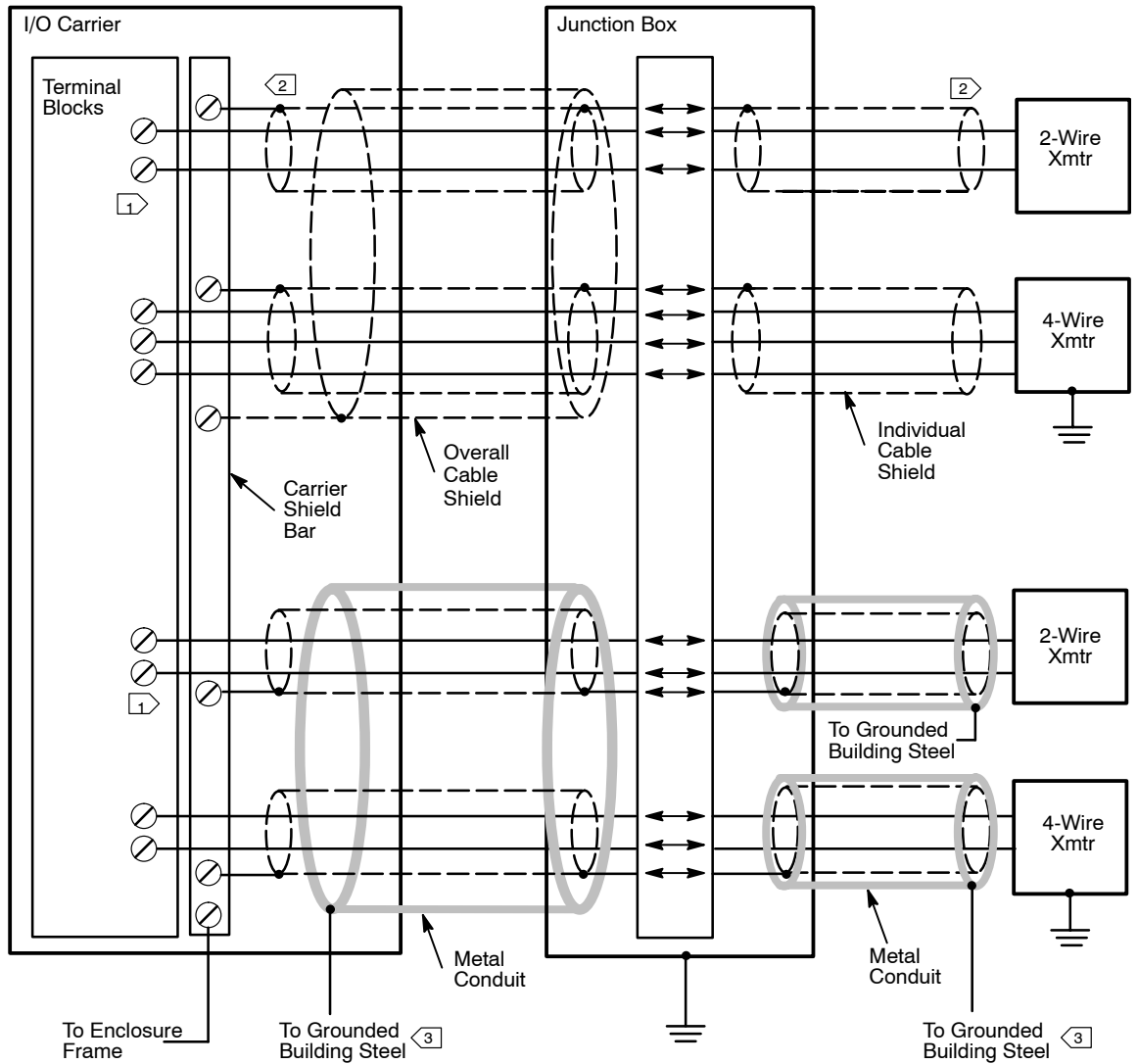
Figure 5-4 illustrates typical wiring and ground connections when junction boxes or marshalling panels are used. The figure shows both overall cable shields and metal conduit. Overall cable shields are used when multiple-pair cables are installed in cable trays. Conduit is used for support when cable trays or other physical support means are not available.



**Notes:**

- 1 Consult the manufacturer's installation manual for actual terminal connections.
- 2 Use 18 to 14 AWG (0.8 to 2.1 mm<sup>2</sup>) stranded, twisted-pair with overall shield, drain wire, and outer PVC jacket.
- 3 Use cable specified for thermocouple signals with overall shield and drain wire and outer PVC jacket. Shield for grounded thermocouple shown. If ungrounded thermocouple is used, install shield in same manner as for a two-wire transmitter.
- 4 Use triple-wire cable specified for RTD signals with overall shield and drain wire and outer PVC jacket.
- 5 Shields should extend to within 1 inch of terminations.
- 6 Normally, the signal is isolated from the case in four-wire transmitters. Therefore, grounding the case does not cause a ground loop situation.

**Figure 5-3 Typical Wiring and Ground Connections for Direct Cable Runs**



**Notes:**

- 1 Consult the manufacturer's installation manual for terminal connections.
- 2 Shields should extend to within 1 inch of terminations.
- 3 If the junction block is grounded, conduit can be grounded to the junction block instead of building steel.

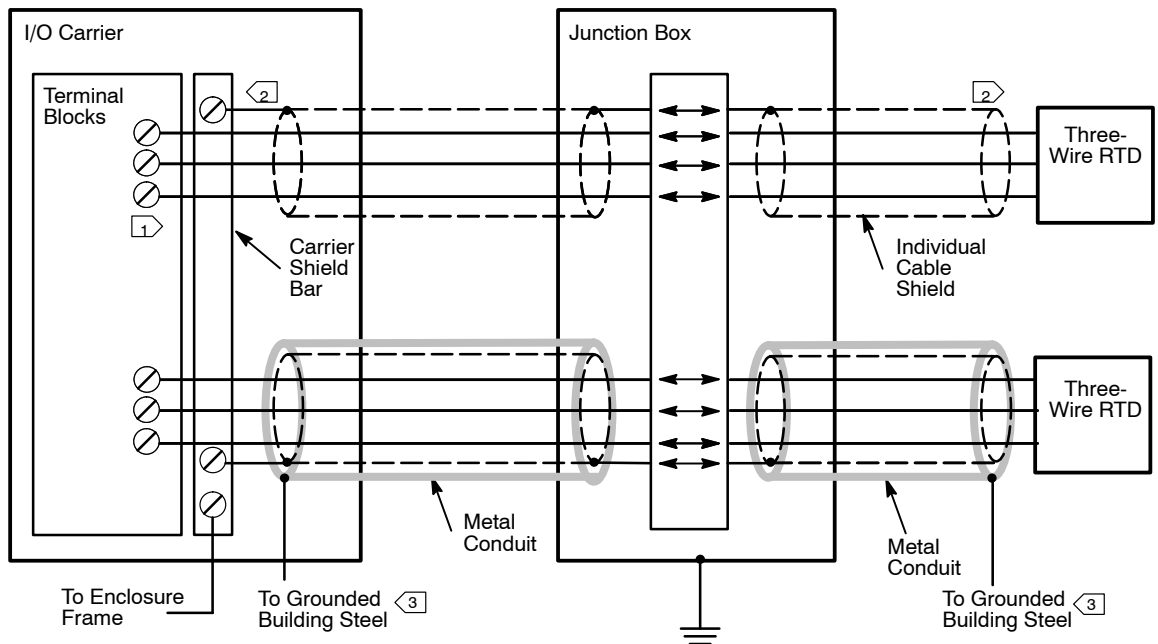
**Figure 5-4 Typical Wiring and Ground Connections for Multiple-Pair Cable Runs Using Junction Boxes or Marshalling Panels**

## Low-Level Signal Cable Runs in Junction Boxes

Figure 5-5, using a three-wire RTD as an example, shows typical connections for running low-level signal lines through junction boxes or marshalling panels. It is preferable to run low-level signal lines directly between field sensing devices and I/O terminal blocks, but the lines may be run through junction boxes and marshalling panels as long as the integrity of the shield is not broken.

Thermocouple cables may be run through junction boxes and marshalling panels, but it is not recommended. Special connection blocks are required in the boxes or panels to maintain the thermocouple signal. It is always better to run continuous (uncut) thermocouple cables between the sensor and the I/O terminal block.

Multiple-pair cables specifically manufactured for multiple runs of the same sensing device type may be used. Each pair must contain individual shielding. For adequate cable support, conduit may be used.



### Notes:

- 1 Consult the manufacturer's installation manual for terminal connections.
- 2 Shields should extend to within 1 inch of terminations.
- 3 If the junction block is grounded, conduit can be grounded to the junction block instead of building steel.

**Figure 5-5 Typical Wiring and Ground Connections for Low-Level Signal Cable Runs Using Junction Boxes and Marshalling Panels**

## Class 1 Division 2 Recommendations

The following recommendations are applicable to signal wiring in Class 1, Division 2 locations, including classic, HART, and fieldbus installations:

- If your site has Class 1, Division 2 locations that are based on NEC 500, power must be removed from the wiring to a transmitter prior to disconnecting or opening up the field instrument.

Quick-disconnect type cable may be used to provide proper protection for personnel in the field. If it is used, you may have to remove power to the affected field instrument. To facilitate unpowering, you can provide an inline switch with the instrument so that, when the switch is open, you are ensured that no energy is present at the instrument.

- If unpowering the system is not feasible, you may use alternatives, such as intrinsically safe or non-incendive systems.
- It is recommended to use 600 VAC-rated cable in applications where the cable might be physically exposed, such as in cable trays. If cable trays are used, ensure that other signal cable types of lesser ratings are not physically exposed.

Refer to applicable NEC, CSA, or local government codes for additional information.



## AS-Interface Considerations

The Actuator Sensor Interface (AS-Interface) is a digital, serial, bi-directional communications protocol and bus system that interconnects simple binary on/off devices, such as actuators, sensors, and discrete devices, in the field. The AS-Interface standard is defined by CENELEC standard EN 50295.

The two-conductor, AS-Interface cable supplies both power and data for field devices. An AS-Interface network can include branches. Refer to AS-Interface standard (EN 50295) for design and engineering details on AS-Interface cable.

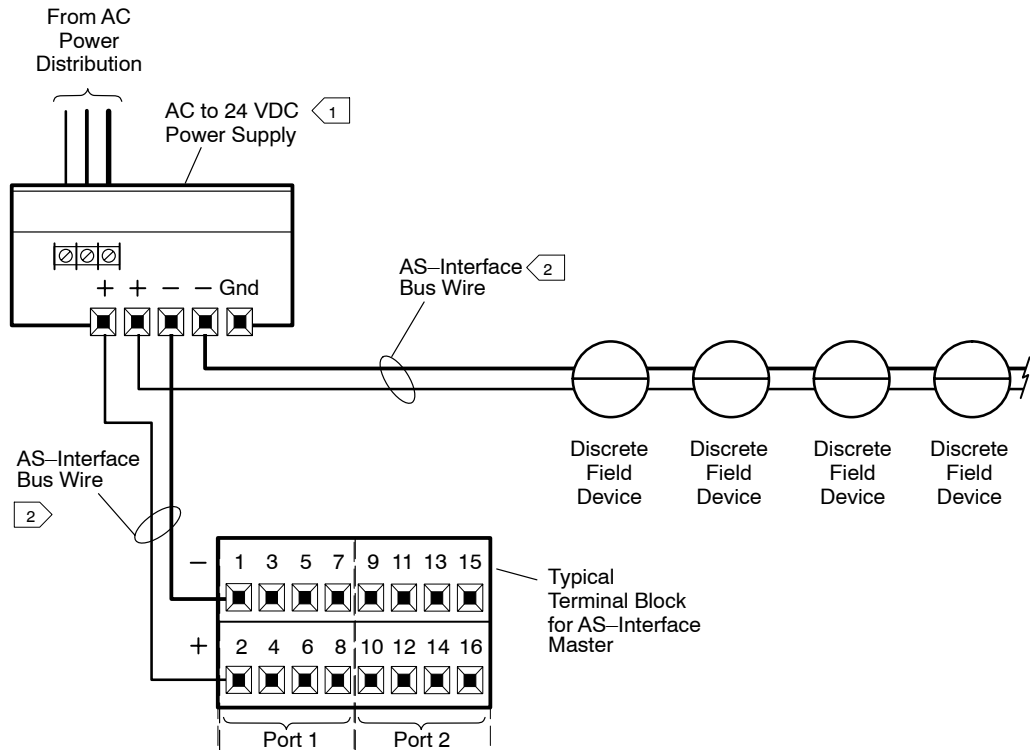
For more information on the AS-Interface and installation of AS-Interface devices, refer to the AS-Interface web site:

<http://www.as-interface.com>.

### **Note ...**

*It is recommended that you do **not** connect AS-Interface devices directly to AS-Interface card terminals. Use one AS-Interface cable to connect the AS-Interface card to the power supply and use another AS-Interface cable to connect the devices to the power supply. If using extenders and repeaters, refer to the device data sheet for additional cabling recommendations.*

The AS-Interface system is a “floating system.” Therefore, an AS-Interface system is never grounded. Only device cases should be grounded to pipes and building steel. These items must provide a good electrical ground to the plant ground grid. The power supply is grounded through the AC ground in the AC power distribution system.

**Notes:**

- 1 AC power supply is shown. Plant 24 VDC can be used if the voltage and ground requirements meet AS-Interface Specifications.
- 2 Brown wire is + voltage; Blue wire is - voltage.

**Figure 5-6 Typical Power and Ground Connections for an AS-Interface Network**

## DeviceNet Considerations

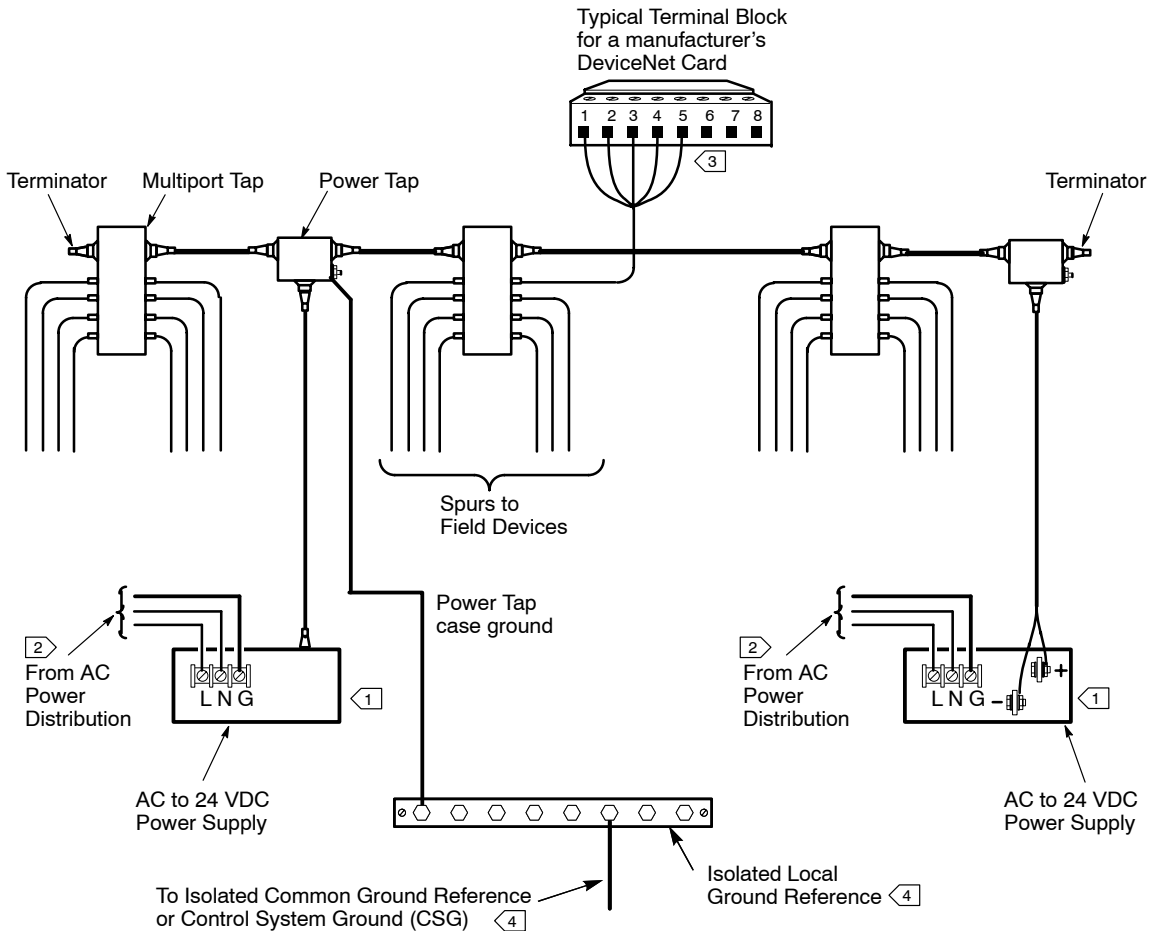
DeviceNet provides single-cable connection of field devices (for example, limit switches, photoelectric cells, valve manifolds, motor starters, drives, and operator displays) to a controller. Many manufacturers provide controller interface specially designed for I/O systems.

It is very important that you understand DeviceNet specifications before attempting an installation. These specifications, along with general user guidelines, are available through the DeviceNet web site:

<http://www.odva.org>

Figure 5-7 shows typical DeviceNet power and grounding. Important power and ground points are:

- 24 VDC power connects to the DeviceNet cable.
- More than one 24 VDC power supply can be used, depending on the load requirements of the devices connected to the cable.
- When using multiple power supplies, the power supply common voltage cannot vary more than 5 VDC between any two points on the network.
- The current should never exceed the cable and connector ratings.
- The voltage drop in the cable should not exceed 5 VDC between a power supply and its associated stations or nodes.
- To avoid ground loops, ensure that there is only one ground point for the entire network. That single ground point should be as near as possible to the physical center of the network.
- To maintain proper signal and ground isolation, DeviceNet specifications describe certain isolating methods to be designed into field devices. Only devices designed according to the specifications should be used.



#### Notes:

- ① DC return must be isolated from chassis.
- ② AC power supplies are shown. Plant 24 VDC can be used if the voltage and ground requirements meet DeviceNet specifications.
- ③ Terminal Designations on the DeviceNet Card Terminal Block:
- Terminal 1 — -24 VDC (black insulation)
  - Terminal 2 — CAN LO (blue insulation)
  - Terminal 3 — Shield (drain) (clear insulation)
  - Terminal 4 — CAN HI (white insulation)
  - Terminal 5 — +24 VDC (red insulation)
  - Terminal 6 — Not used
  - Terminal 7 — Not used
  - Terminal 8 — Shield (drain) (clear insulation)
- ④ Refer to Figure 4-1 and Figure 4-2 for ground connection details.

**Figure 5-7 Typical Power and Ground System for DeviceNet**

## FOUNDATION Fieldbus Considerations

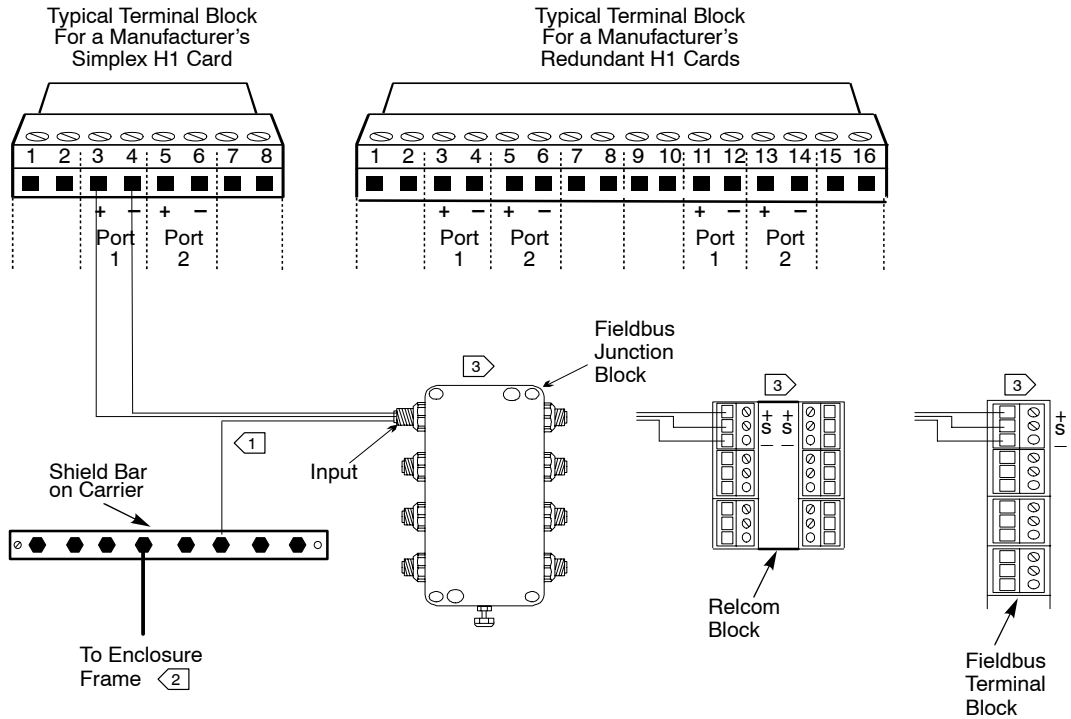
FOUNDATION Fieldbus H1 is a digital, serial, bi-directional communications bus that interconnects field devices, such as actuators, sensors, and discrete devices, with controllers. It includes both a communications protocol and hardware specifications.

Certain consideration must be given to FOUNDATION Fieldbus H1 installations to ensure proper operation. Figure 5-8 provides a typical wiring overview for the FOUNDATION Fieldbus H1 system.

Pay special attention to the power and ground aspects in these figures. For detailed installation information and checkout procedures, refer to the manufacturers appropriate FOUNDATION Fieldbus H1 documentation.

For more information on FOUNDATION Fieldbus specifications, refer to the FOUNDATION Fieldbus web site:

<http://www.fieldbus.org/>



#### Notes:

- 1 Fieldbus cabling must be shielded. The shield is grounded only at the H1 Card end on the carrier shield bar.
- 2 Refer to Figure 4-1 and Figure 4-2 for ground connection details.
- 3 Various termination blocks are available for FOUNDATION Fieldbus systems. These blocks are examples of some of the types you may use.

**Figure 5-8 Typical Ground Wiring for FOUNDATION Fieldbus**

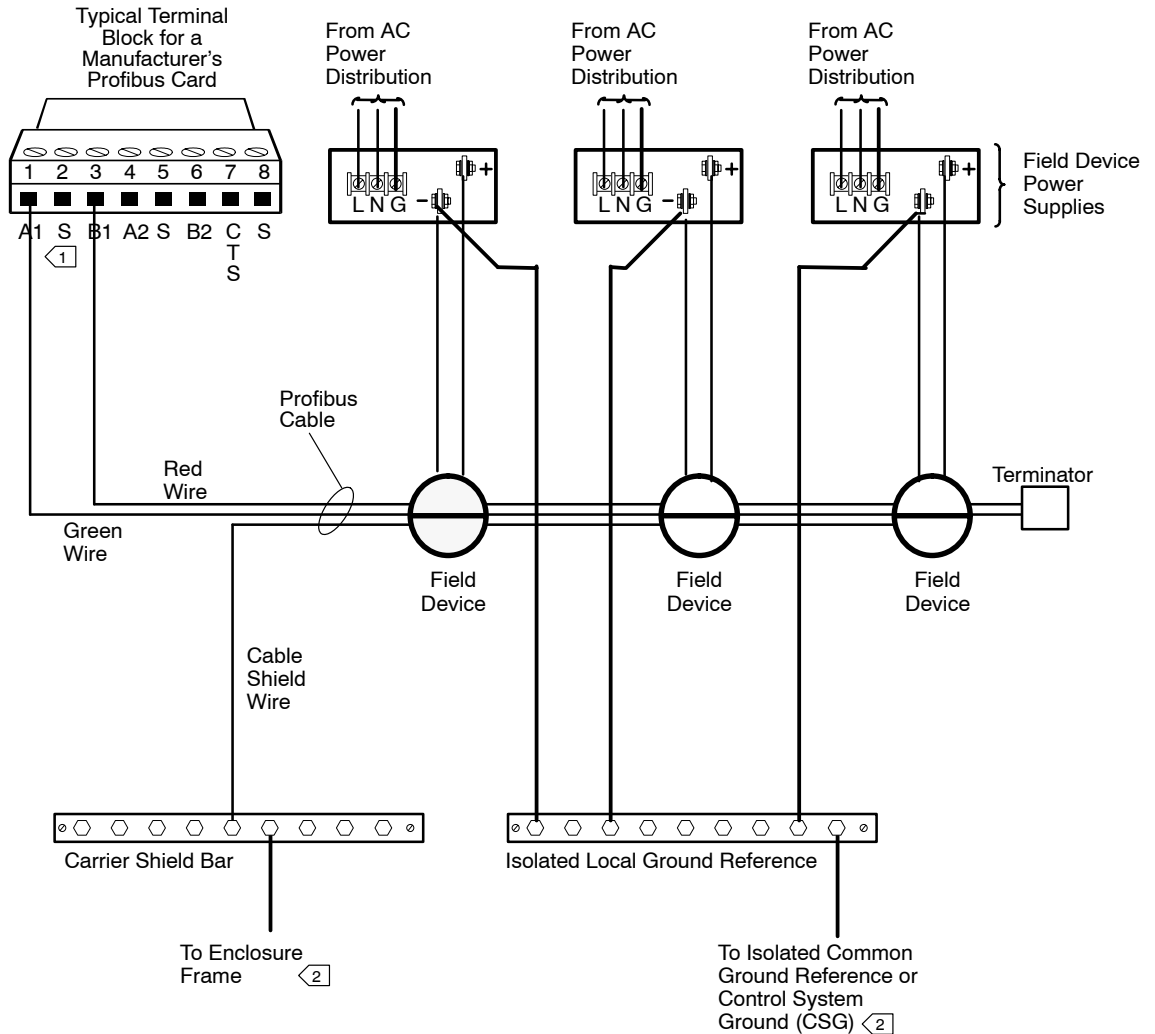
## Profibus Considerations

Profibus is a digital, serial, bi-directional communications protocol and bus system that connects analog and discrete field devices to a control system. The two-conductor plus shield Profibus cable passes data to and from field devices. Devices use external sources for field device power.

Complete Profibus specifications are needed to properly install a Profibus system. The specifications can be found on the Profibus web site:

<http://www.profibus.com>

Figure 5-9 shows example power and ground connections for a Profibus system. The illustration shows one terminator. The second terminator is contained in the master. If the master is between cable end points, a terminator must be placed on each end point.



**Notes:**

- ① When the master is at one end of the Profibus cable, the green wire connects to A1 and the red wire connects to B1. If the master is between the cable end points, use the A2 and B2 terminals. Connect the cable shield wire to the carrier shield bar.
- ② Refer to Figure 4-1 and Figure 4-2 for ground connection details.

**Figure 5-9 Typical Power and Ground Connections for Profibus System**

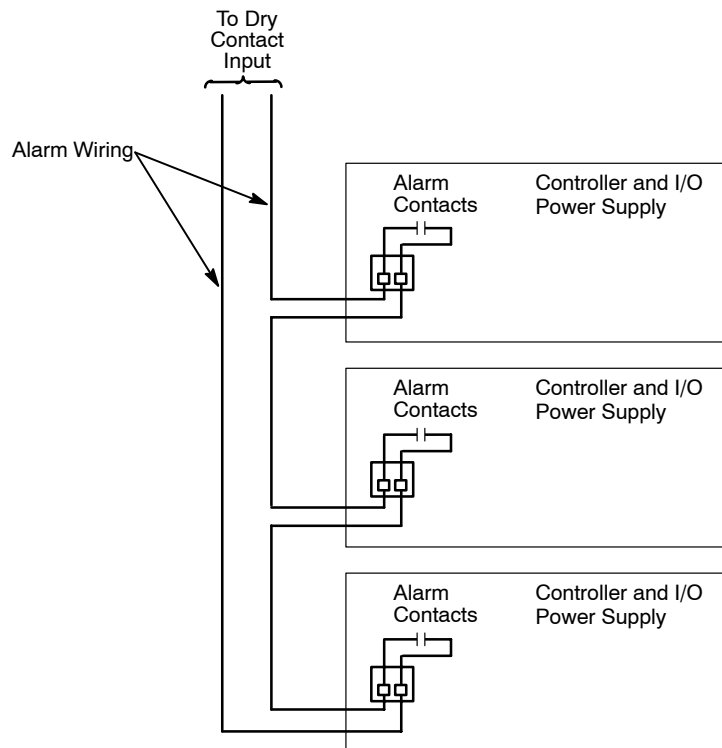


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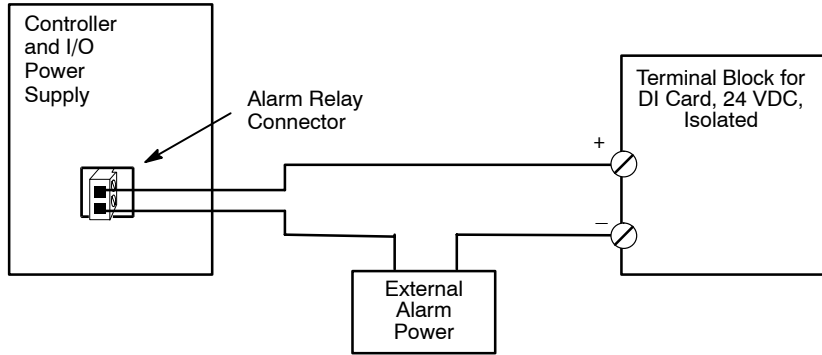
## Chapter 6 Alarm Wiring

Most controller and I/O power supplies include an alarm relay connector for output to alarm systems. The contacts may be either daisy chained so that any controller and I/O power supply in a group triggers an alarm or individually connected to an alarm system so that you know exactly which supply generated an alarm condition. Usually, contacts are normally-open when the supply is not powered (sometimes known as shelf condition).

Figure 6-1 shows a typical wiring arrangement for power supplies in a group. Figure 6-2 shows contacts connected from a single power supply to the input terminals for a typical discrete input card.



**Figure 6-1 Example of Grouped Controller and I/O Power Supplies with One Alarm Output**



**Figure 6-2 Example of Single Controller and I/O Power Supply Alarm through a DI Card**

## Chapter 7 Earth Ground

An adequate earth ground system is extremely important to both user safety and correct operation of a control system. An earth ground, in parallel with the equipment ground system, safely conducts stray or induced electrical currents to earth. In addition, it considerably reduces transient signals as well as signals induced by continuous electromagnetic fields, both of which can cause erroneous control signals in the control system.

The information in this section provides guidelines for constructing a good earth ground. Building steel should never be considered an adequate earth ground for a control system. However, control room grid systems, if they meet the requirements for good earth grounds, can be used. In all cases, construction of and connection to earth grounds must be in accordance with local, state, and federal codes.

### Designing an Earth Ground

For digital switching circuits, several control system industry sources recommend a ground system that has a resistance of one ohm or less between the control system ground and true earth with a maximum resistance of three ohms. A resistance of one ohm or less minimizes the possibility of phantom errors caused by voltage drops in the ground system.

The control system ground must be at least as good as a ground associated with any other system. If a ground used with a radio communication system has a one-ohm resistance to true earth, the control system ground must have a one-ohm (or less) resistance to true earth. Both ground systems should be referenced to the plant grid.

For a plant grid, multiple ground rods provide the most effective ground system for the following reasons:

- The individual rod-to-earth contact resistances are effectively placed in parallel. Adding rods to the system reduces the ground-system-to-earth resistance.
- An element of safety is provided over the single rod system. All ground contact does not depend on a single rod.

The distance between rods in a multiple rod system must be a minimum of twice the immersion depths of the rods. For more information on installing and testing

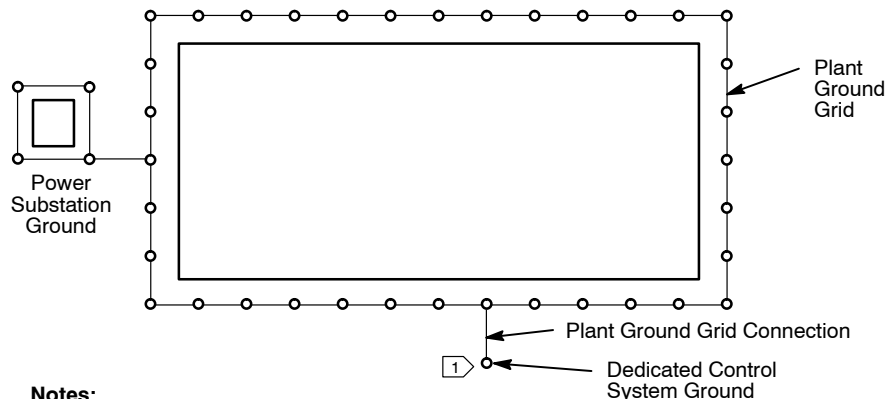
of ground systems, refer to the publication *Getting Down to Earth* from Megger Group Limited (www.megger.com, formerly AVO International and Biddle Instruments).

Figure 7-1 shows an example of a plant grid system. If an existing plant grid is accessible and the ground-grid-to-true-earth resistance meets the requirements, the existing grid can be used for the control system ground.

A dedicated point close to the control system (preferably a ground rod location) is used for the system ground point. The ground rod is connected to one of the plant ground grid rods with AWG 4/0 stranded-copper wire. The ends of the wires are thermally welded to the rods. If either the existing grid is not accessible or the resistance is not within specifications, a new grid is required.

**Note ...** *For platforms used at sea (for example, an oil platform or a gas platform) where process automation equipment is located, one of the legs of the platform is considered to be the connection to the earth ground. Even with floating platforms, the leg is still used. The sea is considered to be earth ground.*

Figure 7-2 through Figure 7-7 illustrate various examples of grounding that may be used.



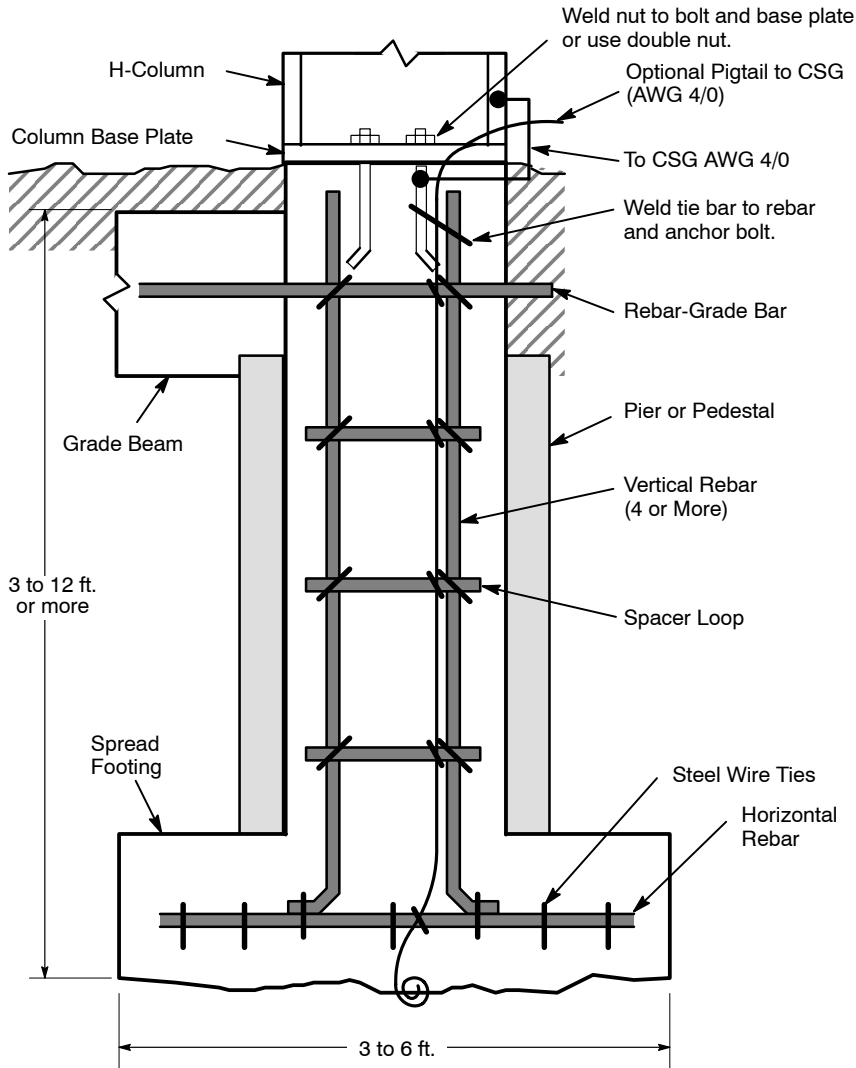
**Notes:**

○ = Ground Rod

All connecting cables should be at least No. 4/0 AWG (107.2 mm<sup>2</sup>) copper wire thermal welded to the rods.

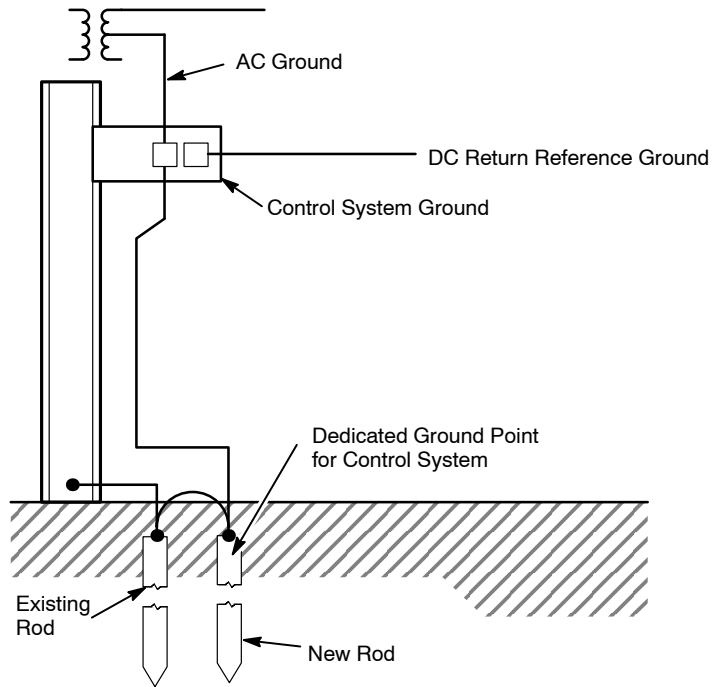
① Ground connection can be a single rod or one of the configurations shown in the following figures.

**Figure 7-1 Example of Plant Ground Grid System**

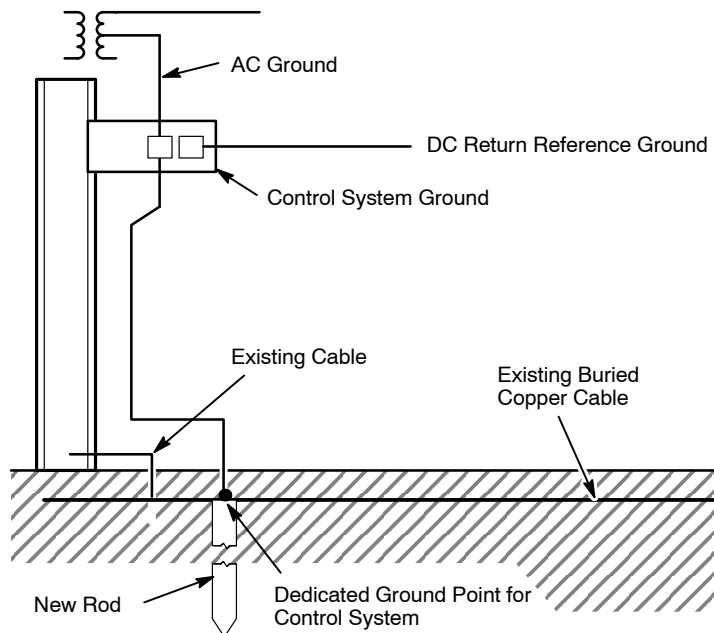
**Note:**

Ufer ground systems (developed by Mr. Herbert G. Ufer during World War II) should be applied to every column. Normally, they are found only at newer facilities. Beware that some rebar is Teflon coated. If it is, this type ground system will not provide a proper control system earth round.

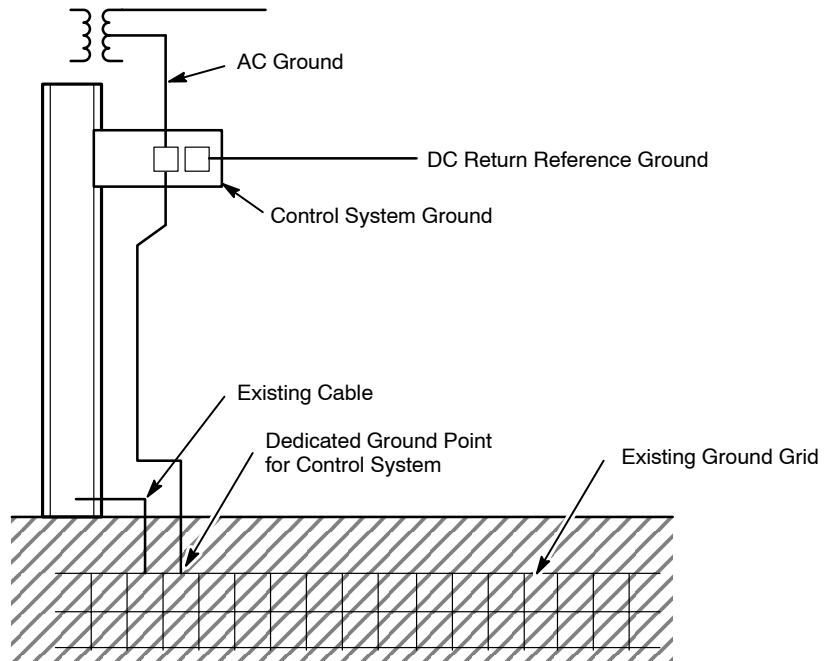
**Figure 7-2 Ufer Ground System Example**



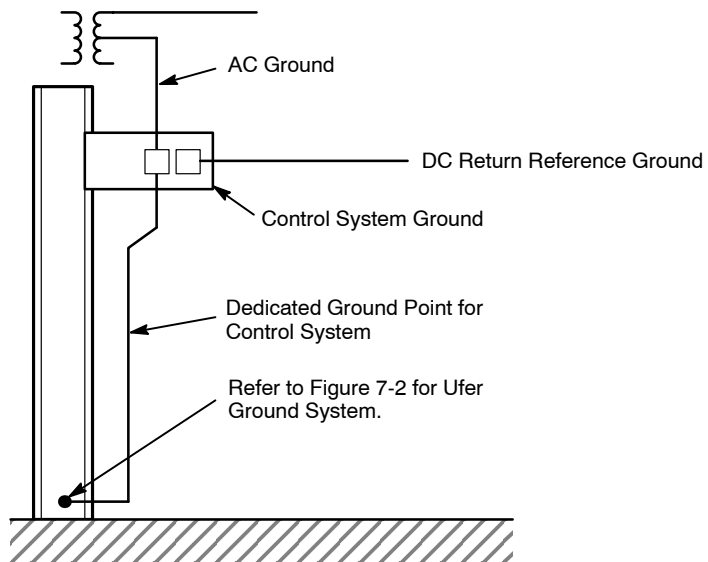
**Figure 7-3 Example Using Existing Ground Rods**



**Figure 7-4 Example Using Existing Counterpoise System**

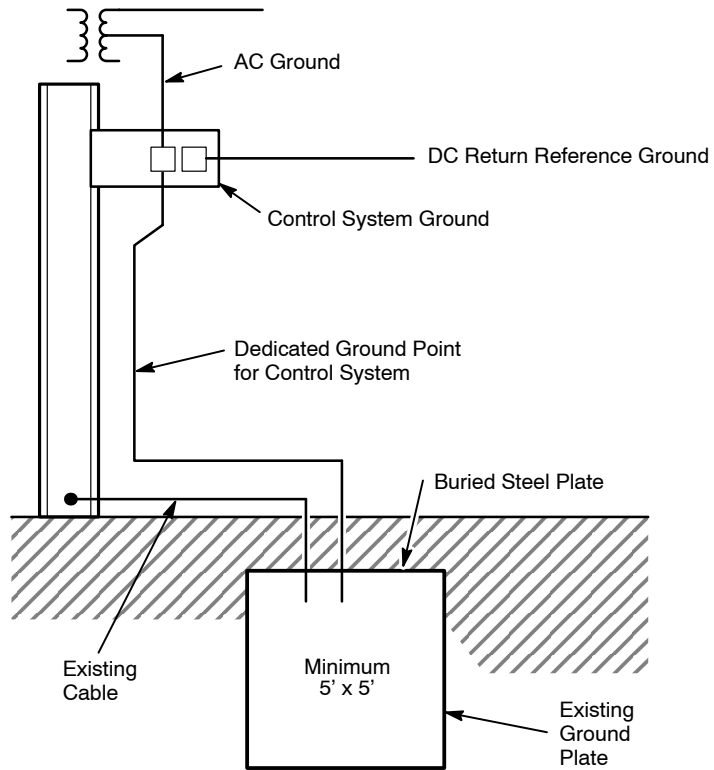


**Figure 7-5 Example Using Existing Ground Grid System**



**Figure 7-6 Example Using Ufer Ground Connections**





**Figure 7-7 Example Using Existing Buried Steel Plate Ground**

## Testing an Earth Ground

The electrical resistance of an earth ground system must be tested to ensure that the ground meets the requirements for control systems. The total resistance of the ground system is comprised of the resistance of the metal used in the plant earth ground grid, the resistance of ground cable connection to the grid, the resistance of the contact between the grid and earth, and the resistance of the earth itself. For a control system, the recommended earth ground resistance is one ohm or less with a maximum resistance of three ohms.

There are several methods for testing earth ground resistance. The three-point (or Fall of Potential) method, the two-point (or Direct) method, and the Slope method are frequently used. Various manuals are available from tester manufacturers and consulting firms that detail earth ground resistance testing. Also, IEEE Std 81, *IEEE Guide for Measuring Earth Resistivity, Ground Impedance, and Earth Surface Potentials of a Ground System*, contains descriptions of these methods.

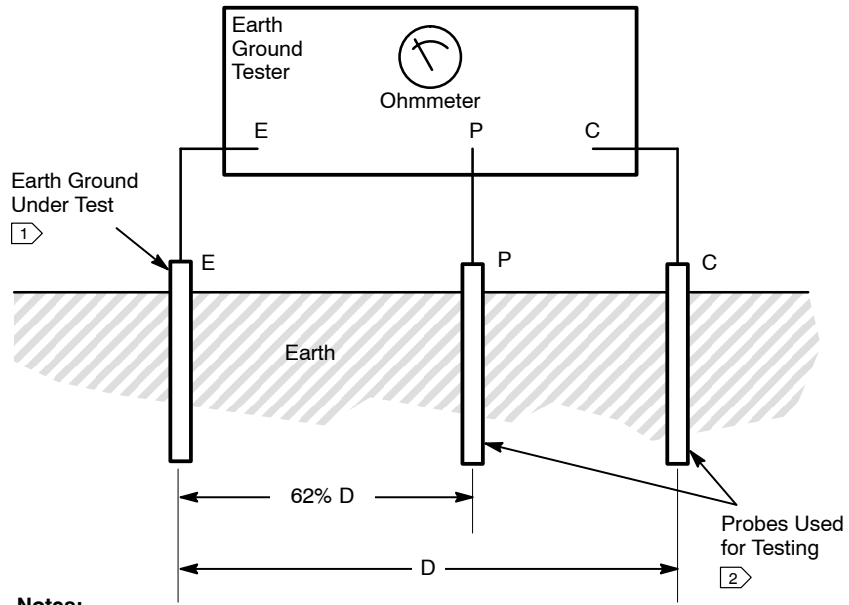
Several internet sites also contain helpful information about earth ground resistance measurements and methods in the forms of white papers and technical articles. It is recommended that you access such sites for further information. Some sites are:

- [www.megger.com](http://www.megger.com)
- [www.aec-us.com](http://www.aec-us.com)
- [www.hoodpd.com](http://www.hoodpd.com)

An earth ground tester is used to determine the total resistance of an earth ground system. (Refer to Figure 7-8). The tester contains an electric current source and connections for probes.

Figure 7-8 shows connections for the three-point ground method. In this method, an electrical current is passed through earth between a current probe (C) and the ground grid being tested (E). At a point between these locations, a third probe (P) is inserted in the ground. Standardized tables are available that give recommended distances between C, E, and P locations to obtain accurate measurements.

A typical point for P is 62% of the distance between C and E, as measured from E. (Refer to Figure 7-8.) The distance between C and E depends on the depth of the ground rods. Table 7-1 lists typical distances.



**Notes:**

- ① Disconnect and ground cables from the ground system while testing is in progress.
- ② Probes used for testing are placed in a straight line from the earth ground under test.

**Figure 7-8 Three-Point Method Setup for Testing an Earth Ground System**

**Table 7-1. Typical Distances for Three-Point Method**

Depth of Ground Rods at E (ft)	Distance Between E and P (ft)	Distance Between E and C (ft)
6	45	72
8	50	80
10	55	88
12	60	96
18	71	115
20	74	120
30	86	140

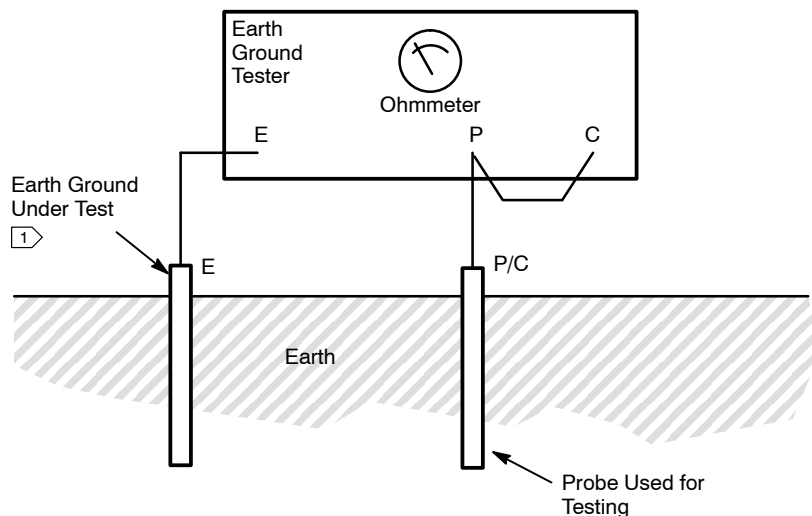
Resistance value is obtained by measuring the current between C and E and the voltage between P and E. Many earth ground testers convert these measurements to resistance and show the resistance on an ohmmeter. Ohm’s Law can be used to determine the resistance if an ammeter and voltmeter are used on the tester.

It is recommended that measurements be made in several directions from the ground system and the values entered into a table to determine possible high resistance areas and to use for future reference. Since earth ground resistance

varies with changes in ground moisture and temperature, it is also recommended that resistance measurements be made at different times during a year.

The three point method works well if you have enough room to lay out the probe locations. Room can be limited both by obstacles, such as buildings, highways, and railroads, and by other ground systems where the electrical currents in those systems could influence the measurements of the system under test. If measurements are attempted inside the perimeter of a ground grid system, such as that shown in Figure 7-1, the measurements can be influenced, and inaccurate readings can result.

In these cases, the two-point method can be used, as illustrated in Figure 7-9. It is not as accurate as the three-point method. In the two point method, terminals P and C are tied together and connected to a known adequate ground system, such as that of a power utility neutral ground. Then, earth ground resistance can be measured between the known system and the system under test. This setup reduces the distance necessary to make a measurement. If a voltmeter is being used in conjunction with an ammeter, the voltmeter is connected between P/C and E.



**Note:**

① Disconnect and ground cables from the ground system while testing is on progress.

**Figure 7-9 Two-Point Method Setup for Testing an Earth Ground System**

The Slope method can also be used when room for inserting probes is limited. This method uses a setup similar to the two-point method, except that the probe P/C (in Figure 7-9) is moved to several locations in a straight line, and a

measurement is taken at each location. Locations are typically at 20%, 40%, and 60% of the distance from P/C. From these readings, a slope coefficient is calculated and the result compared to a standard table of values. From the table, the best location for P/C can be found. Then, an earth ground resistance measurement is made. Because this method can be subject to many extenuating influences, several measurements should be made in all directions from the earth ground system to ensure the accuracy of the results.

When earth ground systems must provide three ohms or less resistance, the resistance of the test leads can no longer be assumed to be negligible, especially since the leads can be many feet long. Therefore, lead resistance should be measured and subtracted from the earth ground reading.

## Annual Inspection

As a preventive maintenance action, each connection on an earth ground system needs to be checked annually. This check ensures that connections are tight, ground wires are in good condition, and no contamination or corrosion exists that could otherwise compromise the ground system integrity.

## Chapter 8 Lightning Protection

This chapter provides guidelines for protecting control systems from lightning damage. A direct strike can disrupt critical processes, start fires, damage buildings and equipment, and injure personnel. Near strikes can disrupt critical processes and damage electronic circuitry, by inducing voltage in unprotected wiring. Therefore, adequate lightning protection is essential in a production plant.

### Reference Documents

The documents listed below provide further information for understanding lightning protection systems:

- Hart, William C. and Malone, Edgar W., *Lightning and Lightning Protection*, 1st ed., Don White Consultants, Inc., Gainesville, Virginia, 1979, ISBN No. 0932263143
- NFPA-78 *Lightning Protection Code 1986*, Quincy, Massachusetts: National Fire Protection Association, 1986.

### Lightning Risk Determination

Factors that determine the level of protection are:

- Geographic location
- Process criticality

Lightning strikes occur more often in some geographic areas than in others. Elevation, humidity, geographical latitude, and normal weather patterns influence the frequency of lightning strikes in a particular area. Therefore, the typical lightning storm patterns in an area will influence the extent of protection needed.

Process criticality also dictates the sophistication of required lightning protection. The more critical a process, the more important lightning protection is, even though the system may be in an area of low lightning occurrence. If any strike or near strike can cause loss of control of a critical process, severe financial loss, major equipment damage, or danger to personnel, a complete lightning protection system is appropriate.

## Lightning Protection Systems

Lightning protection systems provide safe conduction paths to earth ground to minimize equipment damage and personal injury. A complete lightning protection system includes:

- Lightning rods
- Conductor system
- Ground system
- Lightning arrestors and surge protectors

Lightning rods (also referred to as air terminals) intercept lightning discharges above a building or facility. The conductor system is a safe discharge path from the lightning rods to the ground system. The ground system lets the lightning discharge or dissipate safely. Lightning arrestors and surge protectors protect power lines, network cables, instrumentation wiring, and other such equipment from induced voltages. Together, these elements minimize lightning discharge damage.

Although a lightning protection system intercepts, conducts, and dissipates the main electrical discharge, it does not prevent possible secondary effects, such as spark-over, in nearby large metal structures.

### **Note ...**

*To minimize secondary effects of lightning strikes, ensure all adjacent metal structures interconnect with and tie to the main conductor system. This construction design maintains the same electrical potential throughout structures in the vicinity.*

## Lightning Rods

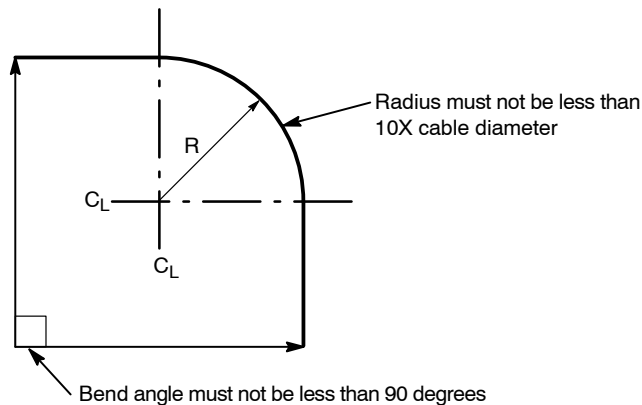
Lightning rods intercept a discharge above a structure and direct the discharge to a safe path. In particular, lightning rods minimize the possibility of fire. A large plant site area needs a complete system of properly located lightning rods.

Lightning rods should be located on the structures most likely to be struck. Chimneys, ventilators, towers, and other high parts of buildings should have lightning rods installed. Roof edges are the parts of flat-roofed building most likely to be struck.

## Conductor System

Once intercepted, a lightning discharge follows a low-impedance path to the earth (path of least resistance). Normally, the least resistant path is metal. A conductor system consists of one or more such metal paths. Each path must be continuous from the lightning rod to the ground. Paths must not have any sharp bends or loops. This ensures that the system provides the most direct path to earth for lightning discharge.

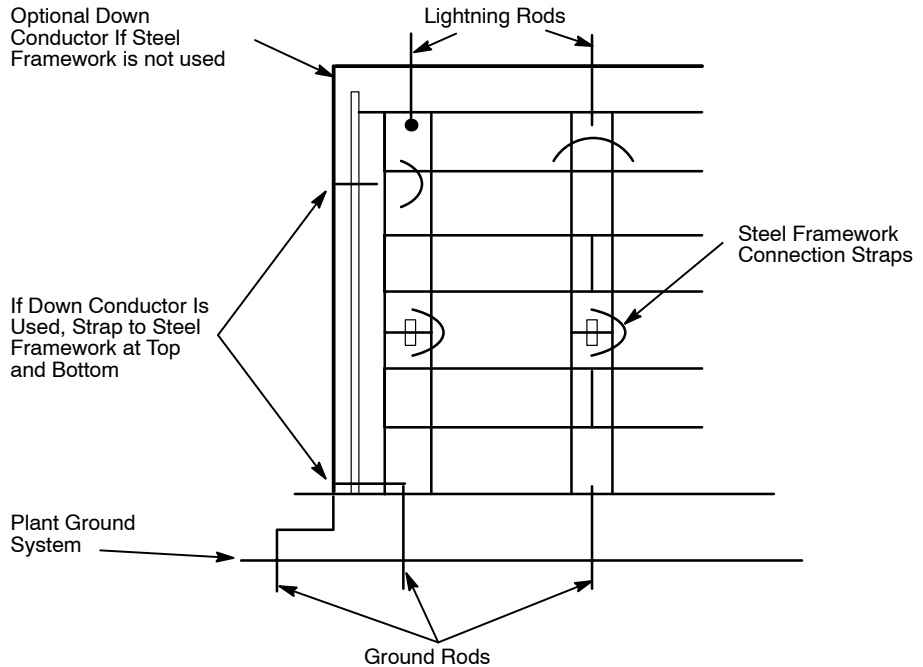
As illustrated in Figure 8-1, no bend in a lightning conductor should form an angle of less than 90 degrees, and no bend should have a radius less than 10X the diameter of the cable used for the path. A non-ferrous metal such as copper or aluminum is the preferred material.



**Figure 8-1 Minimum Conductor Bend Radius Requirements**

The impedance of a conductor system is inversely proportional to the number of separate discharge paths. Therefore, increasing the number of paths decreases the impedance. In a multi-path conductor system, the paths (wires) should form a cage around the structure. The steel framework of a structure can substitute for separate conductors, but smooth connection straps must span any sharp bends or other hindrance. Figure 8-2 shows a typical protection system with a conductor, grounded steel framework, and connection straps.





**Figure 8-2 Typical Lightning Protection System**

In metal structures, the conductor system can use the structure framing instead of separate conductor cables. In such cases, lightning rods should be electrically bonded to the top part of the framework, and ground terminals should be bonded to the bottom. Structures with electrically continuous metal exteriors may not require separate lightning rod and conductor systems, if the metal is at least 3/16 inch (4.8 mm) thick. The metal exterior itself can intercept lightning and conduct it to ground.

## Ground System

Proper grounds are essential for effective lightning protection. Each ground connection, and each branch of each ground connection, should extend below, and at least 2 feet (0.61 m) away from, a building's foundation walls. This construction minimizes wall damage in the event of a lightning strike.

## Lightning Arrestors and Surge Protectors

**Note ...** *Lightning arrestors assist in the isolation of coaxial type highways, but strikes can jump those systems. For the fullest protection, fiber optic links are recommended.*

Lightning arrestors and surge protectors minimize current induced in the wiring of a control system. Induction can occur in two ways:

- A lightning discharge passing through the conductor system generates a transient magnetic field, which induces current in nearby wiring
- As the ground system dissipates a discharge in the earth, a step difference in potential develops in the earth itself. This difference induces current in underground control system wiring

Protection devices use three main types of circuits:

- Varistors
- Semiconductors (avalanche diodes)
- Gas discharge tubes

Varistors and semiconductors provide protection from lower current levels. Gas discharge tubes protect the system from high current and voltages levels. Most protection devices use a combination of these circuits.

## Implementing Lightning Protection

When planning a lightning protection system, carefully consider environmental conditions and plant requirements. Guidelines for implementing a lightning protection system include:

- Ground the building and plant site to a single ground system. If there is a remote or separated building at the plant site, isolate the signals, power, and communications systems of the remote building;
- Use overhead cables when possible. The air around overhead cables acts as an insulator, making them less susceptible to lightning induced voltage than underground cables. Also, overhead cables are less susceptible to step-potential induction in the earth than underground cables. Ground all cables, including the conduits, pipe racking, and cable trays;

- Install surge protection on all metallic cables running outside of buildings by:
  - Installing a protection device for power wiring at either the substation entrance (preferred), or at each piece of powered equipment
  - Installing a protection device on each phone line entering the building
  - Installing a protection device on instrumentation wiring, if the structures are not all grounded to a plant-wide system, or the equipment is not designed to handle an induced voltage surge
- For Control Network cables, install a surge protector in each building at the cable entry site
- Install protected cables in conduit or cable trays
- When building a lightning protection system, use mechanically strong materials with physical properties that resist rust and corrosion

## Inspection of Lightning Protection Systems

Building additions or structural repairs performed without consideration for a lightning protection system can reduce the system's effectiveness. Deterioration of or mechanical damage to the system may reduce its effectiveness.

To prevent loss of protection, evaluate all proposed structural changes for effects on the protection system, and ensure that no structural repairs inhibit system protection. Inspect the structure periodically, at least annually, for deterioration and mechanical damage. Thoroughly inspect and test the lightning protection system every five years.

## Appendix A Variable Speed Drive Considerations

A significant amount of electrical interference is caused by AC Variable Speed Drives (VSD), sometimes called Variable Frequency Drives (VFD). Most VSDs use Pulse Width Modulation (PWM) to control motor speed. The operating characteristics of PWM can create electrical interference because of the fast rise and fall times of the signals used by the PWM control circuits.

This interference can affect the reliable operation of control systems, VSDs, and electric motor components. VSD and motor issues, well documented in technical papers, include failures of motor bearings and stator windings, high frequency electrical interference on control systems, and power cable failures. In addition, common mode electrical noise and reflective wave issues have been experienced with many brands of VSDs. According to VSD manufacturers, electrical interference related issues can be avoided by following the manufacturer's installation recommendations.

### Recommendations

Actions to minimize interference from VSDs include:

- Minimize Cable Lengths between the VSD and Motor

Cable length and type are critical variables in determining the amount of noise generated in a system. The fast rise time of voltage pulses generated by insulated gate bipolar transistor (IGBT) AC drives react with the transmission line. The longer the line, the greater the potential for reflected voltages. The drive manufacturer needs to specify maximum cable length for the given installation. Generally, the cable length should be no more than 200 ft.

- Use Lowest VSD Carrier Frequency

Maximum permitted cable length varies with the switching (carrier) frequency used by the VSD. The lower the frequency, the greater the length of cable that can be used. Drive electronics operate at the lowest switching frequency available for the drive. The frequency of the electrical noise in the motor power wiring is higher than the VSD switching frequencies because of transmission line effect. The electrical noise can reach frequencies of 30 megahertz.

- Use Armored Power Cable

The power cables used between the VSD and motor should have a metallic outer armor (copper or aluminum) to shield the system components from the high frequency electric fields. (The armor also provides a low impedance path back to the AC drive power supply.) Copper or aluminum should be used because steel does not provide effective shielding at higher frequencies.

Extensive testing of various types of cables produced the following results (Table A-1):

**Table A-1. Cable Shield Properties**

Cable Type	Per Unit Cross Talk	Per Unit Common Mode Current
Tray Cable — No shield or Armor (3 grounds)	56 db	11.9 db
MC Type Cable — Aluminum Armor (3 Grounds)	5.0 db	1.0 db
MC Type Cable — Steel Armor (3 Grounds)	44 db	3.9 db

MC Type cable with a continuous corrugated aluminum armor and three symmetrically placed ground wires offers the best shielding for motors that are connected to variable speed drives. (See subsection *VSD Cable Specifications*). Aluminum conduit is not a recommended solution because the threaded couplings corrode and jeopardize the electrical continuity of the shield.

TC cable is available with an overall foil shield. Although the foil shield does not provide the same protection as armored cable, it may offer adequate protection. In some installations, the foil shield has provided the necessary protection and significantly lowered the voltage levels of the electrical interference created by the VSD.

- Use Isolation Transformers for VSD Power

An isolation transformer (separate from the one dedicated to control system power) provides isolated power and a dedicated ground system for the VSD. This ground system creates a path to eliminate unwanted signals. Without the ground system, unwanted signals are routed through the main power system grounds, causing the signals to become common mode noise. The isolation transformer should include electrostatic shields between the windings.

- Use Other Noise Suppression Components

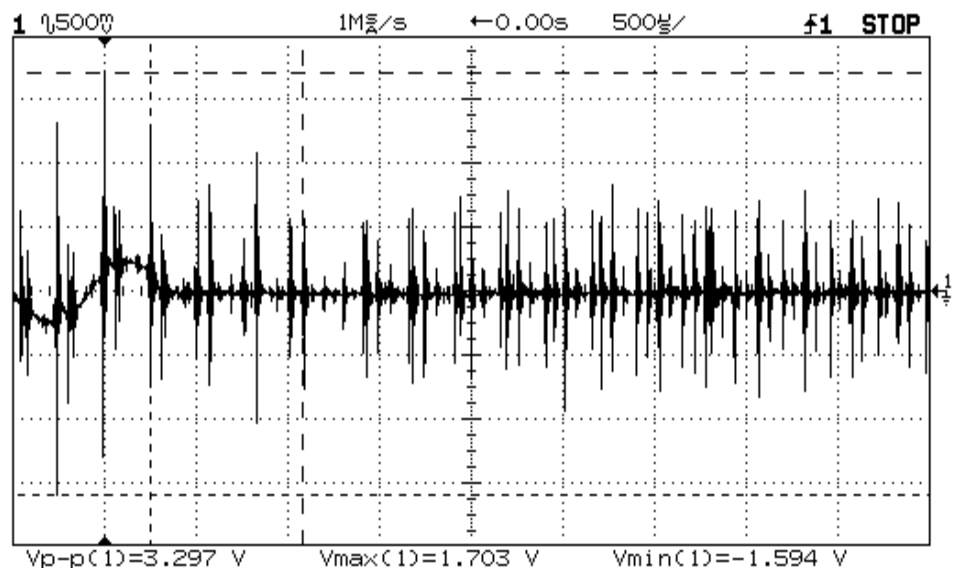
AC drive installations should use components that are designed and tested to meet electromagnetic compatibility (EMC) directives and European Union (CE Mark) approval. Input power filters, output power filters, and common mode chokes often help suppress electrical noise in VSD applications. These noise suppression devices may be required if electrical noise levels prevent normal control system operation.

- Use Control-Matched Inverter-Rated Motors

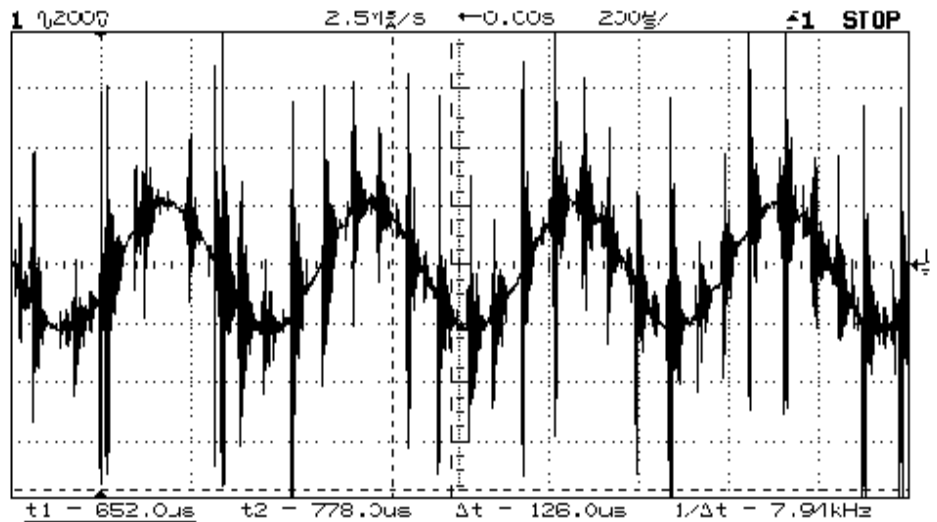
Inverter-rated motors should be used in VSD applications. Inverter-rated motors are designed to withstand the added stresses encountered when controlled by VSDs. Motor and VSD compatibility should be added to the criteria when selecting motors for VSD applications. Motor failures can be reduced if motors are compatible with both the application and the VSD.

## Electrical Noise Examples

Figure A-1 and Figure A-2 show oscilloscope traces of common mode noise on traditional analog and HART signals caused by a low power, variable speed drive. The noise is seen as the large, high frequency spikes superimposed on what would otherwise be fairly smooth trace lines.



**Figure A-1 Common Mode Noise on an Analog Signal (Display A)**

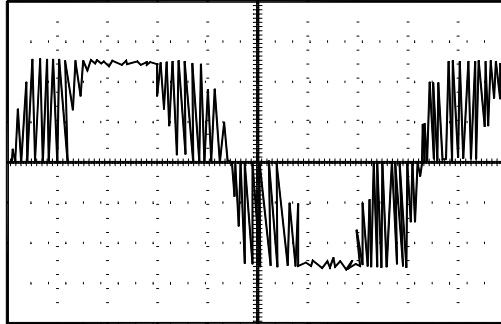


**Figure A-2 Common Mode Noise on an Analog Signal (Display B)**

## Ground Considerations

By their nature, VSD drive systems using IGBT inverters produce high electrical noise levels. The noise is high frequency signals (up to 30 mHz) that are generated by the fast rise times (square-wave type signals) in the systems. The high frequency signals are capacitively coupled from the power cable and the motor to surrounding metal and are magnetically coupled from ground conductors into nearby field instrumentation and its wiring.

Figure A-3 illustrates a typical voltage output of the inverter with superimposed noise. The level of the noise along the power cable and at the motor terminals varies, depending on cable length and other factors. The waveform shown in the figure may vary from manufacturer to manufacturer, but the fast rise times and attendant noise are characteristic of IGBT drives.



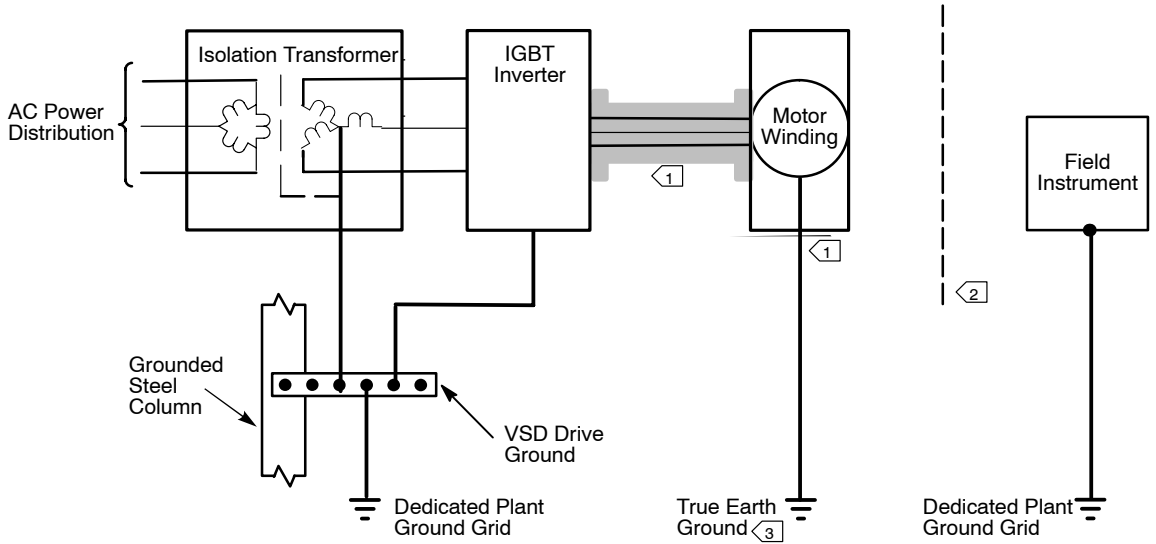
**Figure A-3 Voltage Output Inverter Signal with Superimposed Noise**

If not adequately controlled, the high frequency noise can cause motor stator winding failure from arcing, motor bearing failure from metal transfer, and impeded control system operation from direct coupled noise and stray ground currents. To minimize the effects of the noise, the following is essential:

- Use armor power cable connected at *both* ends. Usually, shielding is connected at one end only, but for VSD drives, all internal cable shields and the armor shield must be grounded at both ends.
- Use the shortest power cable length possible.
- Use motors with shielded stator winding.
- Keep VSD ground cables on or as near as possible to building steel to ground out high frequency signal radiation.
- Be sure that the building ground system provides a low impedance return path to true earth ground (normally, your plant ground grid).

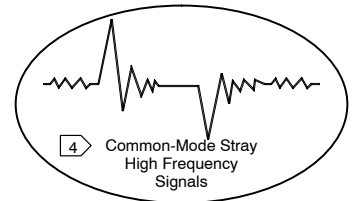
Figure A-4 illustrates power and ground cabling for VSD systems which, if properly installed, normally reduces electrical noise to low enough levels that motor damage is minimized and control system operation is not impeded.





**Notes:**

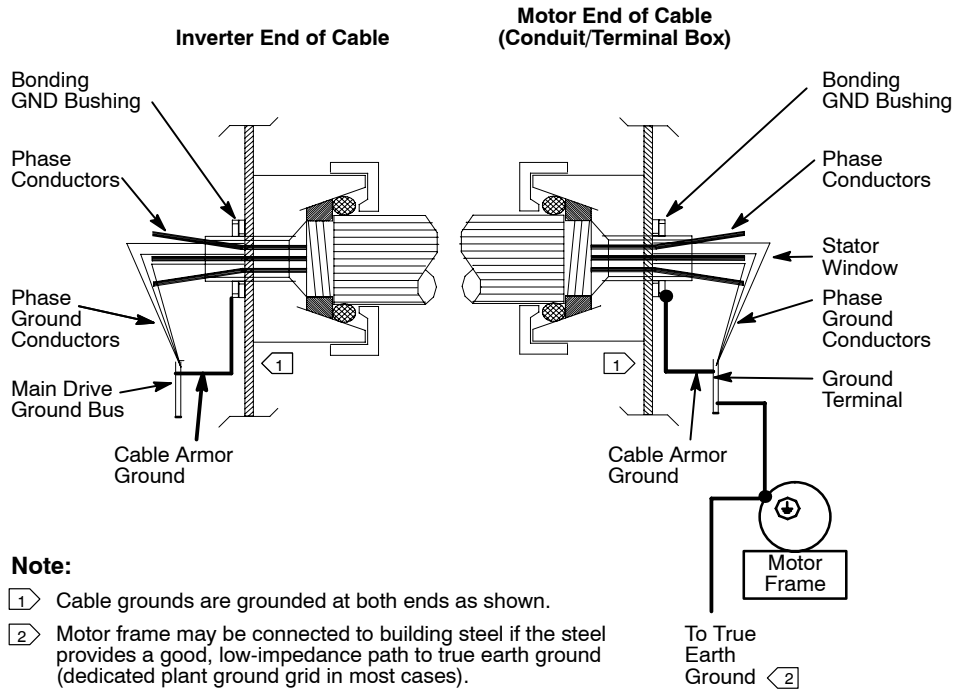
- 1 See Figure A-5 for ground connection details.
- 2 Keep field instrumentation and VSD equipment separated as far as possible and use armored power cable, shielded motor stator windings, and proper grounding to minimize affects of stray high frequency signals.
- 3 Motor frame may be connected to building steel if the steel provides a good, low-impedance path to true earth ground (dedicated plant ground grid in most cases).
- 4 Waveform is typical of high frequency stray signals possible on VSD ground wiring and radiated like radio signals.



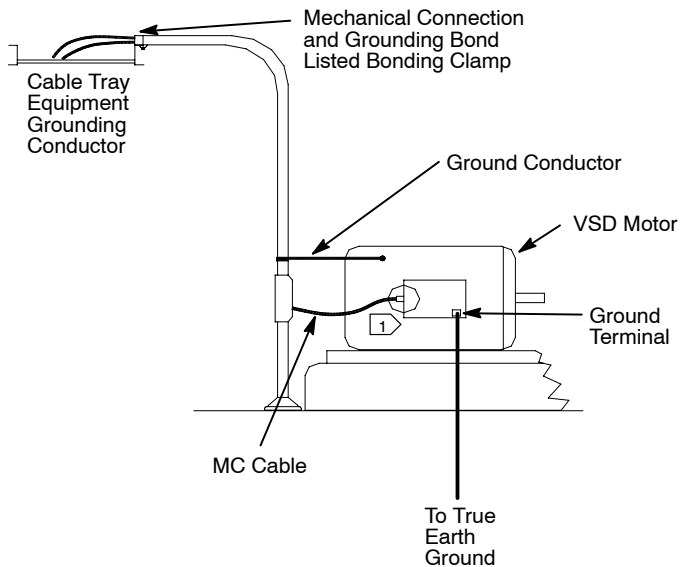
**Figure A-4 Ground Wiring for Adequate Noise Protection with IGBT Inverters**

## Motor Ground Connections

Figure A-5 shows details for ground connections of the motor power cable. As shown, the motor frame is grounded to true earth ground. For new buildings, the frame can be grounded to a UFER ground or to effectively grounded building steel. For existing buildings, the frame can be grounded to the nearest available effectively grounded building steel or grid. Effectively grounded means that building steel provides a good low impedance path to true earth ground. Figure A-6 shows the drop out path from a cable tray to the motor.



**Figure A-5 Ground Connections at Motor Power Cable Ends**



**Figure A-6 Dropouts from Cable Tray to VSD Motor**

## VSD Cable Specifications

Table A-2 lists specifications for recommended VSD cables. Several cable manufacturers produce VSD cable.

**Table A-2. VSD Cable Specifications**

Specification	Description
Cable Type	Type MC metal-Clad three-phase cable per NEC 334-1, UL listed
Phase Conductors	Three phase-conductors with ampacity per NEC
Ground Conductors	Three bare ground conductors per NEC article 250
Metallic Sheath <sup>(1)</sup>	Continuous corrugated aluminum (welded or seamless)
Overall Jacket	PVC
Voltage Rating	≤ 480 VAC, Cable insulation rating of 600 VAC
Connector Type	See Figure A-5
1. Alternate metallic shields may be copper tape spiral shield with galvanized steel interlocked armor or no shield with aluminum continuous armor.	

## Critical Cable Lengths

The critical cable length is based on the pulse rise and fall time. The critical length is the minimum length that does not produce reflected voltage waves at the motor terminals. Table A-3, Table A-4, and Table A-5 show various factors for determining maximum cable length.

**Table A-3. Critical Cable Lengths by Pulse Rise Time**

Pulse Rise Time	Maximum Cable length
50 nsec	13 feet
100 nsec	25 feet
200 nsec	50 feet
400 nsec	100 feet
600 nsec	148 feet
1 μsec	246 feet
2 μsec	592 feet
4 μsec	984 feet
<b>Note:</b> Cable lengths greater than 100 feet are not recommended because of the potential for causing unwanted signals.	

**Table A-4. Critical Cable Lengths by Switching Type**

Switching Device	Maximum Cable length
IGBT 0.1 $\mu$ sec	100 feet
Bipolar	250 feet
GTO 1.0 $\mu$ sec	600 feet
SCR 4.0 $\mu$ sec	600 feet

**Table A-5. Critical Cable Lengths by Switching Frequency for an IGBT Drive**

Switching Frequency	Maximum Cable length
1 kHz	200 feet
3 kHz	175 feet
12 kHz	100 feet
<b>Note:</b> It is recommended to use the lowest possible frequency to minimize the potential for unwanted signals.	

The above tables illustrate the importance of cable length, switching device, and switching frequency in minimizing reflected voltage waves at motor terminals. If the cable is long enough, the voltage at the terminals can be twice the inverter output voltage.



## Appendix B Testing with an Oscilloscope

An oscilloscope can be used to locate electrical interference on control signals and ground systems. A 500 mHz oscilloscope with digital storage capability is preferred. There are several brands available, and most use PC interface software to perform trace data captures.

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**Warning...** *Improper use of an oscilloscope can lead to electrical shock, and it may affect the normal operation of the manufacturing process. Be extremely careful when connecting to high voltage power cables and process signals. Read and follow the directions provided by the oscilloscope manufacturer prior to its use.*

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**Note ...** *If you are using an AC-powered oscilloscope, it must use a floating input signal ground to obtain correct readings. However, as noted above, a floating input signal ground may be hazardous.*

### General Monitoring

The presence of electrical noise may mean that system operation is jeopardized. Monitor the following signals to determine the presence of electrical interference:

- **Analog Input and Output Signals:** Electrical noise on analog-only signals usually does not cause faults because the unwanted electrical noise is filtered out.
- **Digital Communications:** Electrical noise can cause faults in digital communication signals by adding spikes and other noise that the communication system interprets as part of the digital signal.
- **Power Supply Ground to +24 VDC:** Electrical noise will be present. However, the noise spikes should be less than one volt peak to peak. If the noise spikes are greater than 1-volt peak to peak, further investigation is required. The noise source should be located and remedial actions taken.
- **Power Supply Ground to Cabinet Ground:** Electrical noise will be present. However, the noise spikes should be less than one volt peak to peak. If the noise spikes are greater than one volt peak to peak, further investigation will be required. The noise source should be located and remedial actions taken.

## Fieldbus Segment Monitoring

When a Fluke 123 oscilloscope is used to monitor signals on a fieldbus segment, electrical noise caused by the oscilloscope connections (not by noise on the segment) may show on the trace. To minimize noise caused by the oscilloscope connections, use the ground-clip lead that is part of the probe. Do not use the common ground lead connection, which can be susceptible to electromagnetic noise in the plant and, thus, introduce electrical noise on the trace.

## Appendix C Wire Size and Color Codes

Table C-1 provides the recommended size and color coding for power and ground wiring used in control systems with classic I/O and HART I/O subsystems. In most cases, you must also meet applicable government wiring codes.

Wiring for fieldbus systems, such as AS-Interface, DeviceNet, FOUNDATION Fieldbus, and Profibus, may use color codes other than those shown in the table. When available, fieldbus color codes should take precedence over those shown in the table.

Your site may use other color codes. In either case, it is vital that there be consistent color coding for each type of wire used. Also, all ground wiring should be identified and tagged. Inconsistent color application and untagged ground wiring can make subsequent troubleshooting very difficult.

**Table C-1. Wiring Specifications**

Use	Size	North American Insulation Color	European Insulation Color
AC Line	Per Code for distance	Black	Brown
AC Neutral	Per Code for distance	White	Blue
AC Ground	Per Code for distance	Green	Green with Yellow Stripe
+12 VDC	8 AWG (8.3 mm <sup>2</sup> )	Dark Blue	Dark Blue
+12 VDC Redundant	With Bus Bar: 8 AWG (8.3 mm <sup>2</sup> ) between supply and bus bar, and 14 to 12 AWG (2.1 to 3.3 mm <sup>2</sup> ) between bus bar and devices.  Without Bus Bar: 14 to 12 AWG (2.1 to 3.3 mm <sup>2</sup> )	Dark Blue with Yellow Stripe	Dark Blue with Yellow Stripe
-12 VDC		Black with Yellow Stripe	Black with Yellow Stripe
+24 VDC Primary		Red	Red
+24 VDC Redundant		Red with Yellow Stripe	Red with Yellow Stripe
-24 VDC		Black	Black
DC Ground to Local Ground Reference	8 AWG (8.3 mm <sup>2</sup> )	Green <sup>(1)</sup>	Green <sup>(1)</sup>
Cable Shield Ground	12 AWG (3.3 mm <sup>2</sup> )	Light Green	Light Green
Ground to DIG	1/0 to 4/0 AWG (50 to 120 mm <sup>2</sup> ) <sup>(2)</sup>	Green	Green
1. Green always means that the wire is a ground reference with no current flowing through it under normal operating conditions. 2. The wire size is chosen depending on the distance to the DeltaV Instrument Ground. See Table C-2 below.			



Table C-2 lists the wire sizes to use for wiring between an isolated local ground reference and an isolated common ground reference as well as between an isolated common reference point and the control system ground (CSG), depending on distance. Use multiple-strand wire – not solid wire.

**Table C-2. Ground Wire Sizing Chart**

<b>Wire Length</b>	<b>Wire Size</b>
Up to 25 feet	1/0 (50 mm <sup>2</sup> )
Up to 50 feet	2/0 (70 mm <sup>2</sup> )
Up to 200 feet	4/0 (120 mm <sup>2</sup> )

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# Index

---

## Numbers

- 12 VDC to DC system power supply grounding, 4-16
- 200 cable-feet limit, 4-6
- 24 VDC to DC system power supply grounding, 4-16

---

## A

- above ground AC cable, 2-4
- AC conductor isolation, 2-4
- AC distribution system power drop, 2-1
- AC line devices, quality control, 2-2
- AC to DC system power supply grounding, 4-14
- air terminals, 8-2
- alarm contacts, shelf condition, 6-1
- alarms, system power supply, 6-1
- analog current signals, 1-6
- analog voltage signals, 1-6
- ANSI/ISA–84.01–1996, 1-2
- ANSI/ISA–RP12.6–1995, 1-7, 4-20
- applying existing ground systems, 4-7
- AS–Interface, 5-10
- AS–Interface web site, 5-10
- avoiding ground loops, 5-3

---

## B

- backup power considerations, 1-4
- barrier strips with shorting bars, 4-17
- barrier strips, 3-4
- boundary conditions, 1-2
- bulk power supply grounding, 4-17
- bulk supplies, sharing and non-load sharing, 4-17
- bussed field power, 3-3

---

## C

- cable for fieldbus systems, 1-7
- cable for very low signal devices, 1-7
- cable length limit, DC power redundancy, 3-1
- cable specifications, variable speed drives, A-8
- cable trays, 5-2
- cable types, 1-6
- carrier field power connections, 3-4
- CENELEC Standard EN50295, 5-10
- circuit breakers, 2-15
  - ratings, peripheral equipment, 2-14
- Class 1, Div. 2 locations, 5-9
- color codes
  - importance of consistency, C-1
  - wiring, C-1
- commercial AC power, 2-1
- common grounding, 4-14
- conductor isolation, 2-4
- control matched inverter, variable speed drives, A-3
- control network isolation, 4-5
- crossing signal and AC lines, 5-5
- CSA C22.1 Section 10, 4-9

---

## D

- daisy chaining caution, 3-4
- DC passthrough power supplies, 3-1
- DC power distribution, 3-1
- DC power redundancy, 3-1
- DC returns, 4-12
- device case grounding, 5-3
- DeviceNet interface, 5-12
- DeviceNet web site, 5-12
- devices for maintaining AC line quality, 2-2
- distances for earth ground testing probes, 7-7
- distribution system power drop, 2-1

---

## E

earth ground, 1-5  
earth ground resistance value, 7-10  
earth ground testing, 7-7  
earth grounds, maximum resistance, 7-1  
effective grounding, 4-7  
effects of high frequency noise on variable speed drives, A-5  
electrical arc suppression for discrete devices, 3-6  
electrical ground isolation, 4-14, 4-16, 4-17  
electrical noise effects, 1-3  
electrical noise isolation, 1-4  
electrical spikes, minimizing damage, 4-6  
electromagnetic interference (EMI), minimizing, 5-2  
electromagnetic standards compliance, 5-2  
electrostatic coupling, protection from, 5-3  
enclosure group grounding, 4-7  
enclosure or rack power, 2-11  
enclosures. *See also* device case ground  
enclosures and racks, grounding, 4-7  
existing ground systems, 4-7

---

## F

field power, 3-3  
field power connections on a carrier, 3-4  
fieldbus cable, 1-7  
FOUNDATION Fieldbus web site, 5-14  
FOUNDATION Fieldbus wiring, 5-14

---

## G

good installation practices, 1-4  
ground isolation, electrical, 4-14, 4-16, 4-17  
ground loops, avoiding, 5-3  
ground rods, 7-1  
ground system testing, 7-7  
ground wire lengths, C-2

ground wire size, workstations, 4-14  
ground, single-point, 4-2  
grounding  
    device cases, 5-3  
    effective methods, 4-7  
    intrinsic safety installation, 4-20  
    single-point, 4-1  
    system, 4-1  
grounding bars, 4-10  
grounding workstations, 4-7  
grounds  
    braided wire size, 4-13  
    conformance to codes, 4-8  
    earth, 7-1  
    effective grounding, 4-10  
    labeling, 4-12  
    lightening protection, 8-2  
    proper impedance, 4-12  
    termination point, 4-8  
    tying together, 4-14  
    wire color coding, 4-12  
    wire shields, 4-13  
    wire sizing, 4-10  
guidelines, effective grounding methods, 4-7

---

## H

hazardous area considerations, 5-9

---

## I

I/O card pairing, 3-4  
I/O carrier field power connections, 3-4  
IEEE Std 1100–1992, 1-5  
IEEE Std 142–1991, 1-8  
IEEE Std 518–1982, 1-7, 5-4  
IEEE Std 81, 7-7  
IGBT inverter grounding, A-4  
inductive coupling interference, 5-5  
industry standards  
    ANSI/ISA–84.01–1996, 1-2

ANSI/ISA–RP12.6–1995, 1-7, 4-20  
 CENELEC Standard EN50295, 5-10  
 CSA C22.1 Section 10, 4-9  
 IEEE Std 1100–1992, 1-5  
 IEEE Std 518–1982, 1-7, 5-4  
 IEEE Std 81, 7-7  
 IEEE Std 142–1991, 1-8  
 NEC 250–146(d), 4-14  
 NEC 250–30(a)(2), 4-9  
 NEC 250–54 Supplemental Grounding Electrode, 4-9  
 NEC 334–1, A-8  
 NEC 500, 5-9  
 NEC Article 250–119, 4-9  
 NEC Section 504, 4-20  
 NEC Table 250–122, 4-9  
 NEMA Type 5–15R receptacle, 2-14  
 NFPA–78, 1-8

initial inrush currents, 2-2  
 input voltage range limitations, 2-2  
 inrush current limits, 1-4  
 inrush currents, 2-2  
 intrinsic safety installation grounding, 4-20  
 intrinsic safety considerations, 3-6  
 intrinsically safe I/O systems, 1-7  
 isolated common ground reference, 2-13  
 isolated local ground reference, 2-13  
 isolation transformer, 1-4, 2-2  
     variable speed drives, A-2

---

## J

junction boxes, 5-5

---

## L

labeling ground points, 4-12  
 large motor transients, 2-1  
 lightning conductor impedance, 8-3

lightning conductor radius, 8-3  
 lightning discharge, 8-2  
 lightning protection, 1-8  
 limiting EMI coupling on cable, 4-6  
 line voltage variations, 2-3  
 load sharing bulk supplies, 4-17  
 local area definition, 4-2  
 localbus isolator, 1-7, 3-6

---

## M

marshalling panels, 5-5  
 MC Type cable, variable speed drives, A-2  
 mean time between failure (MTBF), 1-2  
 mean time to repair (MTTR), 1-2  
 metal bars for grounding, 4-10  
 metal conduit, 5-2  
 metal conduit use, 5-5  
 minimizing process interruptions, 1-1  
 minimum separation between signal and AC lines, 5-4  
 minimum voltage drop on cable, 3-1  
 motor transients, 2-1  
 multi-conductor cables, 1-6

---

## N

NEC 250–146(d), 4-14  
 NEC 250–30(a)(2), 4-9  
 NEC 250–54 Supplemental Grounding Electrode, 4-9  
 NEC 334–1, A-8  
 NEC 500, 5-9  
 NEC Article 250–119, 4-9  
 NEC cable types, 1-6  
 NEC Section 504, 4-20  
 NEC Table 250–122, 4-9  
 NEC wire types, 1-6  
 NEMA Type 5–15R receptacle, 2-14  
 NFPA–78, 1-8  
 noise  
     caused by static discharge and lightning, 1-5

high frequency spikes from variable speed drive, A-3  
noise isolation, 1-4  
noise suppression, variable speed drives, A-3  
non-load sharing bulk supplies, 4-17

---

## O

operational conditions, 1-2  
oscilloscope testing, B-1  
overhead cabling, 2-4

---

## P

pairing of I/O cards, 3-4  
passthrough power supplies, 3-1  
percent available time, 1-2  
plant grid, 7-1  
plotting earth ground resistance, 7-7  
poor or faulty grounds, 1-5  
power calculation, 2-3  
power for small auxiliary AC loads, 2-15  
power for workstations, 2-14  
power interruptions, 2-2  
power supplies, grounding, 4-14, 4-16, 4-17  
primary power calculation, 2-3  
primary power source, requirements, 2-2  
probes for earth ground testing, 7-7  
Profibus interface, 5-16  
Profibus web site, 5-16  
protecting pulse count signal integrity, 5-2  
protecting signals from AC power fields, 5-4  
pulse count signals, protecting their integrity, 5-2  
pulse rise and fall time, variable speed drives, A-8  
pulse width modulation, A-1

---

## Q

quality  
    helpful devices, 2-1  
    issues, 2-1  
quick-disconnect cable not recommended, 5-9

---

## R

radio frequency interference (RFI), 5-2  
recommended distances between signal cables and power lines, 1-6  
reliability issues, 1-3  
repeating power interruptions, 2-2  
ring tongue connectors, 5-1

---

## S

safety  
    backup power, 1-4  
    earth ground, 1-5  
    intrinsic safety considerations, 3-6  
    minimizing accidental shock hazards, 4-6  
    system electrical ground, 1-5  
    warnings, cautions, x  
separating field and system power, 3-3  
separating plant area power, 4-2  
separating signal cables and power lines, 1-6  
separation between signal and AC lines, 5-4  
shield grounding, 4-13  
shield grounds, recommendations, 5-1  
shielded twisted pair cable, 5-2  
signal wiring guidelines, 5-1  
signal wiring size, 5-1  
signal wiring spares, 5-1  
single-phase AC power, 2-2  
single-point ground, 4-1, 4-2  
slope method, 7-9  
snubbers, resistor-capacitor, 3-6  
spade tongue connectors, 5-1

---

- starting transients, 2-3
- stray current generation, variable speed drive, A-4
- suppressing electrical arcing with discrete devices, 3-6
- system availability, 1-1
- system electrical ground, 1-5
- system grounding, 4-1
- system power supply grounding, 4-16
  - AC to DC, 4-14
- system reliability issues, 1-3

---

## T

- tape-wrapping shield ends, 5-2
- TC Type cable, variable speed drives, A-2
- test points, designing in, 5-1
- testing
  - with grounds, 7-7
  - with oscilloscopes, B-1
- three-phase AC power, 2-2
- three-point method, 7-7
- transients, large motors, 2-1
- true earth ground, 4-12
- twisted-pair cable, 1-6
- twisted-pair wiring, when to use, 5-4
- two-point method, 7-9

---

## U

- Ufer ground systems, 7-2
- underground AC cable, 2-4
- underground cabling, 2-4
- uninterruptible power supplies (UPS), 2-3

---

## V

- variable frequency drives, A-1
- variable speed drives, A-1
  - cable lengths, A-1
  - carrier frequency, A-1
- voltage drop, minimum on cable, 3-1
- voltage regulation, 1-4

---

## W

- web site
  - AS-Interface, 5-10
  - DeviceNet, 5-12
  - FOUNDATION Fieldbus, 5-14
  - Profibus, 5-16
- web sites for earth ground testing, 7-7
- wire braids for grounds, 4-13
- wire lengths, C-2
- wire size, C-1
- wire sizing
  - for load currents, 2-3
  - for voltage drop, 2-3
  - grounds, 4-10
- wire types, NEC, 1-6
- wiring
  - guidelines for signal, 5-1
  - twisted pair, 5-4
- wiring color codes, C-1
- workstation power, 2-14
- workstations, grounding, 4-7

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**Notes**



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