VFD Level II: Application Considerations

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Practical Items

Type questions here and click send.
How familiar are you with variable frequency drive applications?

A. Very familiar
B. Somewhat familiar
C. A little familiar
D. Not familiar at all
Application Considerations

- Installation Practices
- Environment/Enclosure integration/replacement
- Electrostatic Discharge (ESD)
- PID Looping
- Multiple motors on 1 VFD
- Converting from 1-φ to 3-φ
- Bearing Failures
- Long Lead Length
- Conducted Emissions
- Proper Grounding
- Total Harmonic Distortion (THD)
Installation Cautions

- Confirm Voltage
- Mount in a suitable location
- Maintain recommended clearances
- Follow good wiring practices
General Wiring

• Separate control wiring from all power wiring.
• Separate Line and Load wiring
• Keep wiring to motor separate from all other power wiring, whether from the same drive or other drive
General Wiring

- Use metallic conduit
- Separate by at least 3"
- Separate non-metallic conduit by at least 12"
- Cross at right angles
- Fuse drives as recommended
General Wiring

- Use one grounding conductor per device
- Do not loop ground conductors or install them in series

Figure 12: Grounding Multiple Drive Controllers
General Wiring

- Size branch circuit components, conductors, transformers and disconnects per the rated input current of the drive.
General Installation, Motor Cabling

Unique cabling issues:

• PWM drives inherently expose motors to high level common mode voltages and associated high dv/dt.

• These common mode voltages can introduce:
  • Damaging high frequency bearing currents
  • Stray high frequency ground currents which can lead to the malfunction of sensitive equipment (e.g. sensors)

• Prevention requires low impedance high frequency grounding between the inverter and the driven motor

• Acceptable cabling solutions include:
  • Continuous corrugated aluminum armored cable
  • Shielded cable (power)
  • Carefully installed conduit system
General Installation, **Motor Cabling**

**High Frequency Ground Return Paths**

Proper motor cabling should provide a significantly lower impedance high frequency ground return path through direct paths rather than through indirect paths.
General Installation, Motor Cabling

Recommended Cable Construction

- **BARE COPPER**
- **GROUND CONDUCTORS (3)**
- **INSULATED PHASE CONDUCTORS (3)**
- Sized per NEC for the application
- **INSULATING/PROTECTIVE OUTER PCV JACKET**
- **CONTINUOUS CORRUGATED ALUMINUM ARMOR/SHIELD**

Aluminum armor provides an excellent low impedance high frequency ground return path
Recommended Termination Method

Connector should provide:

- 360° contact with armor
- Grounding bushing for connection of safety grounds
- Metal to metal contact with mounting surface
Control Wiring

- Keeps runs short and direct
- Make sure your voltages are correct
- Use shielded cable and ground at drive only
- Use Transient Suppressors on all relays and solenoids
Radiated Emissions
Conducted Emissions

ECM Filter
Output Filter
Shielded Cable

Very High Frequency Waves
600 Khz - 6 Mhz

IEC and CE standards address this issue

100 ns
dv/dt
General Wiring Practices

- Never run motor power cables and control wiring in the same conduit or cable tray.
- Use shielded cable for all analog control signals and any DC control signals that operate below 24 VDC.
- If control signals are not in a separate steel conduit, keep them at least 12” from all power wiring.
- Cross power and control wiring at 90° if they must get close to one another.
- Ensure proper equipment grounding.
General Installation, EMI

Special EMI Reduction Practices

• Motor Cabling
  • Install cabling per Motor Cabling section (or per manufacturer’s recommendations)

• Shielding
  • Use CE rated equipment (shielding is part of design)
  • Follow manufacturer’s instructions for cable termination

• Grounding
  • Follow manufacturer’s instructions for equipment grounding
  • Ground process sensors (including shields) only at the receiver end (i.e. don’t create ground loops)
Enclosure Integration / Replacement
Environment & Performance

Temperature Considerations

• Drives have minimum and maximum temperatures at which they can operate at full rating. SE Nema 1 drives are rated at 0-50°C. However, most drives are typically 0°C (minimum) and 40°C (maximum).

• Often operation at higher temperatures is also possible if the output current is reduced to a specified level.

• In applications where the minimum temperature is expected to fall below the minimum temperature rating, space heaters should be specified.
Contaminate Considerations

- Drives are sensitive to both particulate matter and corrosive contaminates
- Particulate matter is normally specified as being above some minimum size
- Either filters or optional enclosure construction (e.g. NEMA 12 or NEMA 4) can usually solve particulate matter issues
- Corrosive contaminates are typically required to be below some maximum ppm
Ventilation Requirements

- Small drives are often designed to operate based on convection air flow alone.
- As drive size increases larger and larger amounts of forced cooling air are required (2,500 cfm or more).
- If either the quality or temperature of the available ventilation air is not acceptable, ducting of air from an external location may be required.
Mounting Requirements

• Drives have minimum clearance requirements in at least some directions
• Clearances may be required for thermal, access, or safety reasons
• Most drives are expected to be mounted in a specific mounting plane
• Drives carry maximum shock and vibration requirements
Electrostatic Discharge - ESD

- ESD Generation
  - Damages Caused By ESD
  - Preventative Measures
What Causes Electrostatic Charges

• Bringing Materials Together
• Rubbing Materials Against Each Other
• Rapid Separation Of Two Materials
• Placing Materials Close To Each Other

_The size of the charge is dependent of the speed of separation, humidity and materials used._
## Typical Electrostatic Voltages

<table>
<thead>
<tr>
<th>Means Of Static Generation</th>
<th>Voltage Levels</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10-20% Humidity</td>
</tr>
<tr>
<td>Walking Across Carpet</td>
<td>35,000</td>
</tr>
<tr>
<td>Walking Across Vinyl Floor</td>
<td>12,000</td>
</tr>
<tr>
<td>Common Poly Bag Picked Up</td>
<td>20,000</td>
</tr>
<tr>
<td>Common Sandwich Bag Or</td>
<td>20,000</td>
</tr>
<tr>
<td>Styrofoam Cup</td>
<td>18,000</td>
</tr>
<tr>
<td>Work Chair Padded With</td>
<td>6,000</td>
</tr>
<tr>
<td>Polyurethane Foam</td>
<td></td>
</tr>
<tr>
<td>Worker At Work Bench</td>
<td></td>
</tr>
</tbody>
</table>
Voltage Levels

Voltage Level Needed To Feel & Hear 1,000 Vdc

Voltage Level Needed To Damage Printed Circuit Boards 250 Vdc

Voltage Level Needed To Damage The Gate Lead Of An IGBT 25 Vdc
Types Of ESD Failures

**Catastrophic** - The component fails

**Latent** - The component is stressed and functions some of the time and will stop functioning in the future (after hours or when you're on vacation)
Reducing ESD Damage

Environment:

Floors
Work Surfaces
Equipment

People:

Body
Clothing
Procedures

Materials:

Raw Materials
Production Aids
Packaging Material
ESD Wrist Strap

To be worn when ever installing or removing printed circuit boards from drive with power disconnected.

To be worn when ever handling components that have been shipped in black conductive containers.

Test your wrist strap regularly.
PID Loop Control

- Proportional
- Integral
- Derivative
Typical Drive System

Input Power

Control

Motor

Electric Motor Driven Process

PID Control

Adjustable Frequency Drives are just one piece of the system
Multiple Motors

Application susceptible to reflected wave

- Special Considerations – Multiple Motors
  - Size drive for full load amp rating of all motors combined.
  - Provide separate motor overload.
  - Ramp up and down all motors at once
  - If “slamming” a motor into the circuit we need size the drive to provide the inrush requirements of the “slammed” motor.
Single Phase to Three Phase

- Special Considerations
  - Smaller drives are rated for this already
  - For larger, 230V HP’s
    - Size Drive 2x FLA of Motor
    - Add Line Reactor
    - Turn off input phase loss
  - For larger, 460V HP’s
    - Use 1-φ Power Supply
    - Add Line Reactor
    - Turn off input phase loss
Bearing Failures

- Special Considerations – Shaft Voltage Build-Up
  - Voltage build-up of 5-30V AC on the shaft is possible
  - Voltage will flash to ground
  - Typical flash point is bearings
    - This will pit the bearing and the race and cause fluting effect on bearing.
- Common solutions include:
  - Decrease carrier frequency from drive
  - Ground shaft with a brush
  - Use conductive grease
  - Specify ceramic bearings
  - Turn random PWM modulation OFF
Ionization of nitrogen gas caused by an intense electrical field. (Reflected wave) Insulation break down will occur.

Long Lead Length

- Use a cable with low capacitance phase-to-phase and to ground
- Do not use mineral impregnated cable
- Immersing cables in water increases capacitance
- The longer the cable the greater the capacitance
- Do not run cables from several drives near each other
- Don’t use lightning arrestors or pf cap’s on the output of a drive
- Output Disconnect – Make-before-break aux contact
Long Lead Lengths can cause Reflected or Standing Wave Phenomenon and Capacitive Coupling.

- Reflected Waveform is a voltage doubling at the motor terminals. The \( \frac{dv}{dt} \) leading edges are reflected causing voltage overshoot.
- Depending on motor and cable:
  - 25 HP and below ~ 75’ Smaller Motors have a larger inductance and less slot insulation resulting in a higher relative surge impedance.
  - 100HP and above ~300’
- Possible Solutions include: (effectiveness varies)
  - Lowering the carrier frequency of the drive
  - Use NEMA MG-1, Part 31 motors (1600v)
  - Install output reactors, sinusoidal filter or output filters at drive
  - Utilize VFD rated cable
  - Install RC Snubbers at motor (impedance matching network)

**Impedance:** The total passive opposition offered to the flow of electric current. *Note 1:* Impedance is determined by the particular combination of resistance, inductive reactance, and capacitive reactance in a given circuit.
Long Lead Length, Voltage Reflection

Motor Terminal Voltage Without Filter

DC Link Voltage

Voltage Reflection Spikes
PWM VSI Drive, Simplified Circuit

Reactors (design specific)

Rectifier | DC Link | Inverter

Input
Fixed Voltage
Fixed Frequency

Output
Variable Voltage
Variable Frequency

Motor
Long Lead Length, Voltage Reflection

Motor Terminal Voltage
With dv/dt Filter

DC Link Voltage

Voltage Reflection Spikes
(75% reduction)
Line Quality Issues

Total Harmonic Distortion
Sample example of fundamental, 5th and 7th harmonics:

\[
\begin{align*}
    f_1 &= 60 & \omega_1 &= 2\pi \cdot f_1 & i_1(t) &= 1 \cdot \cos(\omega_1 \cdot t) \\
    f_5 &= 300 & \omega_5 &= 2\pi \cdot f_5 & i_5(t) &= 0.32 \cdot \cos(\omega_5 \cdot t - \pi) \\
    f_7 &= 420 & \omega_7 &= 2\pi \cdot f_7 & i_7(t) &= 0.09 \cdot \cos(\omega_7 \cdot t - \pi)
\end{align*}
\]
Line Quality Issues, Harmonics

Summation of fundamental, 5th and 7th harmonics:

\[ i_T(t) = i_1(t) + i_5(t) + i_7(t) \]
Line Quality Issues, **Harmonics**

- **Harmonics are a System Issue**
  - Harmonics drawn (produced) by an individual load are only important to the extent that they represent a significant portion of the total connected load.
  - Linear loads help reduce system harmonic levels.
  - TDD equals the THD of the nonlinear load multiplied by the ratio of nonlinear load to total load:

\[ TDD = \text{THD}_{NL} \cdot \frac{NL}{NL + LL} \]

Where:
- \( TDD \) = TDD of the system
- \( \text{THD}_{NL} \) = THD of the nonlinear loads
- \( NL \) = kVA of nonlinear load
- \( LL \) = kVA of linear load
Line Quality Issues, **Harmonics**

Sample System Configuration

- **PCC1** (Harmonic Current Distortion) 13.8 KV
- **PCC2** (Harmonic Voltage Distortion) 4.16 KV
- **Substation Transformer**
- **MV PWM**
- **480 V**
- **To other utility customers**
Line Quality Issues, Harmonics

PWM Drive Input Current
Line Quality Issues, Harmonics

PWM Drive Harmonic Input Spectrum

![Graph showing PWM Drive Harmonic Input Spectrum with peaks at 5th, 7th, and Fundamental frequencies.](image-url)

**Current in Percent of Fund**

**Frequency in Hz**
Troubleshooting

- Trips-Not Resettable by Keypad/LI/Automatic
- Equipment Damage
- Trips-Resettable by Keypad/LI/Automatic
- Runs-Does Not Perform as Expected

Severity of Fault
Troubleshooting
• The Product Support Group is available 24 hours a day, 365 days a year.
• They will work with you over the telephone to diagnose product problems and advise the correct course of action.
• They are available in Raleigh NC until 5 PM and then available by Pager.
How likely are you to install a VFD in the next six months?

A. Very likely
B. Somewhat likely
C. Unlikely
D. I Don’t know
VFD Incentives

HVAC and non-HVAC (pumps and fans) Variable Frequency Drives (VFDs)

Incentive = $100/horsepower controlled
Energy Advisors

- Located throughout the Ameren Illinois territory
- Assist with projects and applications
- Can go with you to a customer to explain the program
Find a Contractor

Program Allies are here to help

Find a Contractor who is an ActOnEnergy® Program Ally

Searching for a contractor to help with your energy efficiency improvements?

Our ActOnEnergy® Program Ally database makes it easy to find a qualified contractor in your area. This database allows you to search for Program Allies by geographic region or type of service.

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Businesses participating in ActOnEnergy programs can also choose to install upgrades themselves or use other local contractors not registered with the ActOnEnergy business programs. However, because of their familiarity with the programs, Program Allies are well equipped to make your energy efficiency projects a success.

Search for Product or Program Ally

Program Ally Name:

Specialties:

Areas Served:

Customer Type:

Search
Quiz

What did you learn about energy efficiency?

1. How do you properly ground a VFD and motor?

2. When troubleshooting issues with the performance of a VFD, which of the following is the most common cause of fault?

3. What is the incentive amount for Variable Frequency Drives?
Questions?

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