VFD Installation Considerations

Line Side
Input Cabling: Recommendations

In general, the selection of cable for AC input power to a drive has no special requirements. Some installations may suggest shielded cable to prevent coupling of noise onto the cable – typically to meet EMC standards for CE, C-Tick, FCC, or others.

*Not the same recommendation as motor cables. Motor cables must handle PWM signals.

General Requirements

- **Type** - Copper only
- **Size** – differs per drive. Depends on local or NEC codes.
- **Shielded or Unshielded** - Shielded provides noise immunity to EMC standards (CE, C-Tick, FCC, etc). If shielded cable is used the shields must be bonded at both ends to provide a continuous path for common mode noise current.
- **Industries** - Individual industries may have required standards due to environment or experience
- **Be careful** about bundling cables in conduit
Input Protection: Recommendations

Thermal Magnetic Breaker (Acceptable)
Bussmann DFJ Drive Fuse (Recommended)
Ferraz Shawmut HSJ Fuse (Recommended)

2 important considerations when selecting protection:
1. The device must be able to withstand the starting current and duty cycle of the motor circuit without melting.
2. The device must be able to clear a fault quickly enough to minimize damage to the drive or soft starter.

Melting Characteristics

Fast acting fuses have:
Higher interrupt rating
Faster interrupt rating
Prevents rupturing of IGBT’s
Agenda

- VFD Basics
- Proper Input Cabling
- Proper Input Protection

**Proper Grounding**

- Proper Input Impedance
- Power Quality Issues
- Panel Installation
## Types of Secondary Transformer Grounding

The type of transformer and the connection configuration feeding a drive places an important role in its performance and safety.

### Most common

<table>
<thead>
<tr>
<th>Type</th>
<th>Connection Configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 Phase, 3 Wire</td>
<td>Ungrounded Delta</td>
</tr>
<tr>
<td>3 Phase, 4 Wire</td>
<td>Hi-Log Grounded Delta</td>
</tr>
<tr>
<td>3 Phase, 4 Wire</td>
<td>Wild Cat Grounded Delta</td>
</tr>
<tr>
<td>3 Phase, 4 Wire</td>
<td>Center Grounded Delta</td>
</tr>
<tr>
<td>3 Phase, 5 Wire</td>
<td>Open Delta</td>
</tr>
<tr>
<td>3 Phase, 3 Wire</td>
<td>“B” Phase Grounded Open Delta</td>
</tr>
<tr>
<td>3 Phase, 4 Wire</td>
<td>Hi-Log Grounded Open Delta</td>
</tr>
</tbody>
</table>

**Did You Know?**

The type of transformer and the connection configuration feeding a drive places an important role in its performance and safety.
Positives & Negatives of Certain Grounding Systems

**Ungrounded System**
- Provide greater continuity of operations in the event of a ground fault
- Potential for high voltage buildup from the chassis of the VFD and internal power components
- Lack of voltage reference can create unsafe voltage conditions on DC bus
- Potential for arcing ground faults
- Acceptable but MUST remove MOV and Common Mode Cap jumpers

**High resistance grounded or poorly grounded system**
- Added benefit of a controlled path for common mode noise currents
- Designed to limit short circuit currents to ground
- Acceptable but MUST remove MOV and Common Mode Cap jumpers

**Solidly grounded** *(RA recommended for best protection of VFD)*
- No potential for high voltage buildup from the chassis of the VFD and internal power components
- Controlled path for common mode noise current
- Consistent line to ground voltage reference, which minimizes insulation stress
- Accommodation for system surge protection schemes
- Must leave MOV and Common Mode Cap jumpers installed
Grounding System Recommendations

Ungrounded Delta System
Acceptable but adding a grounded isolation transformer is preferred for VFD protection.

High Resistance Grounded System (or poorly grounded systems)
Acceptable

Solidly Grounded System
1 Ohm or less to ground
* Recommended because of VFD internal safety protections require reference to ground.
ATTENTION: When installing a drive on an ungrounded, high-
resistance or B phase grounded distribution system, disconne-
the phase-to-ground MOV circuit and the common mode
 capacitors from ground.

Table 14 - Recommended Power Jumper Configurations Fra

<table>
<thead>
<tr>
<th>Power Source Type</th>
<th>Jumper PE-A (1) (MOV / Input Filter Caps)</th>
<th>Jumper PE-B (DC Bus Common mode Caps)</th>
<th>Benefits Of Correct Configuration on Power Source Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-Solid Ground</td>
<td>Disconnected</td>
<td>Disconnected</td>
<td>Helps avoid severe equipment damage when ground fault occurs</td>
</tr>
<tr>
<td>• AC fed ungrounded</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Impedance grounded</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• B phase ground</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• DC fed from an active converter</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solid Ground</td>
<td>Connected</td>
<td>Connected</td>
<td>UL compliance, Reduced electrical noise, Most stable operation, EMC compliance, Reduced voltage stress on components and motor bearings</td>
</tr>
<tr>
<td>• AC fed solidly grounded</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• DC fed from passive rectifier which has a solidly grounded AC source</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(1) When MOVs are disconnected, the power system must have its own transient protection to insure known and controlled voltages.
Protective Jumper Locations

Powerflex 750 Series Frame 2-5

MOV, AC EMI Capacitor, and Common Mode Capacitor Circuits

Figure 1.12 MOV and AC EMI Capacitor Phase to Ground

Figure 1.13 Common Mode Capacitors to Ground

Figure 1.15 Typical Frame 2...5 Jumper Screw Installation Locations (Frame 4 shown)

Powerflex 525 All Frames

Jumper Location (Typical)

Power Module

IMPORTANT
Tighten screw after jumper removal.

Phase to Ground MOV Removal

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MOV and Common Mode Cap Jumpers PF750 Series Drives
#6 Common Fault- F13 Ground Fault

<table>
<thead>
<tr>
<th>Type</th>
<th>Cause</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (resettable)</td>
<td>A current path to earth ground has been detected at one or more of the drive output terminals. &gt;25% of drive rating</td>
<td>Check the motor and external wiring to the drive output terminals for a grounded condition</td>
</tr>
</tbody>
</table>

Troubleshooting: Does the motor run across the line, or disconnect motor from drive and see if drive does not trip. Remember proper jumpers for MOV and Common Mode Caps.
#2 Common - F05 Over Voltage

- DC bus voltage exceeded maximum value.
  - Decelerating too fast with high inertia load
  - Sudden loss of load
  - Input line voltage disturbance
  - Power factor correction caps
  - Wrong Jumper of Common mode capacitors cause bus voltage to increase
  - MOV jumpers in on ungrounded system
  - Tach Loss

Solutions

- Dynamic braking is needed
- Extend deceleration time
- Install input line reactor or isolation transformer
- Check MOV and Common Mode Capacitor jumper
- Turn on Bus Regulation
How do I know when I need to add impedance?

1. Installation site has switched power factor correction capacitors.
2. Installation site has reoccurring lightning strikes or voltage spikes in excess of 6000V Peak.
3. Installation site has power interruptions or voltage dips in excess of 200VAC.
4. Voltage unbalance trips
5. The transformer is too large in comparison to the drive. General rule is if the transformer is more than 10x the impedance of the VFD. See calculation:
Rule of thumb:
1. Is the transformer kVA greater than 10x the drive kVA?  
   or
2. Is the transformer impedance less than 0.5% of the VFD.

If so, Add impedance

Drive Impedance (in ohms)

\[ Z_{\text{drive}} = \frac{V_{\text{line-line}}}{\sqrt{3} \cdot I_{\text{input-rating}}} \]

Transformer Impedance (in ohms)

\[ Z_{\text{xfmr}} = \frac{V_{\text{line-line}}}{\sqrt{3} \cdot I_{\text{xfmr-rated}}} \times \% \text{Impedance} \]

\[ Z_{\text{xfmr}} = \frac{(V_{\text{line-line}})^2}{VA} \times \% \text{Impedance} \]

\% Impedance is the nameplate impedance of the transformer
Typical values range from 0.03 (3%) to 0.06 (6%)
Sample Calculation of Impedance

**EXAMPLE**

The drive is rated 1 Hp, 480V, 2.7A input.
The supply transformer is rated 50,000 VA (50 kVA), 5% impedance.

\[ Z_{\text{drive}} = \frac{V_{\text{line-line}}}{\sqrt{3} \cdot I_{\text{input-rating}}} = \frac{480V}{\sqrt{3} \cdot 2.7} = 102.6 \text{ Ohms} \]

\[ Z_{\text{xmr}} = \frac{(V_{\text{line-line}})^2}{\text{VA}} \cdot \% \text{ Impedance} = \frac{480^2}{50,000} \cdot 0.05 = 0.2304 \text{ Ohms} \]

Note that the percent (%) impedance has to be in per unit (5% becomes 0.05)
for the formula.

\[ \frac{Z_{\text{xmr}}}{Z_{\text{drive}}} = \frac{0.2304}{102.6} = 0.00224 = 0.22\% \]

0.22% is less than 0.5%. Therefore, this transformer is too big for the drive and
a line reactor should be added.

For a more accurate portrayal of impedance you can add the impedance
of the cable from the transformer to the drive. It can add another 5-20
ohms to the transformer.
Multi-Drive Questions?

Use a separate line reactor for each drive that shares a common power line. Individual line reactors provide filtering between each drive to provide optimum surge protection for each drive. However, if it is necessary to group more than one drive on a single AC line reactor, use this process to verify that the AC line reactor provides a minimum amount of impedance:

- In general, up to five drives can be grouped on one reactor.
- Add the input currents of the drives in the group.
- Multiply that sum by 125%.
- Refer to 1321 Power Conditioning Products Technical Data, publication 1321-TD001, to select a reactor with a maximum continuous current rating greater than the multiplied current.

**Example**

There are five drives. Each drive is rated 1 Hp, 480V, 2.7 A. These drives do not have internal inductors.

- Total current is $5 \times 2.7 \text{ A} = 13.5 \text{ A}$
- $125\% \times \text{Total current is } 125\% \times 13.5 \text{ A} = 16.9 \text{ A}$

From 1321 Power Conditioning Products Technical Data, publication 1321-TD001, we selected the catalog number 1321-3R12-C reactor. This reactor has a maximum continuous current rating of 18 A and an inductance of 4.2 mH (0.0042 henries).

$$
Z_{\text{drive}} = \frac{V_{\text{line-line}}}{\sqrt{3} \times I_{\text{input-rating}}} = \frac{480\text{V}}{\sqrt{3} \times 2.7} = 102.6 \text{ Ohms}
$$

$$
Z_{\text{reactor}} = L \times (2 \times 3.14) \times f = 0.0042 \times 6.28 \times 60 = 1.58 \text{ Ohms}
$$

$$
\frac{Z_{\text{reactor}}}{Z_{\text{drive}}} = \frac{1.58}{102.6} = 0.0154 = 1.54\%
$$

1.54% is more than the 0.5% impedance recommended. The catalog number 1321-3R12-C reactor can be used for the five 2.7 A drives in this example.
Isolation Transformers vs Line Reactors

**Isolation transformers**

Are generally used to:
- Establish a grounded secondary
- Provide additional source impedance
- Add a neutral secondary

Transformers will not saturate as quickly as a reactor and therefore provide a better solution on distributions having Power Factor correction capacitors or subject to non sinusoidal transients.

Cost $$$, Size $$$

**Reactors**

Are generally used to:
- Provide additional source impedance
- Dampen input voltage signal from poor power quality

Cost $, Size $ - Pub 1321
Power Quality vs. Power Reliability

- **Power Quality**: Related to fluctuations in electricity, such as momentary interruptions, voltage sags or swells, flickering lights, transients, harmonic distortion and electrical noise
  - Fewer such incidents indicate greater power quality
  - Events go mostly untracked by Utilities

- **Power Reliability**: Continuity of electric delivery measured by the number and duration of power outages (Zero voltage)
  - Outages are tracked by Utilities
  - Power can be as high as 99.999% reliable
  - Remaining 0.001% can disrupt process as many as 20-30 times per year

The Grid is designed for Reliability, not Quality...
**Common Problems: Power Sags & Surges**

**Power Surges** – A rapid short-term increase in voltage. Surges often are caused when high power demand devices such as air conditioners turn off and the extra voltage is dissipated through the power line. Under these conditions, computer systems and other high tech equipment can experience equipment shutoff, errors or memory loss, component stress, and cause premature failure.

**Power Sags** A rapid short-term decrease in voltage. A sag typically is caused by simultaneous high power demand of many electrical devices such as motors, compressors and so on. The effect of a sag is to “starve” electronic equipment of power causing unexpected crashes and lost or corrupted data. Sags also reduce the efficiency and life span of equipment such as electric motors.
The Most Common Event: Voltage Sag

**Sag** - RMS voltage reduction between 1/2 cycle - 60 sec

- **Primary impact** is equipment drops offline
  - PLC shutdown, Open contact or Relay
  - PF750-series drives have passed SEMI F47 testing – some sag protection built-in
- **Secondary Impact:** As voltage returns, high current inrush can damage susceptible equipment
  - RF Amplifiers, Gradient Amplifiers, and Low Voltage Power Supplies subjected to repeated hits—Failure or reduced product life.
  - Potential impact for all electronic equipment varies by installation

**Voltage Sags < 2 seconds account for over 90% of all grid events**

*Source: EPRI*
What can you do about sags?

### i-Sense Voltage Monitor
- Provides instant notification via text or email when an event occurs
- Offers a cost-effective, permanent monitoring solution
- Identifies the most common source of disruptive dirty power events in utility feeds
- Provides 26 voltages 100...480V AC
- Supports modem or Ethernet connectivity
- Offers 50...60 Hz auto-sensing capabilities

### DySC Voltage Sag Protectors
- Prevents damage to sensitive electrical equipment
- Offers machine to facility-wide protection
- Includes a single- and three-phase portfolio
- Provides up to five seconds of ride-through
- Protects against brief, complete voltage loss
- Environmentally friendly – no batteries
- 2A – 2400A available
Balanced Voltage

3% Imbalanced Voltage

Fig. 5. Line currents of a 5 HP AC PWM drive for balanced voltages.

Fig. 6. Line currents of a 5 HP AC PWM drive for 3% voltage unbalance.
When a sine wave is distorted by harmonics it can look like this.
What are harmonics?

Harmonics are additional waveforms caused by fast switching of electronic components. They are multiples of the fundamental frequency (60Hz) and typically represented as the 3rd, 5th, 7th, 9th, 11th, etc. frequencies.

When they are summed together they distort the fundamental frequency that is seen by electric equipment.
Harmonics exist here…

Power Source → AC Drive → Motor

Line Current Harmonics
What types of devices cause harmonics?

**Linear Loads don’t cause harmonics**
- Induction motors
- Incandescent lights
- Resistance heaters
- Electromagnetic devices
- Transformers

**Non-Linear Load cause harmonics**
- Welders
- Arc furnaces
- UPS
- DC power supplies
- DC Drives
- **AC Drives**
- Fluorescent lights (ballast)
- Incandescent lights with light dimmers
- Anything with an ac-dc power supply: Computers, Monitors, TVs, Fax machines
When are harmonics a problem?

- If service transformer is loaded near rating 60%
- 20% of total load is non-linear electronic load
- When PF correction capacitors used or planned
- When voltage distortion exceeds 8%

Per IEEE 519, harmonics are measured at the PCCC, not at each drive input terminals.
What problems do harmonics create?

- Increased Utility current requirement
  - Inability to expand or utilize equipment
  - Larger wire size needed = increased installation costs

- Component overheating
  - Distribution transformers, generators & wires

- Reduced Utility power factor
  - Increase in utility costs

- Equipment malfunction
  - Due to voltage distortion with multiple or loss of zero crossing
  - Due to voltage distortion such as flat topping

- Excitation of Power System Resonance’s creating over-voltage’s (If PFCC in system)
Current Harmonic Limits as defined by IEEE519: 5 levels based on \( \frac{I_{sc}}{I_{load}} \) or the “stiffness” of the supply. TDD % refers to measurement at full load (not half, quarter, etc).

**Table 10.3**

<table>
<thead>
<tr>
<th>( \frac{I_{sc}}{I_{load}} )</th>
<th>&lt;11</th>
<th>11&lt;=h&lt;17</th>
<th>17&lt;=h&lt;23</th>
<th>23&lt;=h&lt;35</th>
<th>35&lt;=h</th>
<th>TDD (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;20</td>
<td>4.0</td>
<td>2.0</td>
<td>1.5</td>
<td>0.6</td>
<td>0.3</td>
<td>5.0</td>
</tr>
<tr>
<td>20&lt;50</td>
<td>7.0</td>
<td>3.5</td>
<td>2.5</td>
<td>1.0</td>
<td>0.5</td>
<td>8.0</td>
</tr>
<tr>
<td>50&lt;100</td>
<td>10.0</td>
<td>4.5</td>
<td>4.0</td>
<td>1.5</td>
<td>0.7</td>
<td>12.0</td>
</tr>
<tr>
<td>100&lt;1000</td>
<td>12.0</td>
<td>5.5</td>
<td>5.0</td>
<td>2.0</td>
<td>1.0</td>
<td>15.0</td>
</tr>
<tr>
<td>&gt;1000</td>
<td>15.0</td>
<td>7.0</td>
<td>6.0</td>
<td>2.5</td>
<td>1.4</td>
<td>20.0</td>
</tr>
</tbody>
</table>

**Even harmonics are limited to 25% of the odd harmonic limits above**

**Maximum Harmonic Current Distortion in Percent of \( I_{load} \)**

\( I_{sc} = \) maximum short circuit current at PCC

\( I_{load} = \) maximum demand load current (fundamental frequency component) at PCC
6 Pulse VFD

- Typical I(THD) of 30 to 40%
- Less sensitive to line transients

NOTE: $I_{pk}$ about 1.5x $I_{rms}$
6 Pulse VFD w/ 3% Line Reactor

- Typical I(THD) of 20 to 35%
- Big help for drives w/o DC link choke
- .75 - .95 PF

NOTE: shown is 3% LR
6 Pulse VFD w/ Passive Filter

- Typical I(THD) of 4 to 7%
- .3 to 1 PF
6 Pulse VFD w/ Active Filter

- Typical I(THD) of 3 to 6%
- .9 - .99 PF

Current from Transformer
Multi-Pulse VFD

- 12-Pulse Typical I(THD) of 9 to 12%
- 18-Pulse Typical I(THD) of 4 to 5%
- .90 - .99 PF
Publications

Wiring and Grounding Guidelines for PWM Drives
  - drives-in001_en-p

1321 Power Conditioning Products Technical Data
  - 1321-td001_en-p

Drives Engineering Handbook
  - 1300-DEH-10

AC Drive Installation Considerations
  - DRIVES-IN003A-EN-P