Understand your Risks & Costs in Selecting the Wrong VFD Cable

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Why use Variable Frequency Drives?

• Greater Efficiency--Faster Return on Investment, Profitability
  – Increased system reliability
  – Reduced downtime
  – Reduced equipment setup time
  – Energy savings
    • A motor running at 63% speed uses 75% less energy
    • A motor running at 50% speed uses 90% less energy
  – Lower maintenance
  – Smoother operation (soft start)
Why use Variable Frequency Drives?

- Greater Control
  - Speed control
  - Flow control
  - Pressure control
  - Temperature control
  - Tension control
  - Torque control
  - Monitoring quality
  - Acceleration/deceleration control
    - Ramping up speeds increases equipment life
    - Smoother conveyer acceleration/deceleration
VFD Applications - Multiple

- Pumps
  - Chilled & Hot Water Pumps
  - Condensed Water Pumps
  - Booster Pumps
- Conveyers
- Centrifugal Fans
- Cooling Towers
- Circulation Fans (Parking Garages)
- Exhaust Fans (Clean Rooms, Labs, Hospitals)
A VFD System

Variable Frequency Drive

Variable Frequency Drive Cable

Motor
A Real World Factory Environment
Understand VFD system parameters

And the effect on the VFD Cable

\[
\text{CableType} + \sum_{n=\text{Cable Length}}^{\infty} \left( \frac{\text{Motor} \cdot \cos \left( \frac{n\pi \text{Gland}}{\text{Electronics}} \right) + \text{Drive} \cdot \sin \left( \frac{n\pi \text{Path}}{\text{Radios}} \right)}{\text{Bonding Straps} \cdot \text{Risetime}^2 + \frac{\text{Termination}}{\text{Building Impedance}}} \right)
\]
Understand VFD system parameters

Technology advances creating the migration from traditional **BJT** (Bipolar Junction Transistor) semiconductors to the newer **IGBT** (Insulated Gate Bipolar Transistor) semiconductors:

- Lower switching loss
- Lower drive package cost
- Faster transition rise times
- Higher frequency (Pulse Wave Modulation)
The High Frequency- Pulse Wave Modulation

PWM high frequency waveforms are a major cause of issues
The Fall of Rise times

Rise time in microseconds

Year

1970 1985 2000

Trise falls through the years
Understand VFD system parameters

• New Technological Advances
  • IGBT - PWM VFD technology
  • Insulated Gate Bipolar Transistor - Pulse Wave Modulation

• Benefits of VFDs using PWM technology
  • More control over motors
  • Improved system efficiency
  • Smaller drive sizes

• Challenges of VFD systems
  • Rapid switching rates
  • Induced voltage hazards
  • Standing or reflected waves
  • Common mode ground current

*General Cable estimates that half of our customers who use VFDs are not using VFD cable*

There are no UL standards for VFD cable at this time
VFD System Concerns- From newer technology

Issues

– Premature Motor Failure
– Premature Cable Failure
– Malfunction of other equipment
  • Intermittent issues
  • *Complete shut down*

The Cause

– The High Frequency components of the Inverter output
  • Electromagnetic Interference
  • Common Mode Current
  • Reflected Waves
VFD System Concerns-
From Newer Technology

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VFD System Concerns

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  - Electromagnetic Interference
    - EM Radiation
    - EM Induction
  - Common Mode Current
  - Reflected Waves
Electromagnetic Radiation

- Traditional power cable can act as a large radiating loop antenna.
- Radiated noise negatively affects instrumentation controls, radio devices, and fire & gas alarms.
- Severity is related to:
  - The distance between the cable and the equipment.
  - The design of the equipment
  - The high frequency information in the inverter output waveform.
  - The terminations used
  - The type of cable used
  - The shielding between the cable and the equipment

- Can choosing the Right Cable help?

*Shielded cable is a must to minimize radiated EMI.*
Electromagnetic Radiation

• **An effective cable system can help!**
  - An effective overall shield greatly reduces radiated EMI.
  - Shield and ground wires should be terminated as directed by the VFD manufacturer (single vs. multi-point).
  - 360 degree termination of the cable’s shield.

• **Electromagnetic Radiation can**
  - Kill equipment
  - Kill drives
  - Kill People

*There is more to a shielded cable solution than a shielded cable!*
VFD System Concerns - From New Technology

Issues

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- The High Frequency components of the Inverter output
  • Electromagnetic Interference
    - EM Radiation
    - EM Induction
      » Common Mode Current
      » Reflected Waves
Electromagnetic Induction & Common Mode Current

- Electromagnetic Induction: The production of a voltage across a conductor when exposed to a varying magnetic field.

- Common mode current is the total net flow of current in the cable.

\[ i_{cm} = i_{conductors} + i_{grounds} + i_{shield} \]

- The ideal (and least problematic) situation is for the common mode current equal zero. The less the CM current the better!
What’s bad about CM Current?

- Premature motor bearing failure
- **Interference** with
  - PLC’s and PLC communication Networks
  - Sensors,
  - Encoders
  - AM radio interference
  - 0 – 10 volt or 4 – 20 mA signal interference
- **Shock Hazard**
  - Motor frame voltages at a potential of 100 Volts higher than the inverter frame have been measured.
To Summarize: Electromagnetic Induction Kills

- **Killing/Injuring People**
  - Energized VFD Cable can induce dangerous or potentially fatal voltage/current in a locked out nearby cable.

- **Killing Motors/Equipment**
  - Energized VFD Cable will induce current in the cable itself.
  - This current is called common mode current.

Can you afford this?

*Common mode currents are a big issue in VFD systems*
Why?

The High Frequency PWM waveforms

No issue in 60 Hz systems
The common mode source?

High frequency PWM waveforms

Not this

But this

It’s that high frequency stuff once again.
The common mode source?

- High frequency PWM waveforms

It’s that high frequency stuff once again.
Why?

• Because $V = IR$

• Common Mode Current will cause a voltage potential difference between the inverter ground and the motor frame.

• This voltage will cause current to leak from the motor frame *back to the inverter frame.*
Possible CM Current Paths

Where does the current go?

Where is it going to go?
Possible CM Current Paths

• The current may flow through the motor cable ground from the motor terminal box to the inverter ground.

• The current may also flow through the motor frame to a grounded motor base plate from there it can travel through any and all conducting paths to the ground grid, from there back to the transformer grounds, and finally back to the inverter ground.

• Another possible path is through an alternate path of equipment connected to the motor via a conducting shaft, and through the connected equipment then through any and all conducting paths to the ground grid.

• The current can flow from the motor cable shield, armor or conduit from the motor terminal box to the inverter frame.
Possible CM Current Paths

Where is it going to go?

Where does the current go?
What?

The cable ground conductor is
– a great path for 60Hz Power
– a horrible path for HF components

Why?
– Because the resistance of a round wire is…

\[ R = \frac{\sqrt{2\pi f \mu}}{\sigma \pi d} \left[ \frac{\text{Ber}(q)\text{Bei}'(q) - \text{Bei}(q)\text{Ber}'(q)}{(\text{Ber}'(q))^2 + (\text{Bei}'(q))^2} \right] \Omega \frac{m}{m} \]
– As frequency increases (f), so does resistance (R)!
Possible CM Current Paths

Through the motor cable ground from the motor terminal box to the inverter ground.

Where does the current go?
Possible CM Current Paths

Through the motor frame through some path to the ground grid, to transformer grounds, to the inverter ground bus.

Where does the current go?
Possible CM Current Paths

Through the motor frame through motor bearings, through motor shaft, to mine equipment… you know the rest!

Where does the current go?
Possible CM Current Paths

All these paths are possible, none are guaranteed to be a low impedance path at high frequency.

Where does the current go?
Possible CM Current Paths

Best Case
Through the cable shield or armor from the motor frame to the inverter.

Conduit Warning!!!
How Cable can Help

• An overall shield provides a **large surface area** with a low impedance at high frequency

  *Lower impedance = reduced potential @ Motor*

• Not all shields are created equal

• Terminations matter

• The cable itself should not promote CM current

The shield helps in multiple ways!
The difference

The cables behave differently
Reflected Waves

- Peak voltage spikes caused by a motor/cable impedance mismatch
- Not an issue with traditional power (60 Hz)
- Can be much higher than the motor operating voltage
  - Maximum voltage will be $2x$ peak motor voltage

Increased voltage require special design consideration
Reflected Waves

• Higher voltage stress than traditional systems

• Can cause damage to cable insulation
  – Higher peak voltages
  – Higher $dV/dts$ (Instantaneous High Voltage Spikes)

• Insulation compounds matter
  – Thermoset insulations have a proven track record
  – Avoid thermoset (cheaper) PVC insulations

Less expensive PVC can be more costly in the long run
Reflected Waves, then vs. now

• Case Study:
  – 480V drive system (650V dc bus voltage)
  – 100 feet of cable between the inverter and motor.
  – Cables can see twice the CD bus voltage.
  – Cables can see three times the operating voltage.

<table>
<thead>
<tr>
<th>Technology</th>
<th>Drive Type</th>
<th>Risetime</th>
<th>Peak Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Old</td>
<td>BJT</td>
<td>1 μs</td>
<td>780 V</td>
</tr>
<tr>
<td>New</td>
<td>IGBT</td>
<td>100 ns</td>
<td>1300 V</td>
</tr>
</tbody>
</table>

Make sure you have adequate insulation.
Then and Now, distances

Faster rise times mean more standing wave issues.

<table>
<thead>
<tr>
<th>Type</th>
<th>Risetime</th>
<th>Start of reflected waves</th>
<th>Maximum reflected wave</th>
<th>Timeframe</th>
</tr>
</thead>
<tbody>
<tr>
<td>GTO</td>
<td>4 μs</td>
<td>1000 ft.</td>
<td>2800 ft.</td>
<td>‘70s &amp; ‘80s</td>
</tr>
<tr>
<td>BJT</td>
<td>2 μs</td>
<td>500 ft.</td>
<td>1400 ft.</td>
<td></td>
</tr>
<tr>
<td>BJT</td>
<td>600 ns</td>
<td>150 ft.</td>
<td>420 ft.</td>
<td></td>
</tr>
<tr>
<td>BJT</td>
<td>200 ns</td>
<td>50 ft.</td>
<td>140 ft.</td>
<td></td>
</tr>
<tr>
<td>IGBT</td>
<td>100 ns</td>
<td>25 ft.</td>
<td>70 ft.</td>
<td>1990s an beyond</td>
</tr>
<tr>
<td>IGBT</td>
<td>50 ns</td>
<td>12 ft.</td>
<td>35 ft.</td>
<td></td>
</tr>
</tbody>
</table>

Not an issue if you have a really small mine!
Cable Insulation Matters—Why not PVC?

• It’s hydroscopic
  – PVC absorbs moisture from the air, dropping it’s dielectric withstand to 55% of rated voltage

• It can cold-flow
  – Insulation will displace when pressure is applied

600 x 55%... factor in a thinner wall... oh no!
So what about 600V Cable?

We use this on 480V standard power systems. Why not on 480V VFD systems?

- Standard (60 Hz) 480V System
  - $480V < 600V$ (rms looks good!)
  - $678V_p < 850 V_p$ (peak looks good!)

- VFD 480 V System
  - $1300V_p < 850 V_p$ (Not what we want to see!!!)

- Don’t forget the increased stress from high dv/dts!

Fun with Numbers!
In Summary:
Here are the Risks (+ COSTs)

- CM current can flow through the motor bearings causing bearing fluting and premature motor failure.

- Over 100V has been measured between the inverter and the motor.

- Potentially lethal currents/voltages have been measured in unshielded, locked out inverter to motor cable.

Three reasons you want a shielded cable
In Summary: Cable Investment Required for VFDs

VFD Cables safeguarding features are:

• An Overall Shield
  o Reduced electromagnetic interference and radiation
  o A controlled path for common mode current to flow

• Symmetrically Designed Conductors
  o To minimize induced currents

• Robust Insulation
  o Increased resistance to voltage peaks and high dv/dts that stress the insulation.

Things you want your VFD cable to have
**Many Types of VFD Cables**

<table>
<thead>
<tr>
<th>Cable</th>
<th>Voltage</th>
<th>Temp</th>
<th>Stranding</th>
<th>Grounds</th>
<th>Shield</th>
<th>Insulation</th>
<th>Jacket</th>
<th>Armor</th>
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</thead>
<tbody>
<tr>
<td>4560</td>
<td>600V 1000 V</td>
<td>90</td>
<td>Class K/H</td>
<td>1</td>
<td>AL Tape + CU Braid</td>
<td>XLPE</td>
<td>PVC</td>
<td>No</td>
</tr>
<tr>
<td>4565</td>
<td>600V 1000 V</td>
<td>90</td>
<td>Class K</td>
<td>1</td>
<td>AL Tape + CU Braid</td>
<td>XLPE</td>
<td>PVC</td>
<td>No</td>
</tr>
<tr>
<td>4570</td>
<td>600V 1000 V</td>
<td>90</td>
<td>Class I</td>
<td>3</td>
<td>Cu Tape</td>
<td>XLPE</td>
<td>PVC</td>
<td>No</td>
</tr>
<tr>
<td>4575</td>
<td>2000V</td>
<td>90</td>
<td>Class B</td>
<td>3</td>
<td>AL Tape + CU Braid</td>
<td>XLPE</td>
<td>PVC</td>
<td>No</td>
</tr>
<tr>
<td>4580</td>
<td>2000V</td>
<td>90</td>
<td>Class B</td>
<td>3</td>
<td>Cu Tape</td>
<td>XLPE</td>
<td>PVC</td>
<td>No</td>
</tr>
<tr>
<td>9675</td>
<td>1000V</td>
<td>90</td>
<td>Class B</td>
<td>3</td>
<td>CCW (AL)</td>
<td>XLPE</td>
<td>PVC</td>
<td>Yes</td>
</tr>
<tr>
<td>9700</td>
<td>2400V</td>
<td>90</td>
<td>Compact</td>
<td>3</td>
<td>CCW (AL)</td>
<td>EPR</td>
<td>PVC</td>
<td>Yes</td>
</tr>
<tr>
<td>9800</td>
<td>5000V</td>
<td>105</td>
<td>Compact</td>
<td>3</td>
<td>CCW (AL)</td>
<td>EPR</td>
<td>PVC</td>
<td>Yes</td>
</tr>
<tr>
<td>9815</td>
<td>8000V</td>
<td>105</td>
<td>Compact</td>
<td>3</td>
<td>CCW (AL)</td>
<td>EPR</td>
<td>PVC</td>
<td>Yes</td>
</tr>
<tr>
<td>Mining</td>
<td>2–15 kV</td>
<td>90</td>
<td>Class H</td>
<td>3</td>
<td>AL Tape + CU Braid</td>
<td>EPR</td>
<td>CPE</td>
<td>No</td>
</tr>
</tbody>
</table>

So many cables... so little time
Mining VFD Cables

The Big Three

• Overall Shield
  – Copper Braid & Foil Shield

• Symmetrical Designed Conductors
  – Even the ground check is symmetrical!

• Insulation
  – Thermoset, Robust EPR

Other Features

• Flexible
  – Finely stranded

• Durable
  – Extra Heavy Duty CPE Jacket

• Rated from 2kV to 15kV

• Conductor Sizes from #6 AWG to 500 kcmil

• MSHA Certified

Mining Cables are the best cables!
Mining VFD Cables

If you need a ground check we got you covered twice!

Type VFD

Type VFD-GC

Type VFD-BGC
Thank you!