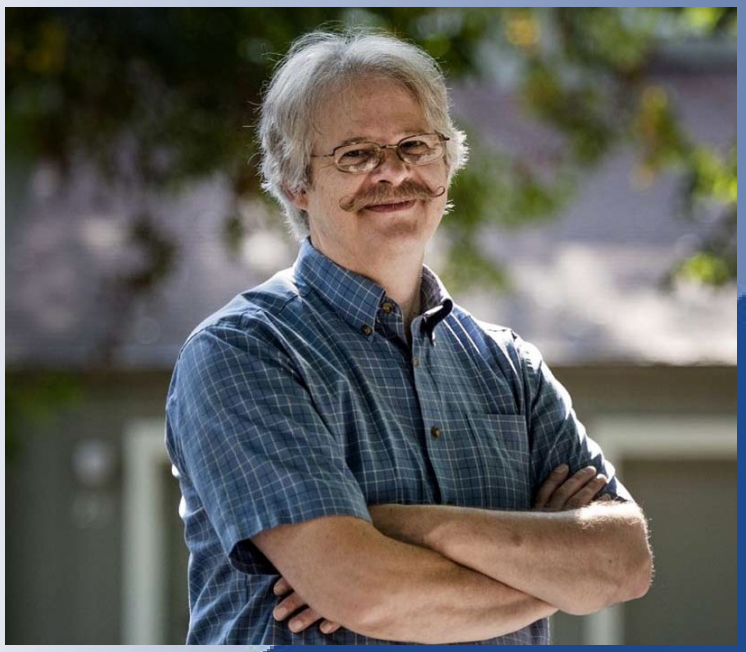
Better Plants
U.S. DEPARTMENT OF ENERGY

Motor Systems
Virtual INPLT Training & Assessment

Session 3

U.S. DEPARTMENT OF ENERGY

Motors Virtual INPLT Facilitator



Ron Wroblewski, PE,
Productive Energy Solutions, LLC
Madison, Wisconsin

ron@productiveenergy.com
(608) 232-1861

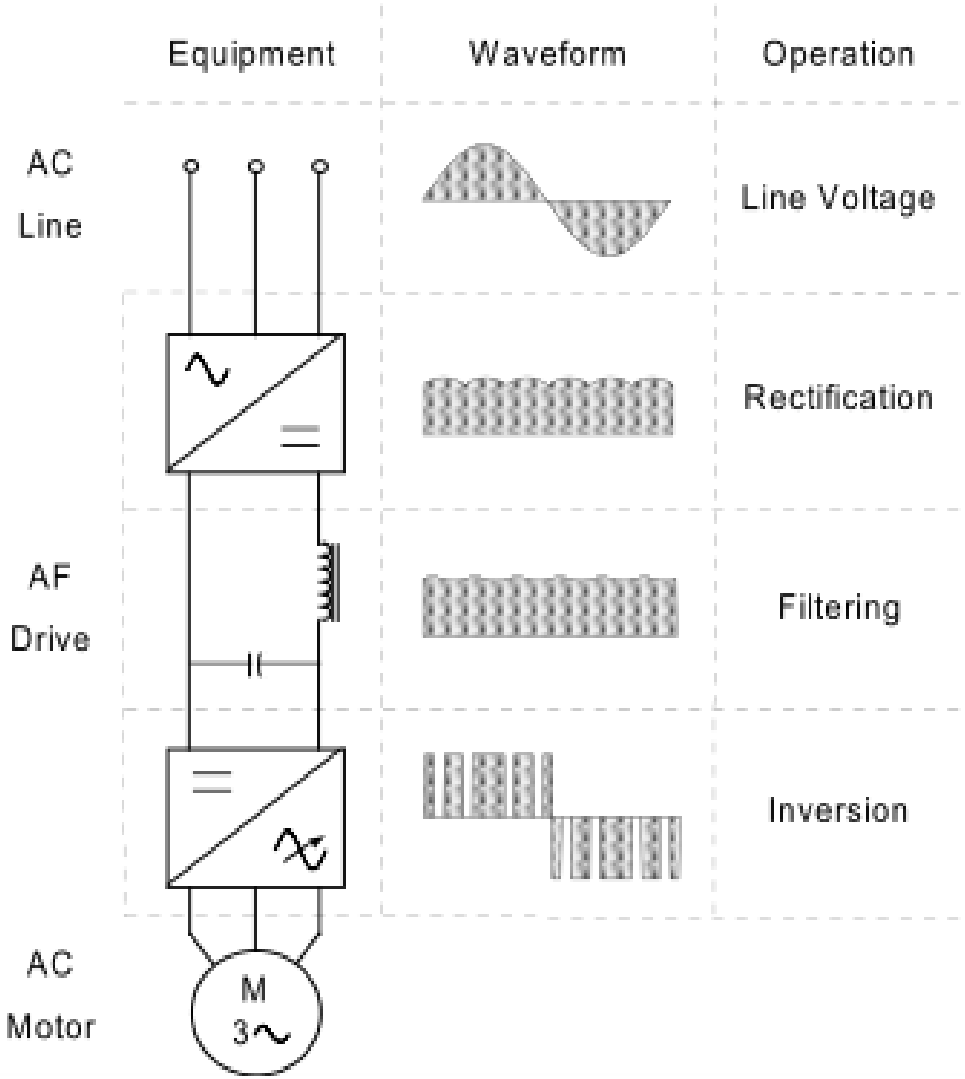
Learning Objectives

- List common problems associated with VFDs.
- Recognize critical requirements for VFD cables.
- Consider four key factors that dictate the critical (maximum) VFD cable length.
- Compare strategies for successful VFD operation with long motor cables.

Agenda

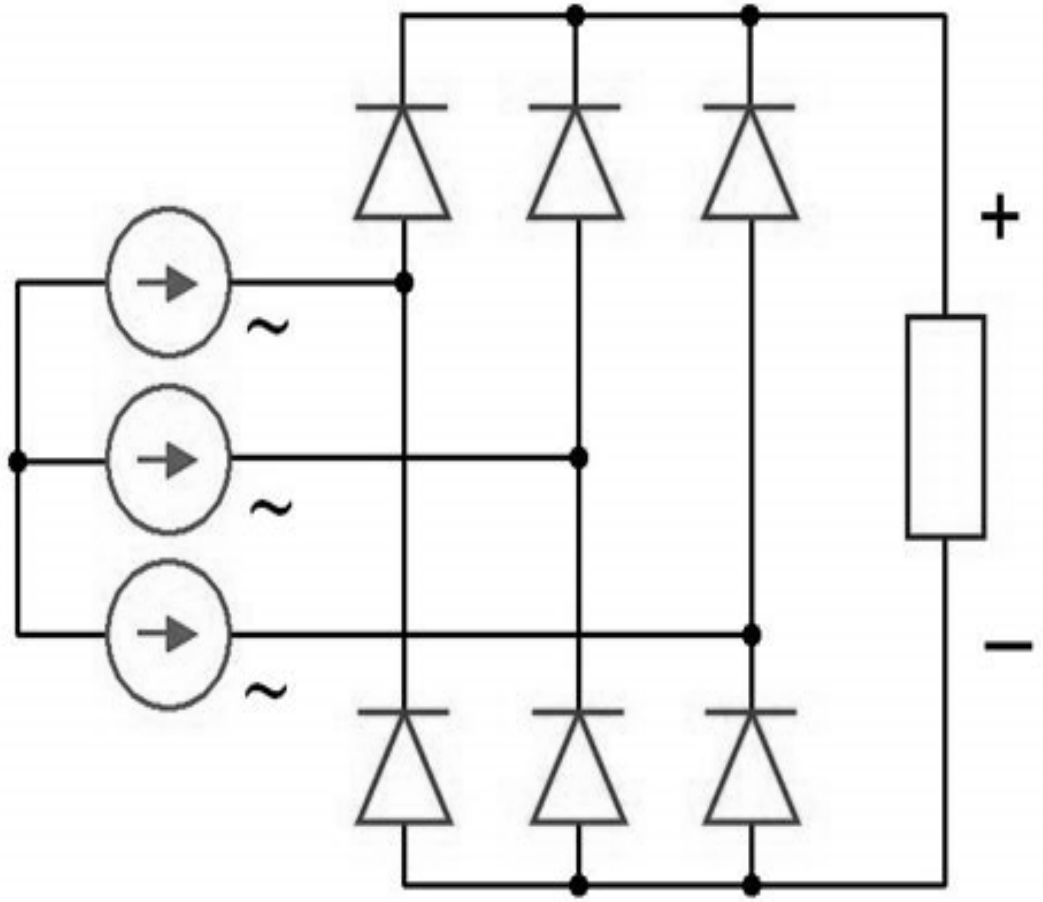
- Advantages of problems of VFDs
- Minimum specifications for VFD cables
- Advantages and applications of inverter duty motors
- Causes and damaging effects of overvoltage reflection
- Strategies to avoid problems with bearing currents

VFD Components

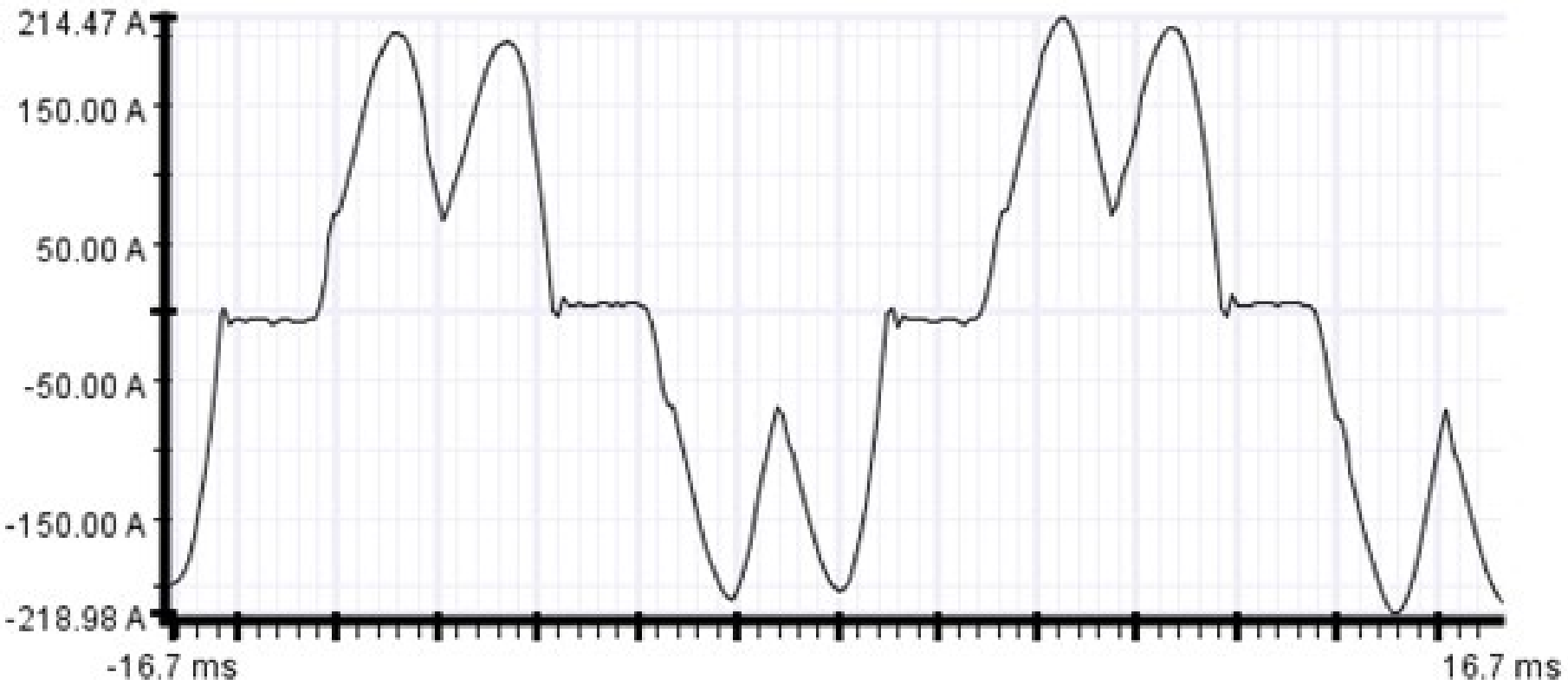


The Rectifier

The most common VFD design uses a 6-diode bridge rectifier



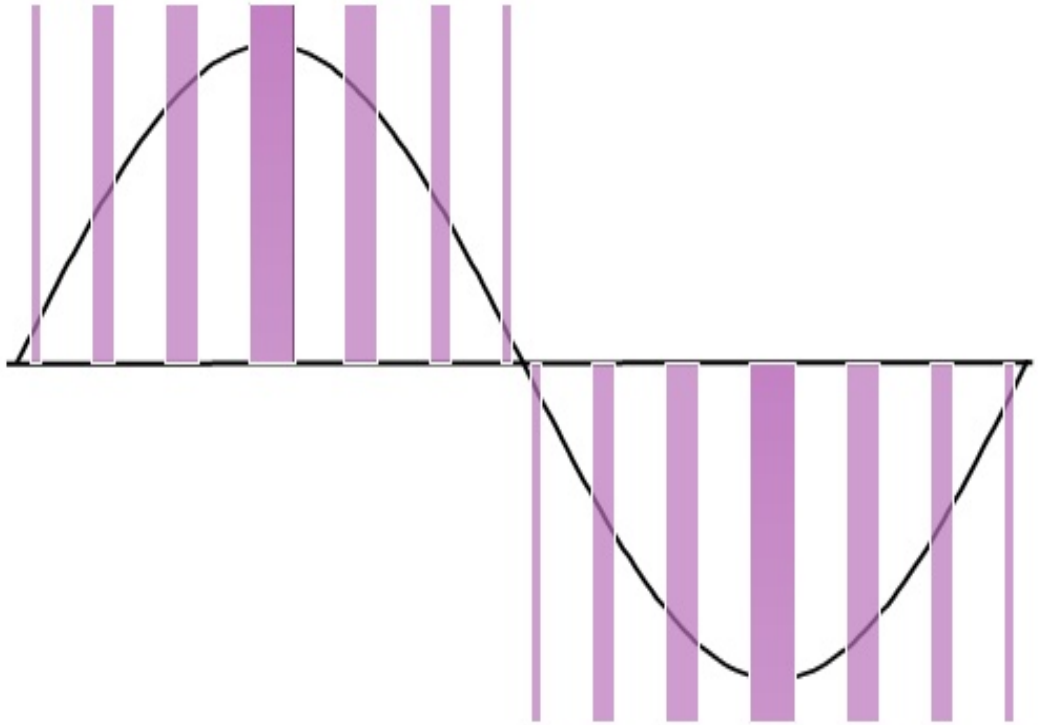
VFDs cause Non-Uniform Current Draw



More on this later when we discuss harmonics

The Inverter

IGBT transistors that fire very rapidly to convert the DC power into something that vaguely resembles alternating current (AC)



Advantages and Problems of VFDS

Activity

Answer the question below in the chat

1. What are the advantages of using VFDs?

You will have 2 minutes to put something in the chat.
Don’t worry if someone else already said the same thing, say it anyway.

Activity

Answer the question below in the chat

2. What problems have you experienced with VFDs?

You will have 2 minutes to put something in the chat.
Don’t worry if someone else already said the same thing, say it anyway.

Cable considerations between the VFD and the motor

Problems with reusing the old cables laying loose in the cable tray:

- Radio Frequency (RF) noise cross talk can corrupt critical control signals
- Shaft currents
- Nuisance trips of VFD
- Probably THHN on old cables will become brittle
  - Loose their dielectric properties and short
  - Cables with decaying insulation are a safety hazard
  - Cables with decaying insulation are a fire hazard

Avoid using cables with conductors twisted together

Feeder Cable Insulation (Between VFD and Motor)

Minimum insulation thickness is 15 mil, 20 mil or more is better.
XLPE is far superior to THHN

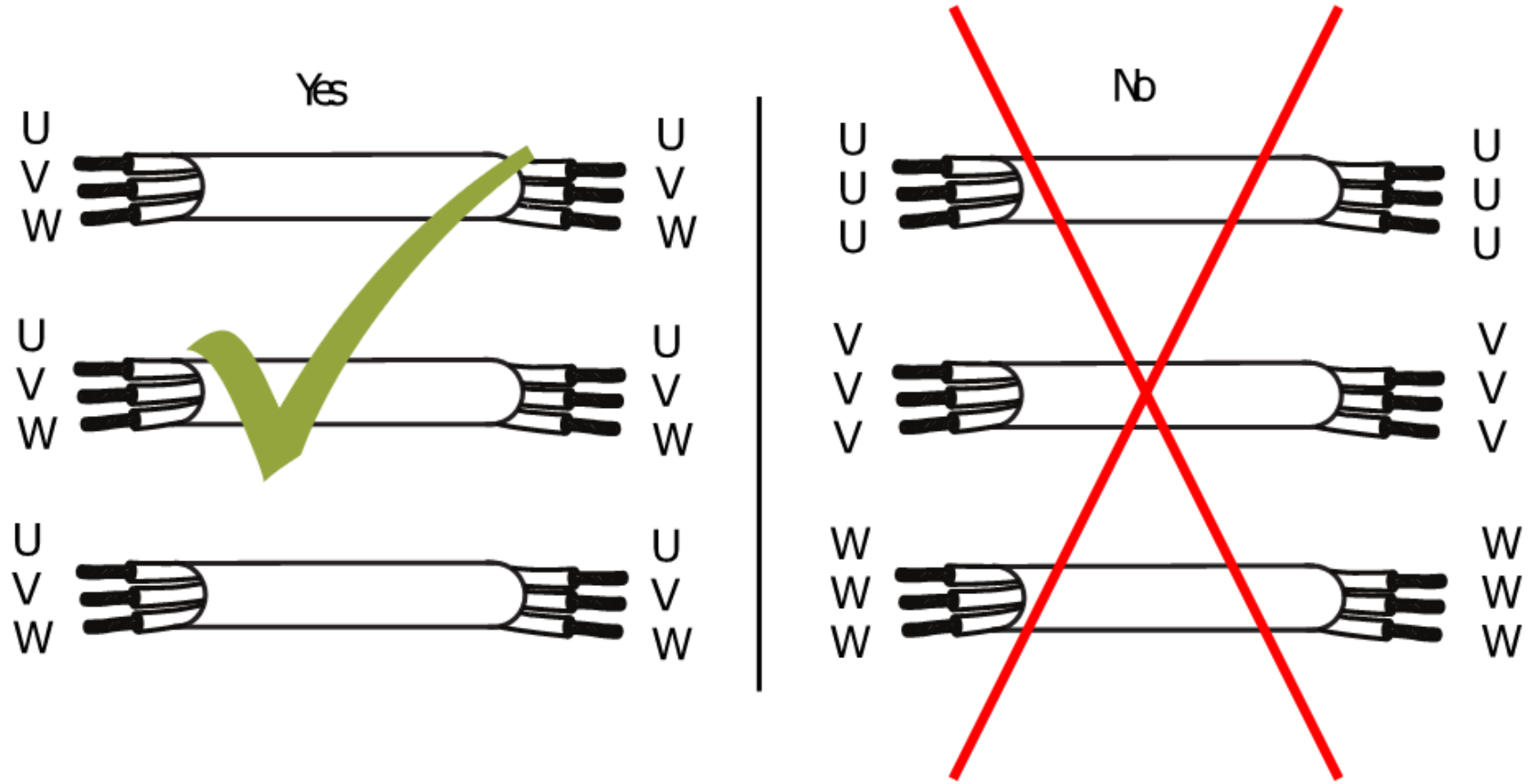
Poor, <15 mil (0.4 mm)

Better, ≥15 mil

Best, ≥20 mil

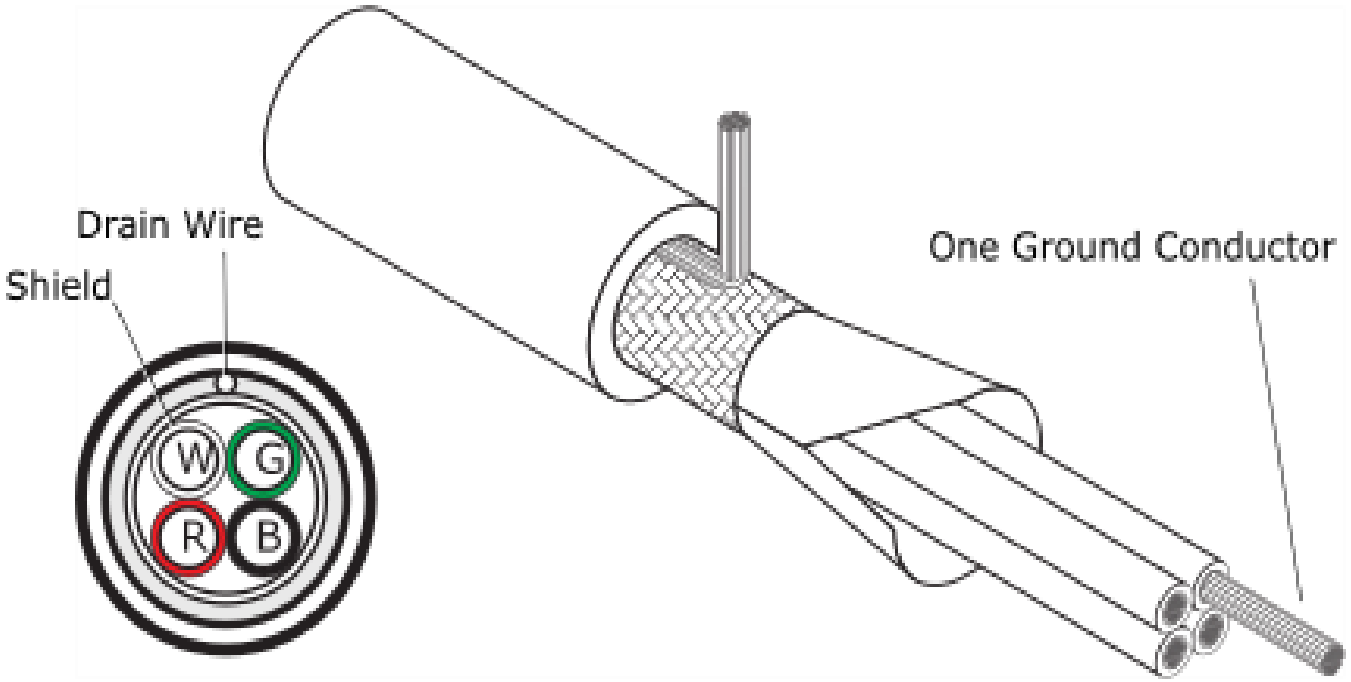
Multiple Cables (Between VFD and Motor)

Use 3 phases in each cable if more than one cable is required.



Cable Types for Drives

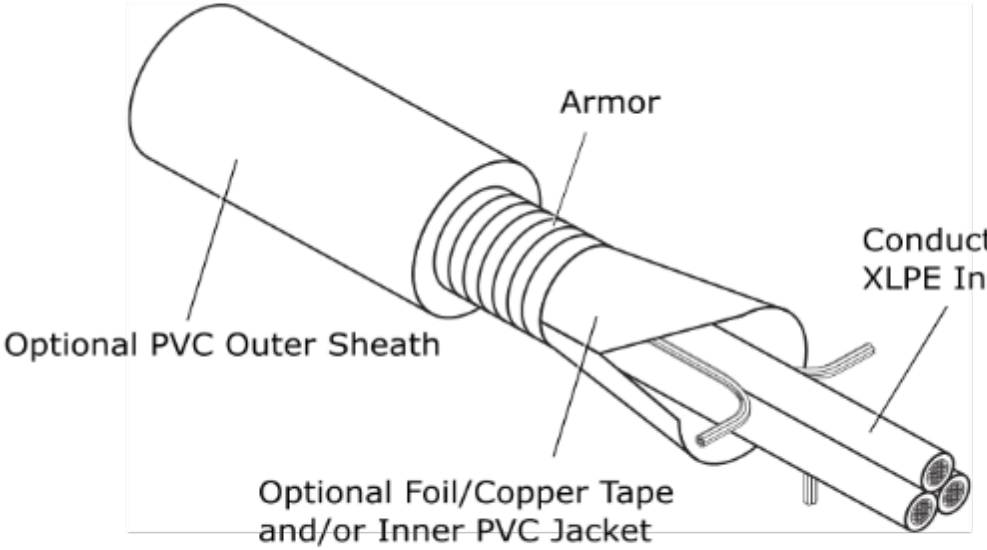
Cable type for drives ≤100 or 200 HP



Cable Types for Drives

Cable type for drives ≥100 or 200 HP

Cable with 3 ground Conductors



Video 3 + 3 Cable for VFD

Video link

3 plus 3 cable video from General Cable

Factors to Consider When Choosing a VFD Cable

Factors to consider	Why it's important
DV/DT and clock rate	Faster switching puts more stress on the cable, and exacerbates reflected voltage
Fixed geometry NOT twisted conductors	Twisted conductors and loose cables in a tray cause many problems including RF and nuisance trips
RF (radio frequency) noise containment	Can cause interference with other equipment
Water, chemical, or crush resistance	Depending on where it will be installed
Dynamic braking	If the drive will be used for dynamic braking, a specialized cable is required

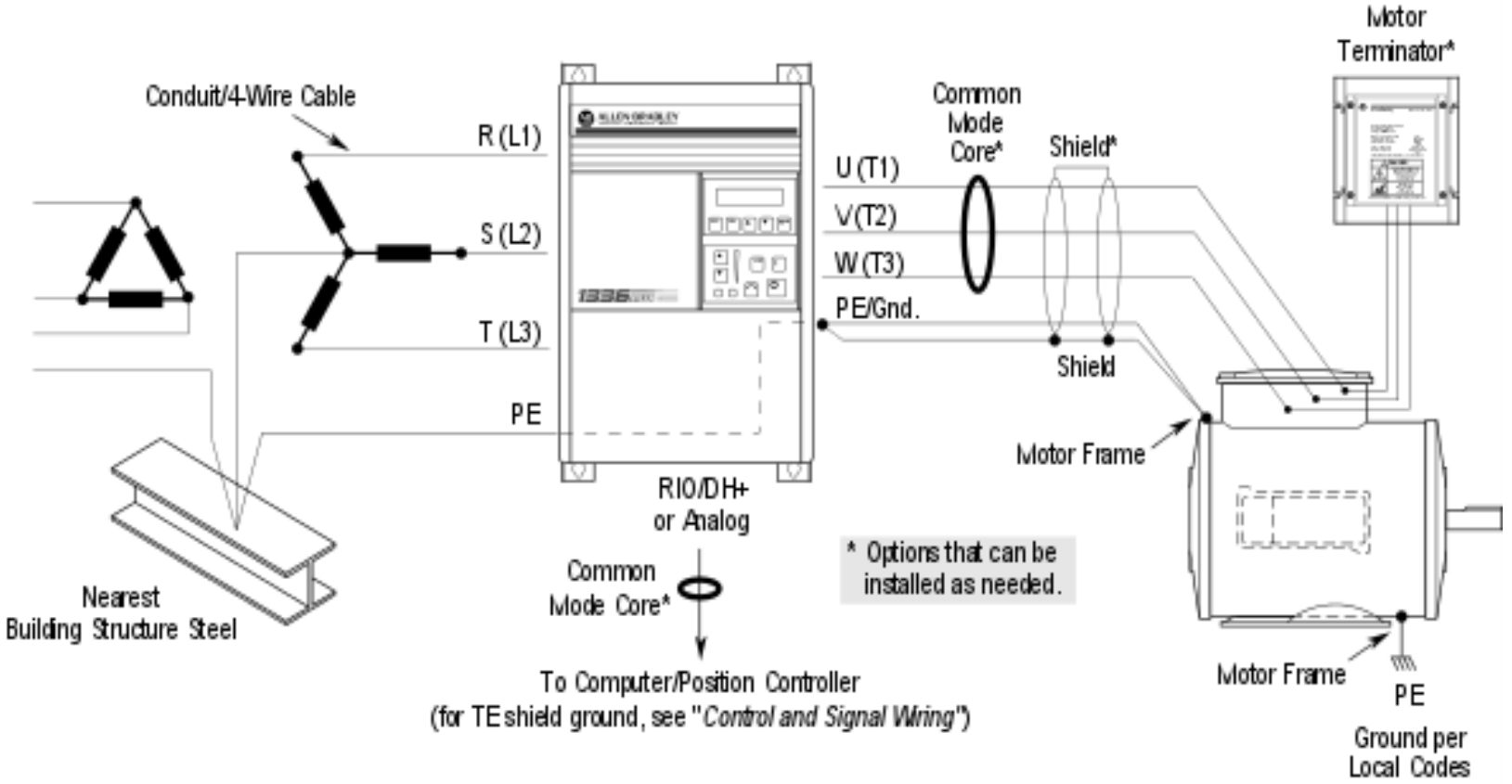
Factors to Consider When Choosing a VFD cable (cont)

Factors to consider	Why it's important
XLPE insulation	Cross-linked polyethylene is thicker and tougher, less likely to become brittle, also reduces capacitance. Avoid THHN
Ampacity (NOT < 12 AWG)	VFD manufacturers recommend minimum 12 gauge to minimize nuisance trips
Voltage rating	May need 1000 or 2000 volt rating for lengthy cable runs to cope with reflected voltage (More on this in session 4)
Capacitance	If the capacitance it too high, it may overload the drive, especially small drives
Charging current of VFD	The charging current of the drive is needed to overcome the capacitance of the cable

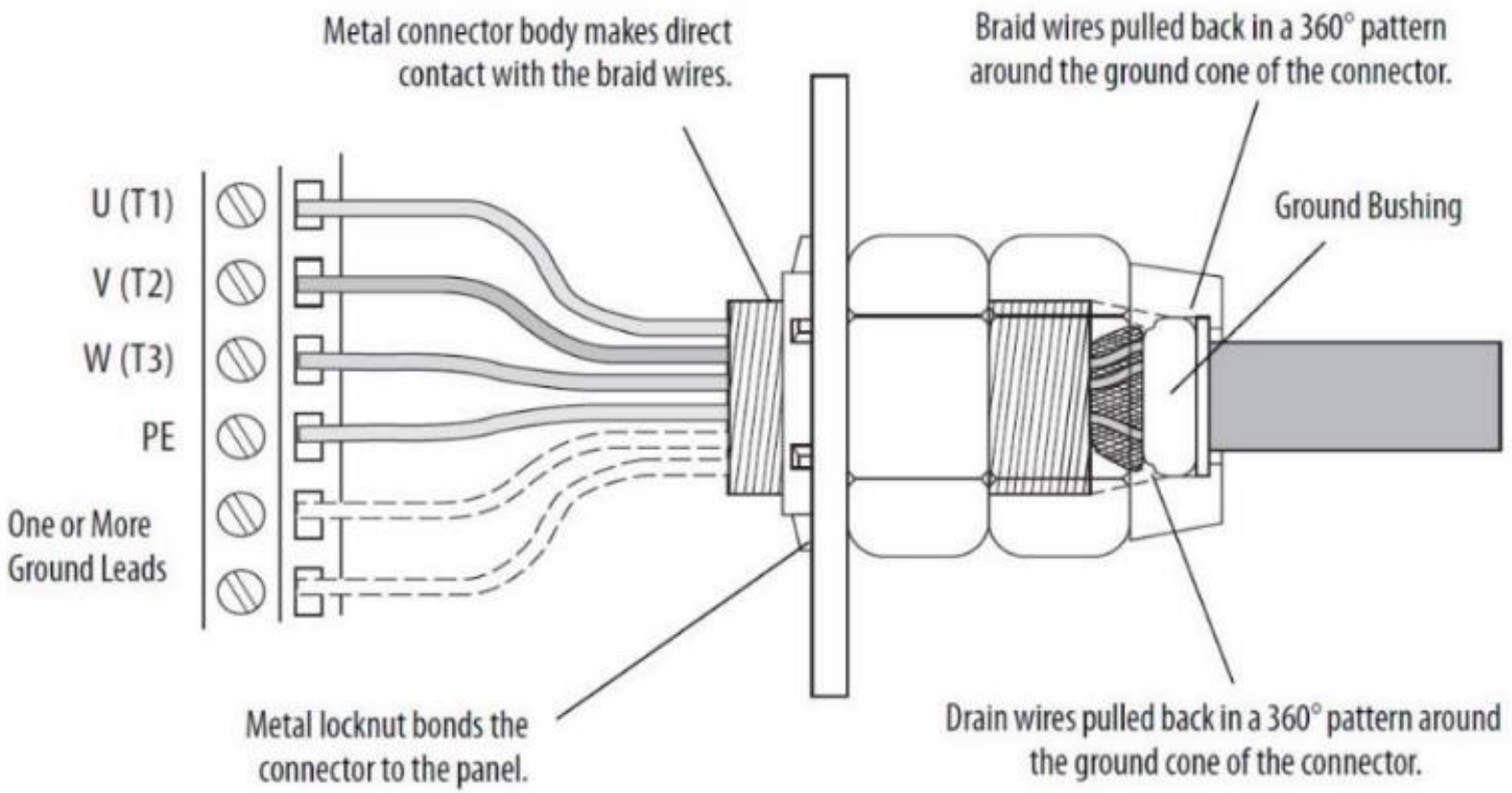
Video Cable Capacitance

Grounding Connections

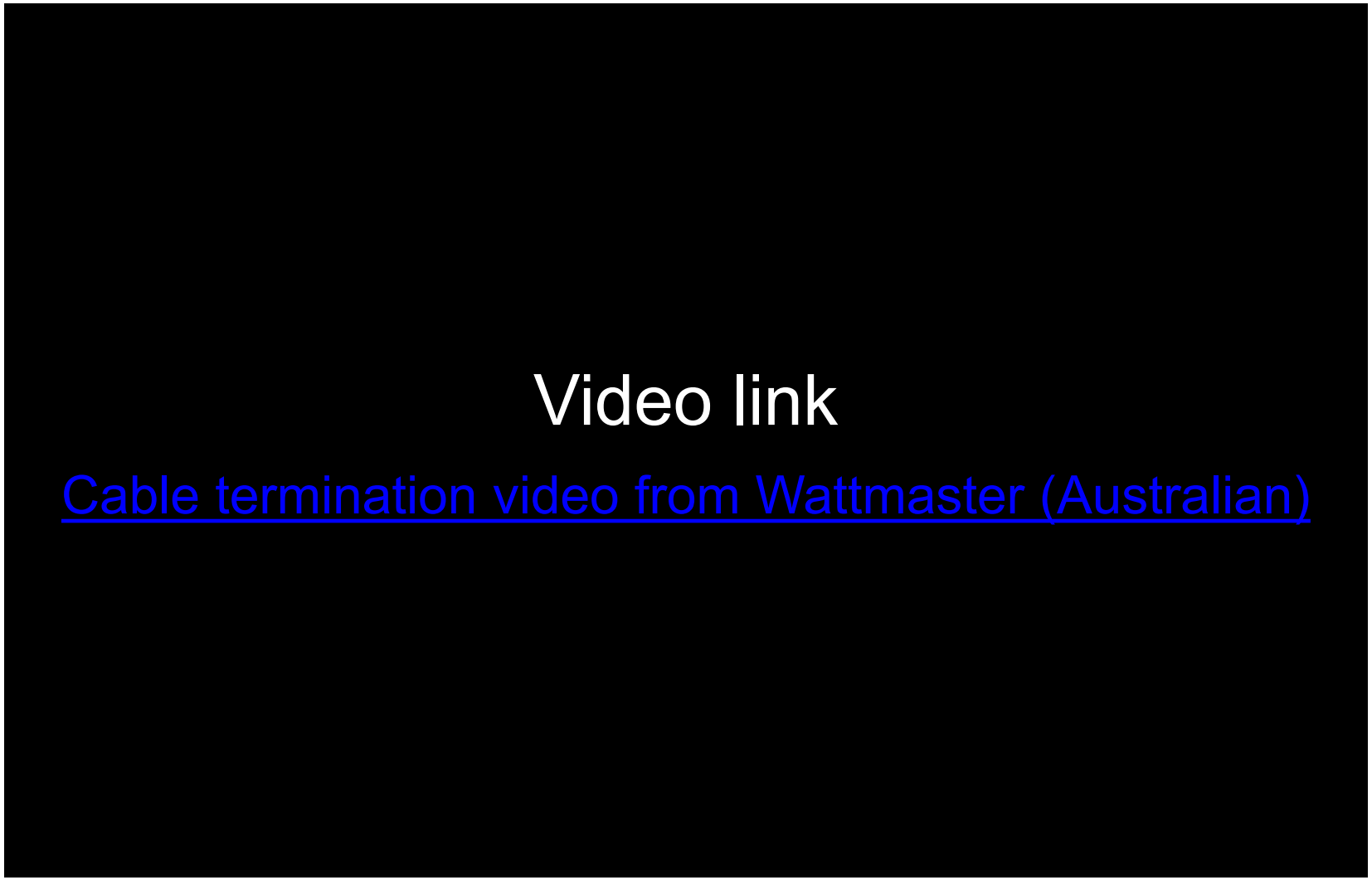
Critical to follow grounding and connection recommendations



Recommended Cable Termination



Video


Video link
Cable termination video from Wattmaster (Australian)

Advantages and Applications of Inverter Duty Motors

Inverter Duty Motor Has Tougher Insulation

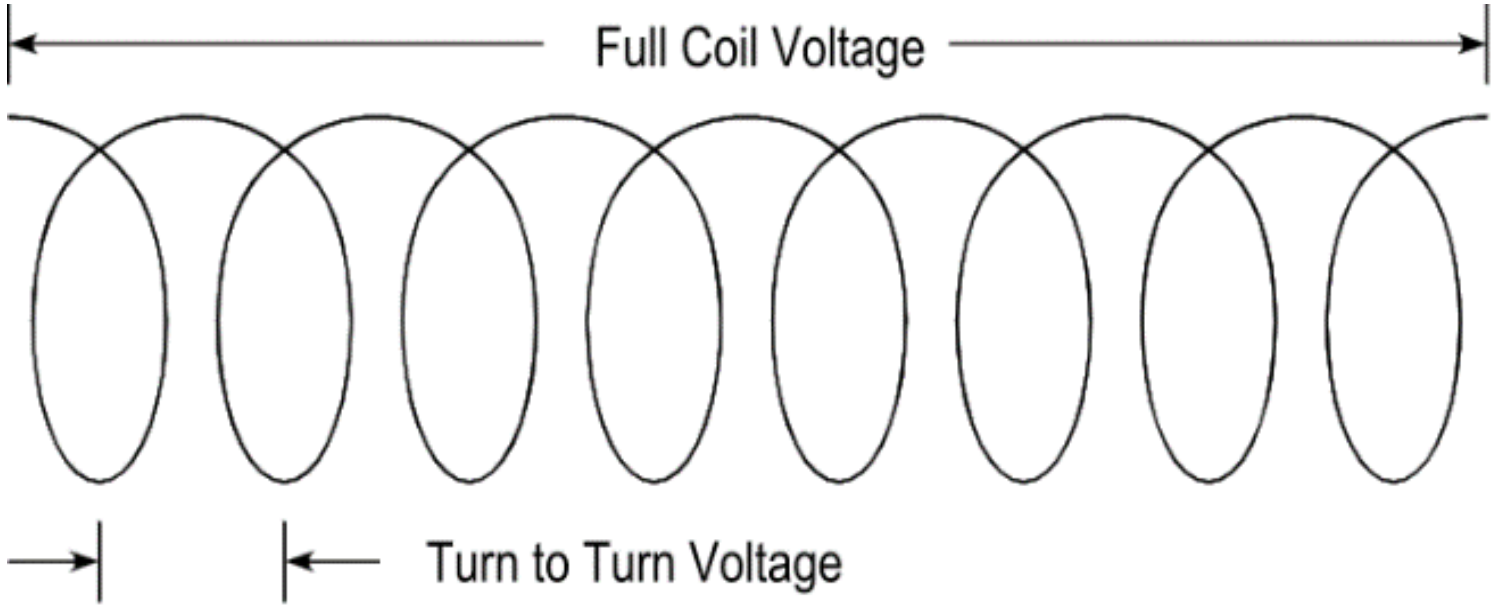
Better insulation in the windings protects against overvoltage reflection phenomenon.

NEMA MG1 requires 1600 volt insulation in inverter duty motors

Voltage Rating	Not inverter duty	Inverter duty
Older motors	1000 v	1488 v
Newer motors	1200 v	1600 v

Turn-to-Turn Voltage

The loss across one turn might only be ~20 volts, (assuming 30 turns) compared to the 600 volt drop across the entire coil

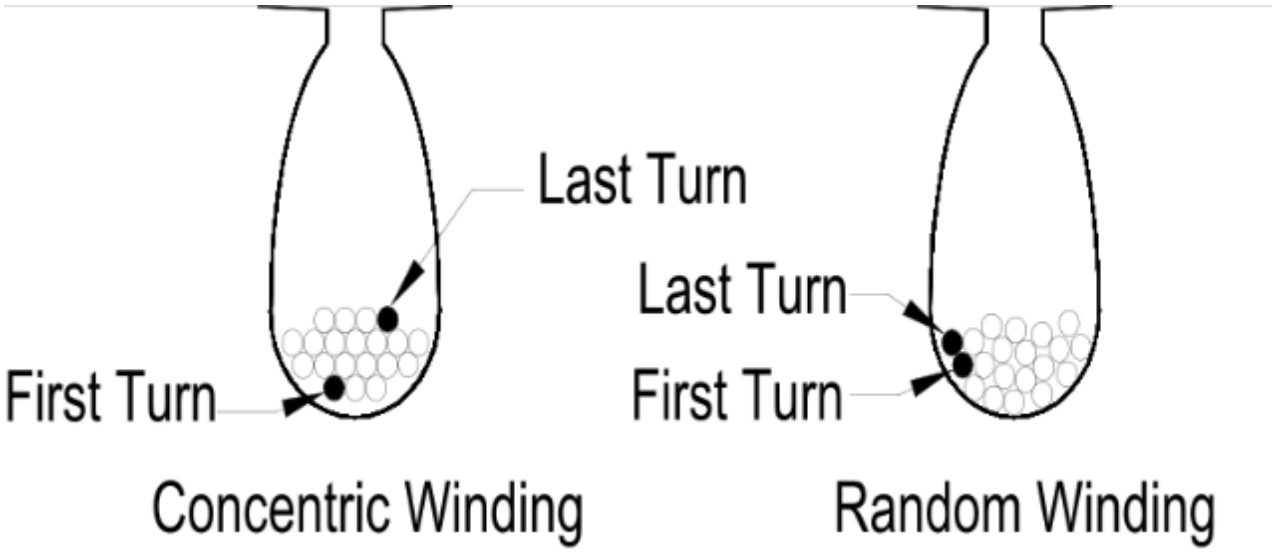


The peak voltage the insulation sees is higher than the 460 volt RMS voltage

Inverter Duty Motor May Have Concentric Winding

Concentric winding greatly reduces chance of short-circuits

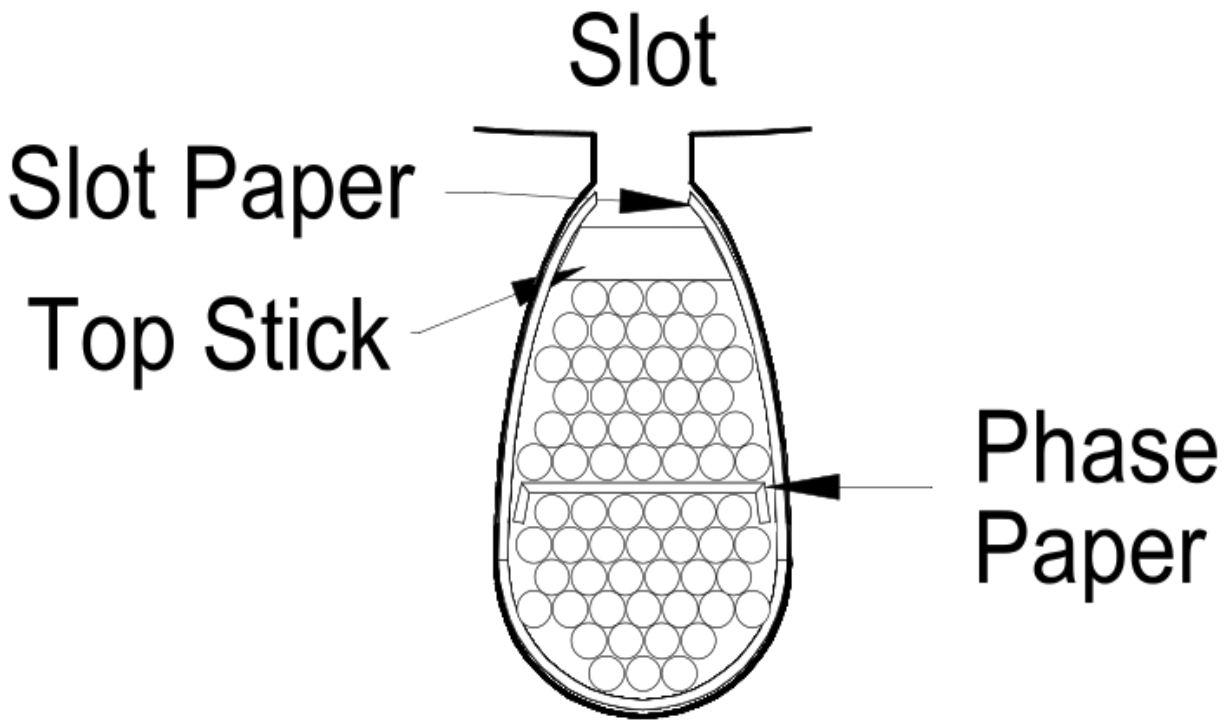
- With concentric winding, the first and last turn will be separated by the other turns.



Inverter Duty Motor May Have Phase Paper & Top Stick

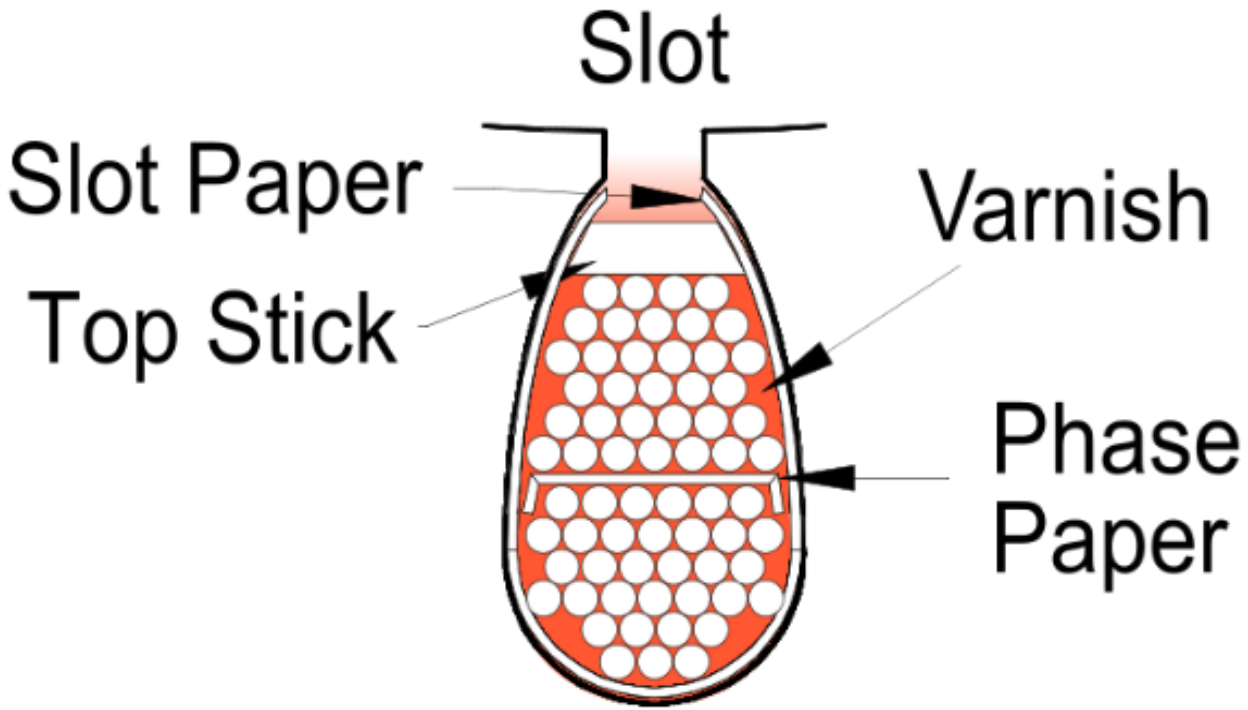
Phase paper helps to avoid short circuits.

Top stick holds winding rigidly in place.



Inverter Duty Motor May Have Extra Varnish

Extra varnish dip and bake locks the windings more firmly in place.



Inverter Duty Motor May Have Coated Bearings

Aluminum oxide coated bearing provides electrical insulation.

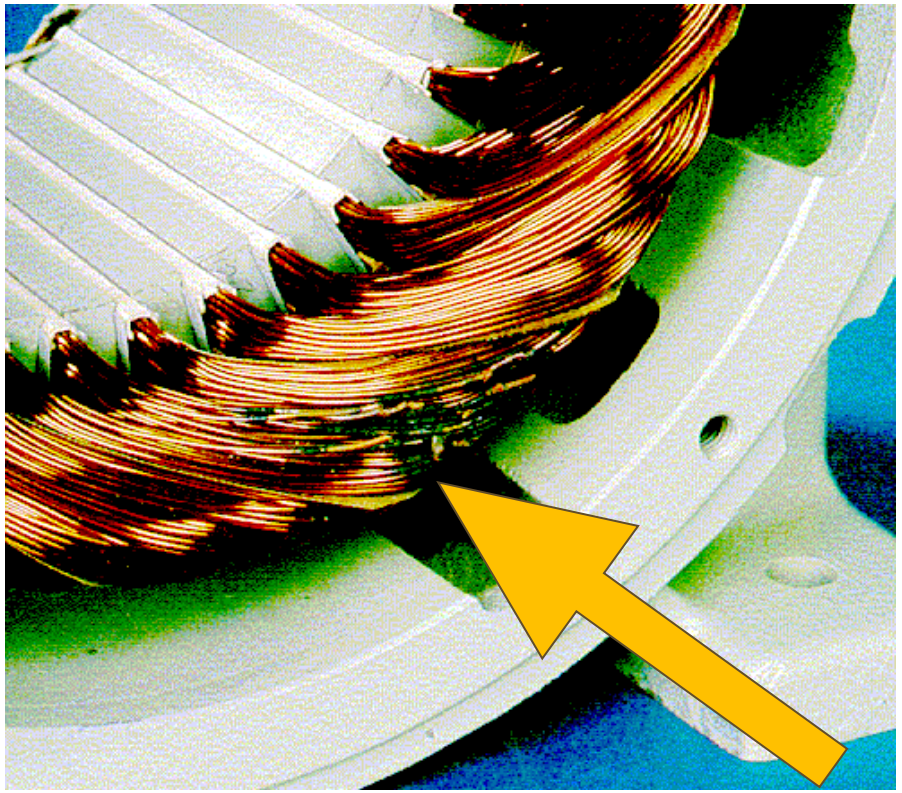
Relatively inexpensive, so sometimes included in GP motors

Causes and Damaging Effects of Overvoltage Reflection

Overvoltage Reflection

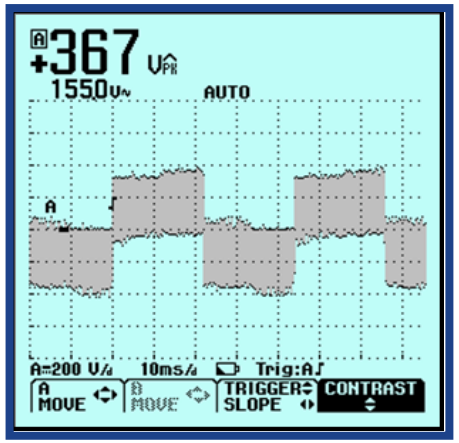
Typical failure from overvoltage reflection:

Winding shorted, turn-to-turn

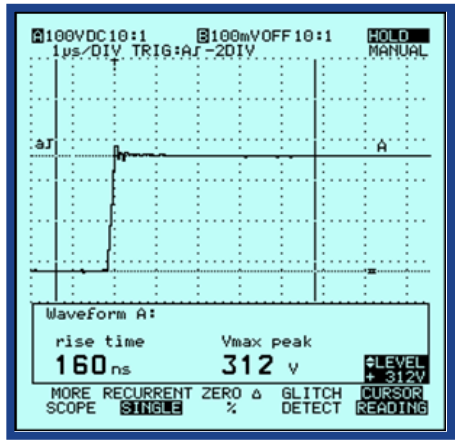


Comparison of PWM waveform and pulses

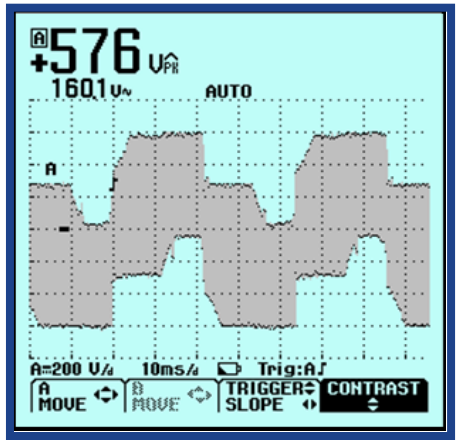
Normal PWM waveform



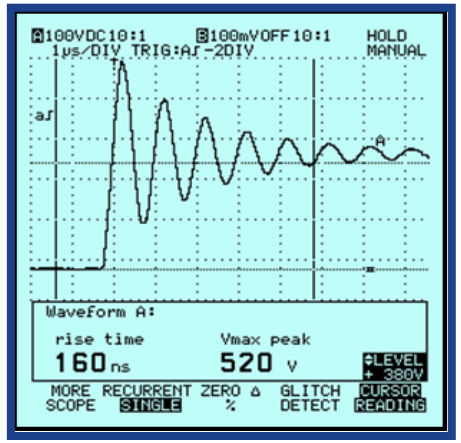
Leading edge of normal PWM pulse



PWM waveform with reflected voltage



Leading edge of PWM pulse with reflected voltage (ringing)



What Causes Overvoltage Reflection?

Mismatch between line impedance and load impedance + **long cable** = **reflected wave**

	Typical Surge Impedance (ohms)
Cable	80-180 Ω
Motors <5 hp	2000-5000 Ω
Motor 125 hp	800 Ω
Motor 500 hp	400 Ω

Voltage at the Motor

Voltage at the motor can be 2.4 times higher than VFD output.

$$\Gamma = \frac{Z_{load} - Z_{\theta}}{Z_{load} + Z_{\theta}}$$

$$V_{motor} = (1 + \Gamma) \times V_{drive}$$

TIP – for smaller dual voltage motors

TIP: For smaller, dual-voltage motors, reconfigure the motor wiring and VFD settings for 230 volt operation!

- At the lower output voltage, you are much less likely to exceed the ratings of even older motors with insulation rated at 1,000 volts.

Critical Cable Length

To determine the critical cable length, consider the following:

- Motor characteristics
  - NEMA (or IEC) frame size
  - HP (or kW) rating
  - Insulation rating on the wire used in the windings
- Drive characteristics
  - kHz Frequency

This information is contained in the 150 or 200 page installation manual that comes with the drive.

Example: Finding the Critical Cable Length

- Model XY3 wall mount drive
- 400 volt motor

Table 4.4 – Example Model XY3 and XY5 Wall Mount Drives 400V Shielded/Unshielded Cable – Meters (Feet)

Drive	Rating		No Solution m (ft.)				Reactor Only m (ft.)				Reactor and Damping Resistor or 1321-RWR m (ft.)				Reactor/RWR (see page 152)	Resistor		Available Options			
Frame	kW	kHz	1000V	1200V	1488V	1600V	1000V	1200V	1488V	1600V	1000V	1200V	1488V	1600V	Cat. No.	Ohms	Watts	TFA1	TFB2	RWR2	RWC
3	15	2	7.6 (25)	137.2 (450)	365.8 (1200)	365.8 (1200)	91.4 (300)	365.8 (1200)	365.8 (1200)	365.8 (1200)	365.8 (1200)	365.8 (1200)	365.8 (1200)	365.8 (1200)	1321-RWR35DP				•		
		4	7.6 (25)	91.4 (300)	152.4 (500)	213.4 (700)	18.3 (60)	91.4 (300)	365.8 (1200)	365.8 (1200)	182.9 (600)	304.8 (1000)	365.8 (1200)	365.8 (1200)							
	18.5	2	7.6 (25)	137.2 (450)	365.8 (1200)	365.8 (1200)	91.4 (300)	365.8 (1200)	365.8 (1200)	365.8 (1200)	365.8 (1200)	365.8 (1200)	365.8 (1200)	365.8 (1200)	1321-RWR35DP				•		
		4	7.6 (25)	91.4 (300)	152.4 (500)	213.4 (700)	18.3 (60)	91.4 (300)	365.8 (1200)	365.8 (1200)	182.9 (600)	304.8 (1000)	365.8 (1200)	365.8 (1200)							

Example: Finding the Critical Cable Length (cont.)

Example find the critical (maximum) cable length for the VFD:

- Model XY3 wall mount drive
- 400 volt
- Frame 3
- Rating of 15 kW
- Default carrier frequency in the VFD is 4 kHz
- Newer energy efficient motor

First look up the insulation rating of the motor, then find the corresponding table in the VFD manual

Example: Finding the Critical Cable Length (cont.)

Drive	Rating		No Solution m (ft.)			
Frame	kW	kHz	1000V	1200V	1488V	1600V
3	15	2	7.6 (25)	137.2 (450)	365.8 (1200)	365.8 (1200)
		4	7.6 (25)	91.4 (300)	152.4 (500)	213.4 (700)
	18.5	2	7.6 (25)	137.2 (450)	365.8 (1200)	365.8 (1200)
		4	7.6 (25)	91.4 (300)	152.4 (500)	213.4 (700)

Coping With Reflected Wave - Dual Voltage Motors

If the motor is dual voltage, use 230 volts if practicable.

Coping With Reflected Wave - Motor Insulation

Use a motor and cable with higher voltage rating.

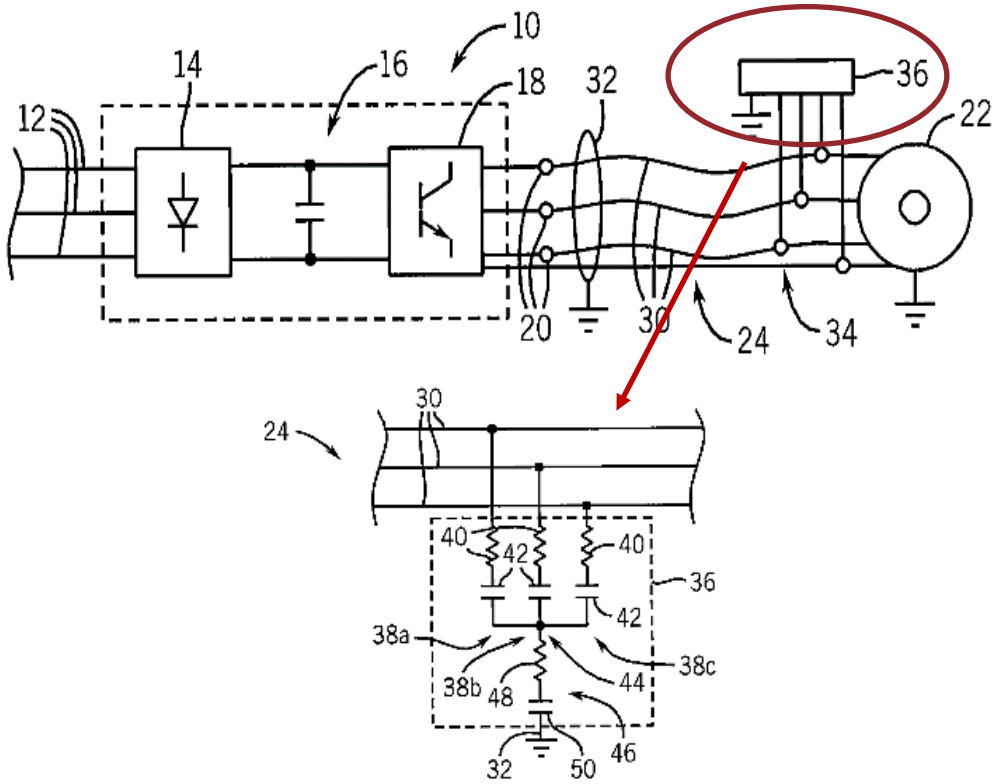
	Not Inverter Duty	Inverter Duty
Older	1000	1488
Newer	1200	1600

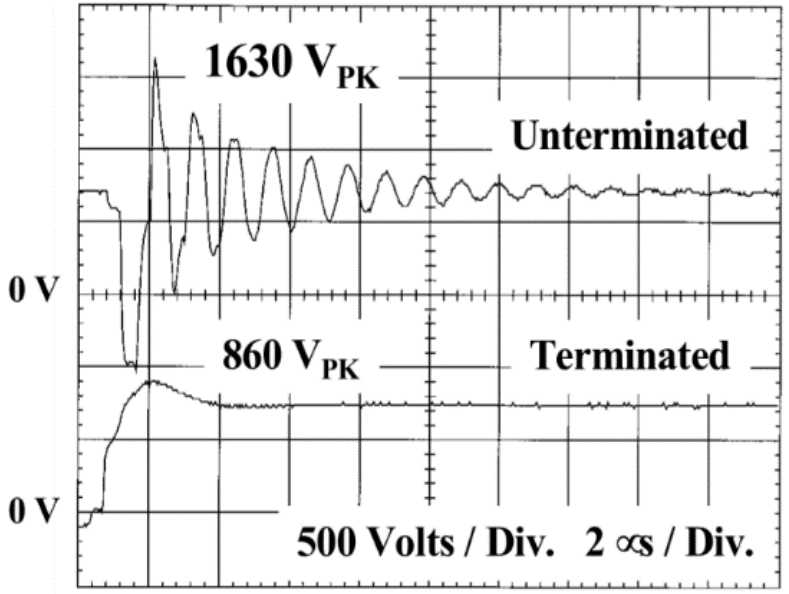
Coping With Reflected Wave – Minimize Cable Length

Move VFD closer to motor

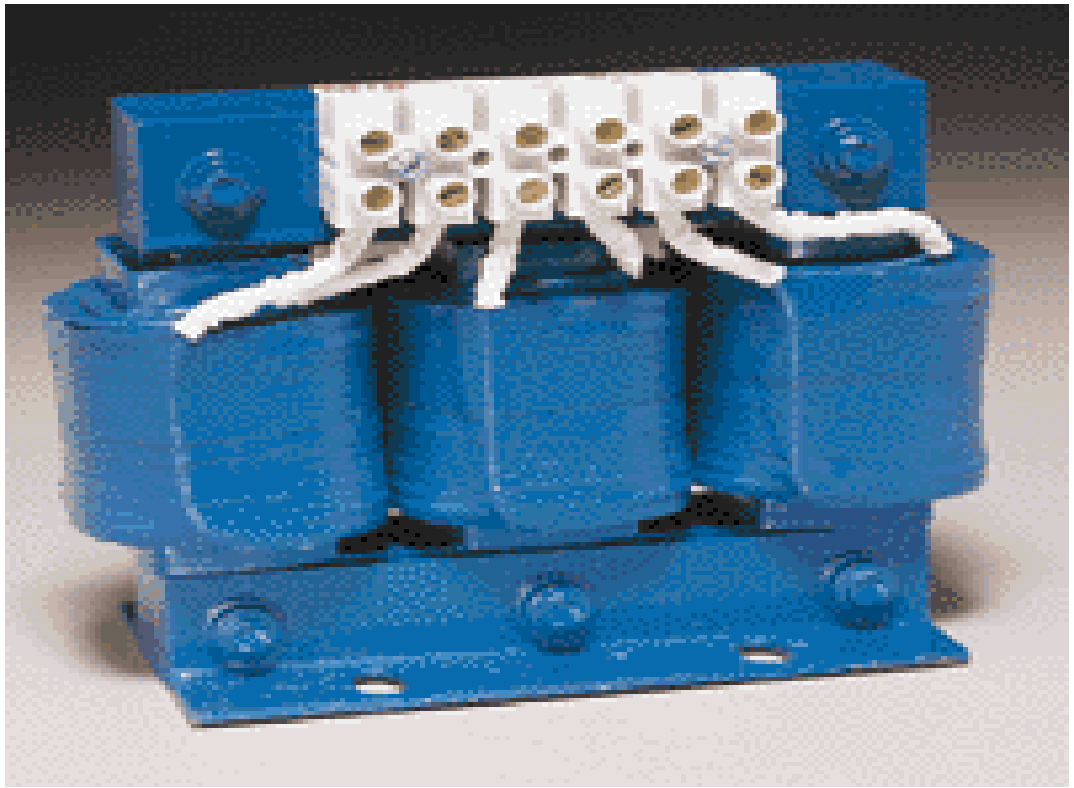
Coping With Reflected Wave – Line Termination Network

Use a line termination network – A clever arrangement of capacitors and resistors that balances the impedance

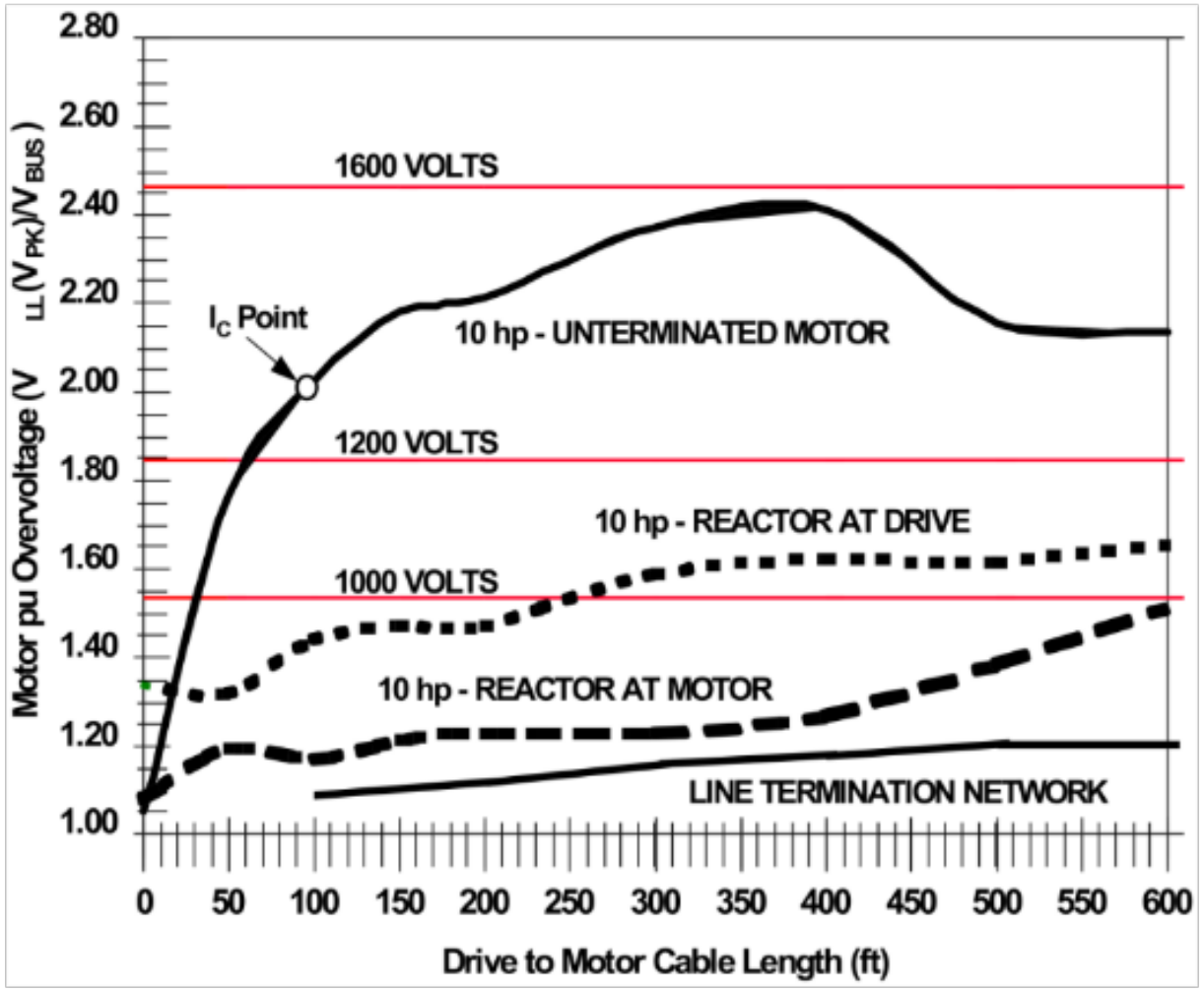




Coping With Reflected Wave - Use an Output Reactor



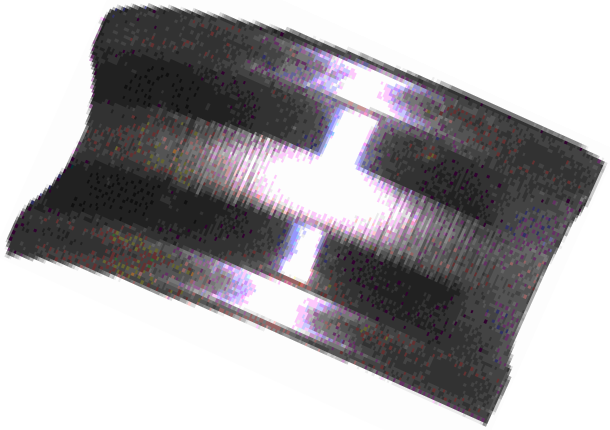
Use Sine Wave Filter or DV/DT Filters

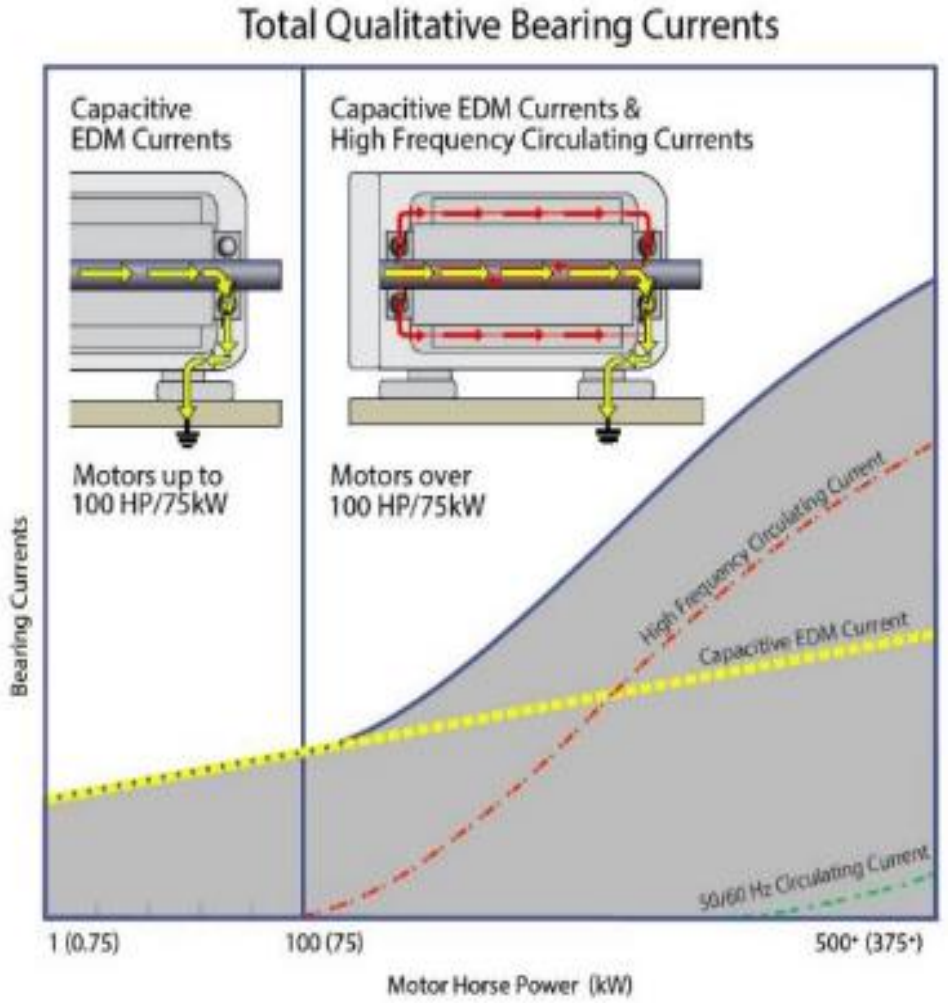


Strategies to Avoid Problems with Bearing Currents

Sometimes VFDs Cause Bearing Fluting

- Bearing currents occur when shaft voltages exceed the insulating capability of the grease.
- We call this an EDM current Electrical Discharge Machining

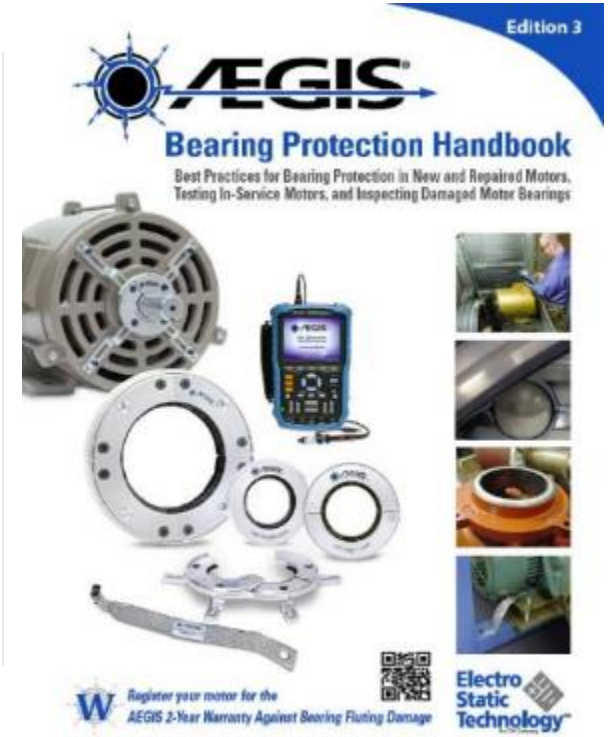




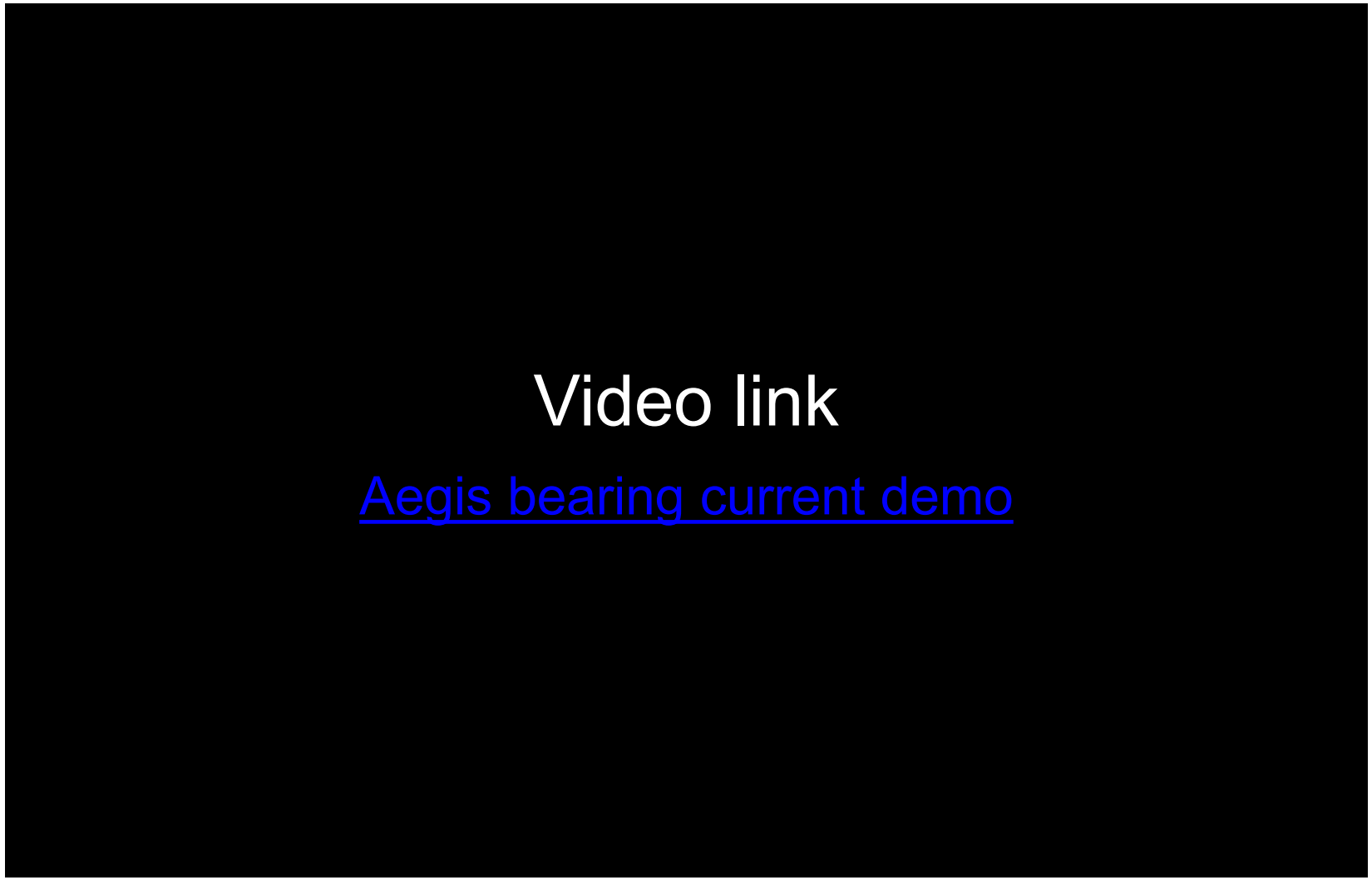
Avoid Bearing Damage from VFDs

Avoid Damage:

- Proper cable type
- Proper cable termination strategies
- Proper grounding
- Insulated bearings
- Shaft grounding



Shaft Grounding Video (optional)



Questions

Thank you!

For Questions or Comments please reach out to the following:

Ron Wroblewski, PE
Productive Energy Solutions, LLC
ron@productiveenergy.com

Thomas Wenning
Oak Ridge National Lab
wenningtj@ornl.gov