VFD Installations and Applications

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Chicago IEEE Chapter

Part 2

Have you had a drive/motor system where the motor failed prematurely, or while the drive was running, odd things were happening elsewhere in the facility?

Today’s topics will cover some of these types of events -

odd stuff with respect to installations and applications of drives.

Agenda

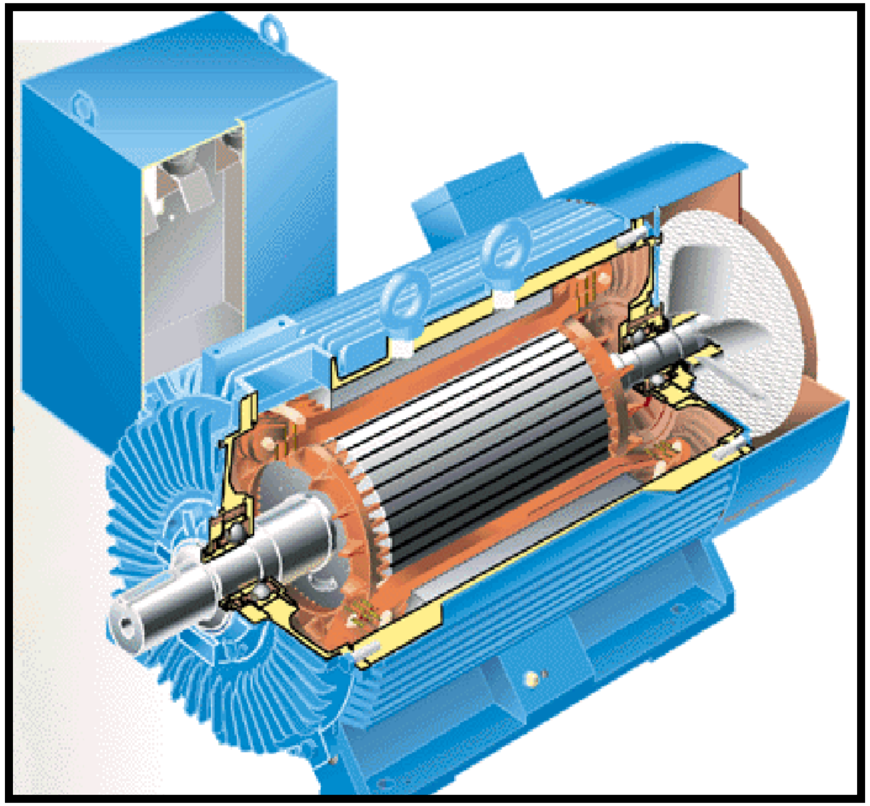
Part 2:

- Motor speed vs max load / cooling, use of motor RTDs
- Overspeed with fans / pumps and increase in torque and power (2.5%, 5% increases)
- Min speed with pumps
- SCCR for drives
- HRG vs solid ground
- Load reactors on the output
- Shaft grounding brushes / bearing currents
- Wiring on input / output
    - Insulation types
    - Conduit, tray
    - Type (VFD, individual wires)
    - Control wiring management

Motor Speed, Cooling, RTDs

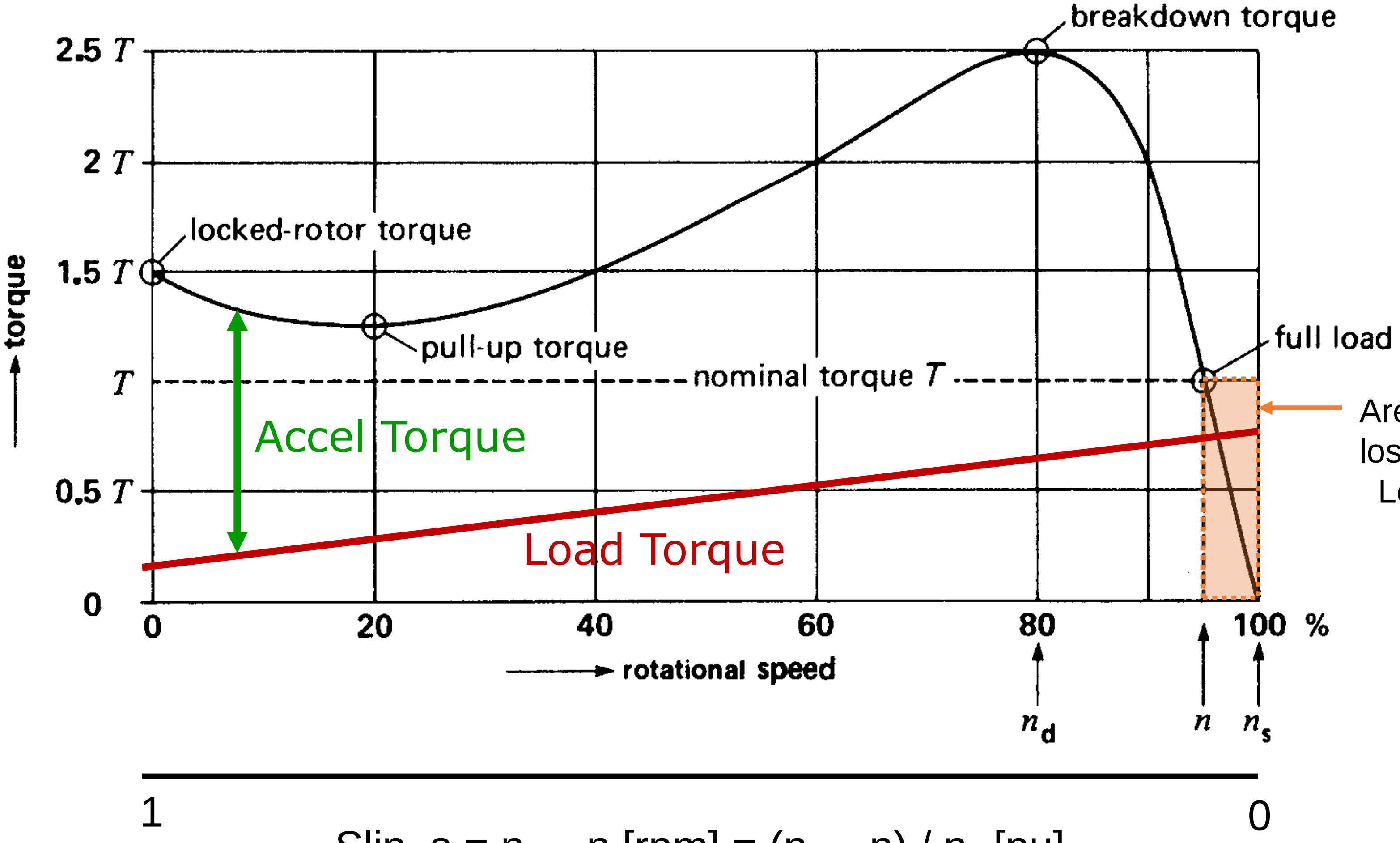
Operating Motors on Inverter Power

- Motors are designed for optimized operation at rated horsepower and speed.
- Heat dissipation is reduced when cooling air generated by integrated motor fan is diminished at continuous lower speed operation.
- Inverter harmonics (non-sinusoidal waveforms) can increase losses in the motor. Which in turn may increase operating temperatures in motor components.



Tq-Spd Characteristics, DOL

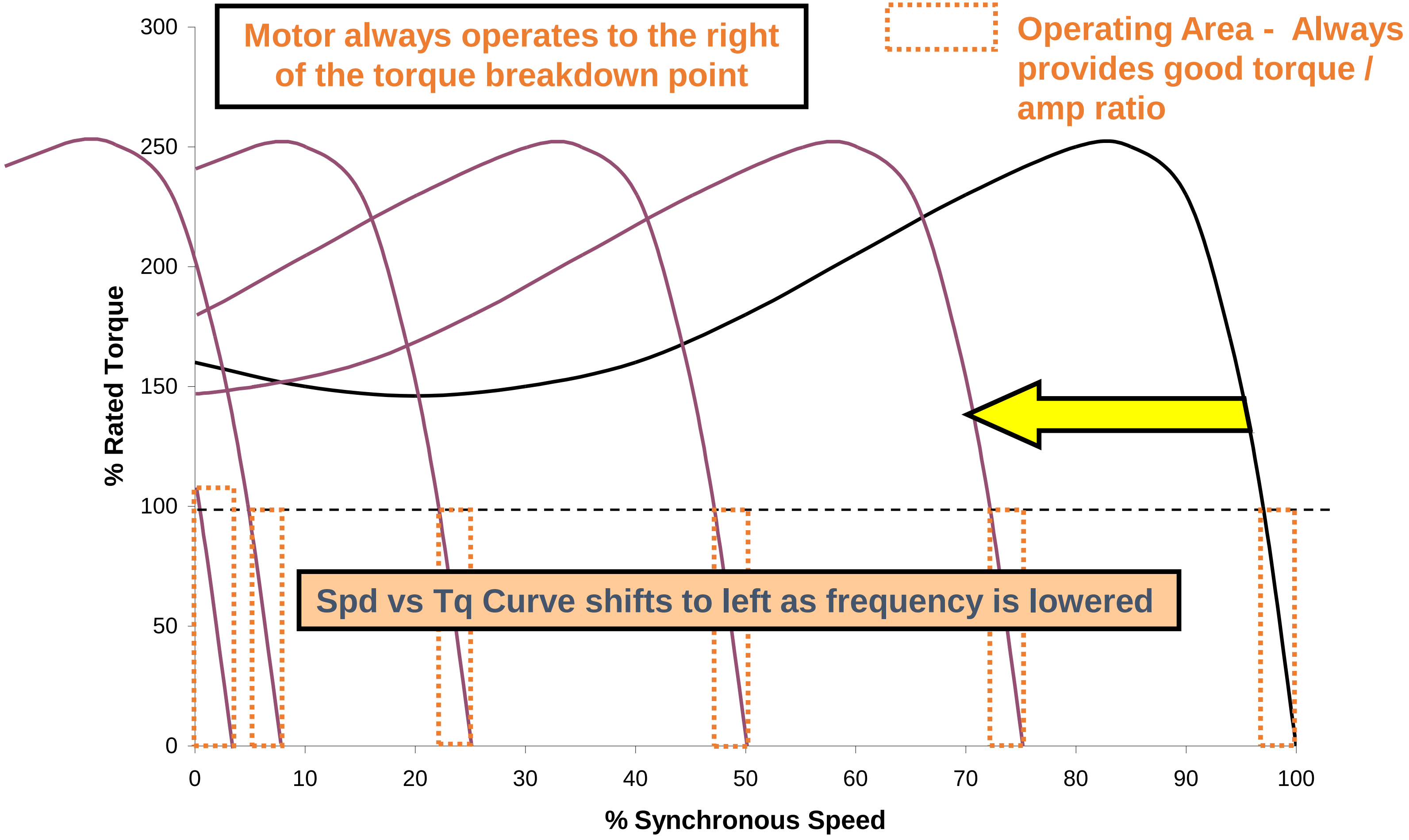
Torque vs. Speed - NEMA B Motor



Area proportional to rotor losses (speed x tq = power):
Less slip = lower losses

Slip, $s = n_s - n$ [rpm] = $(n_s - n) / n_s$ [pu]

Tq-Spd Characteristics with Changing Frequency



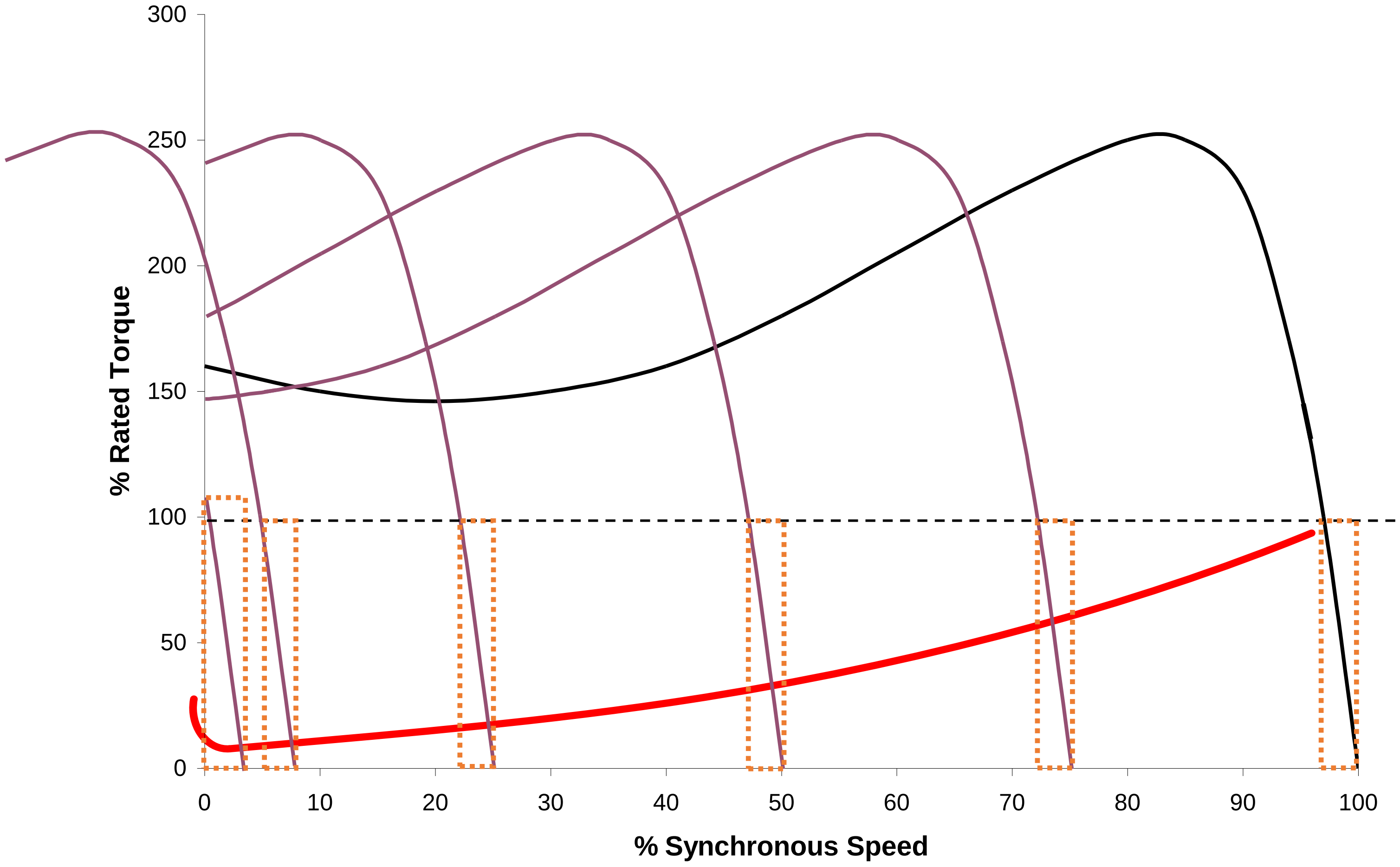
Motor always operates to the right of the torque breakdown point

Operating Area - Always provides good torque / amp ratio

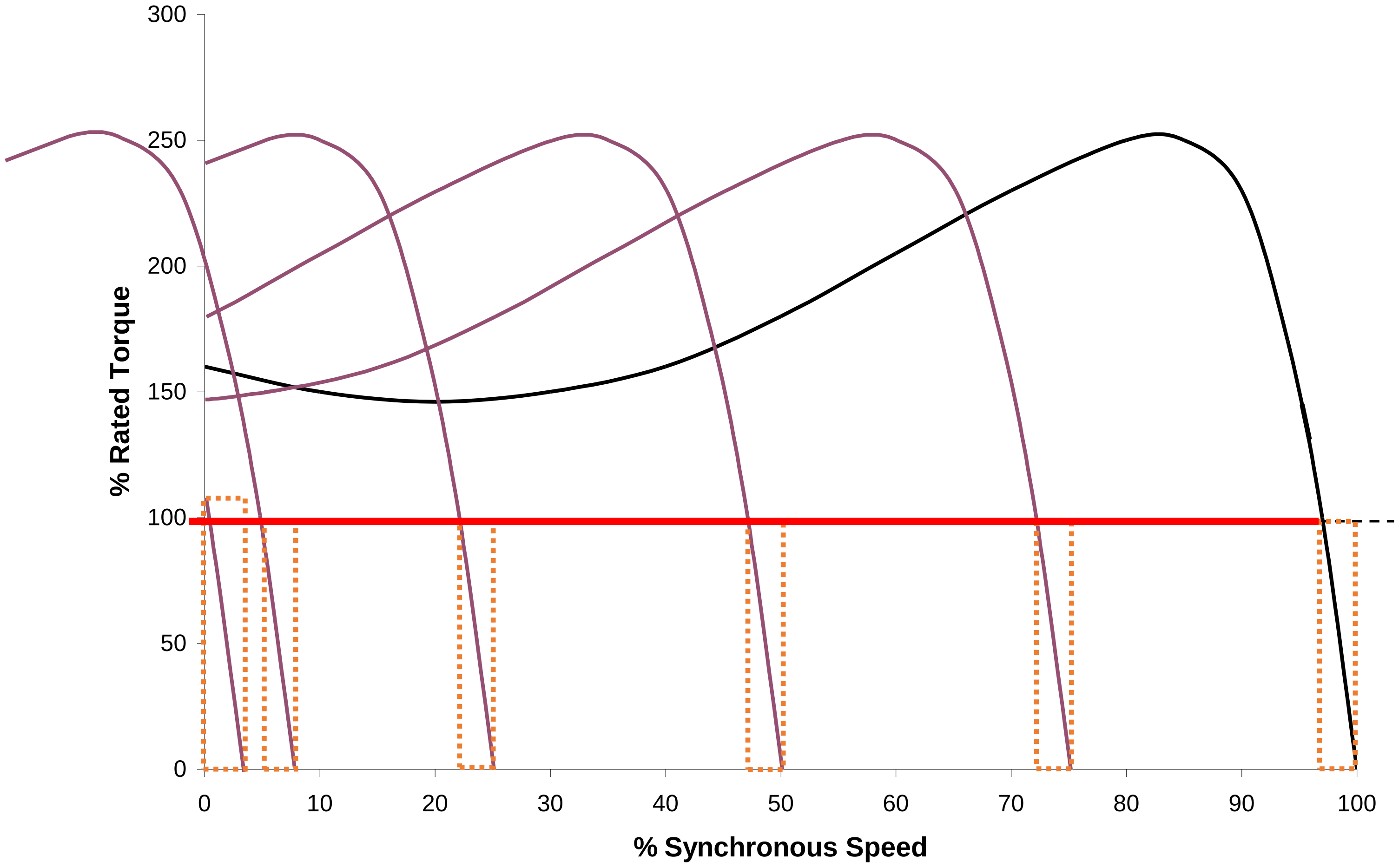
Spd vs Tq Curve shifts to left as frequency is lowered

Spd vs Tq Curve has same shape if Flux (V/Hz) is kept constant

Tq-Spd with Fan or Pump Load



Tq-Spd with Constant Torque Load (conveyor)



Motor Loadability Curve – Thermal Cooling Limitations

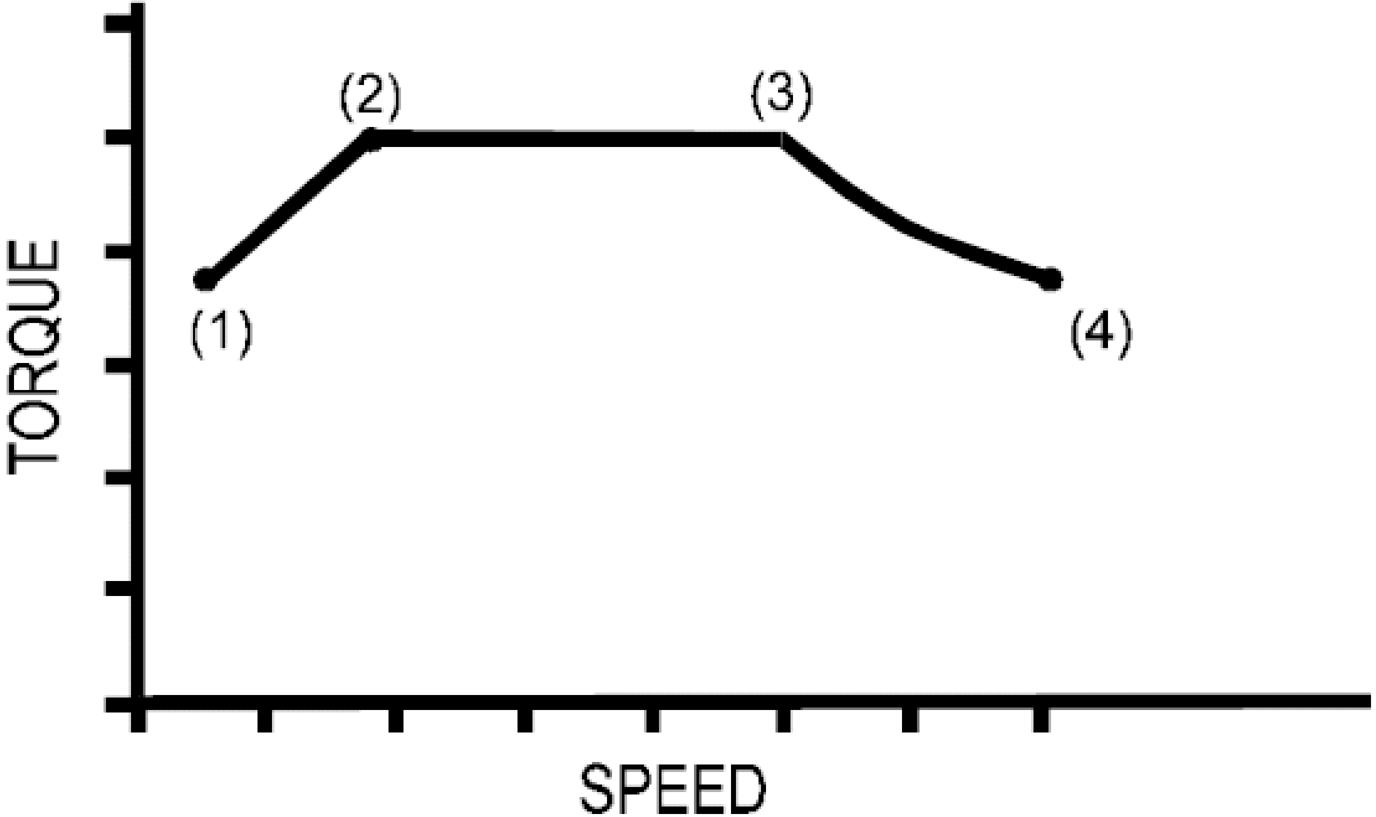
(3) is the nominal HP rating (rated torque and rated speed)

(2) is the thermal limit for constant torque below base speed

(1) is the thermal limit for max torque at minimum speed

(4) is the speed limit when operating at constant HP (field weakening)

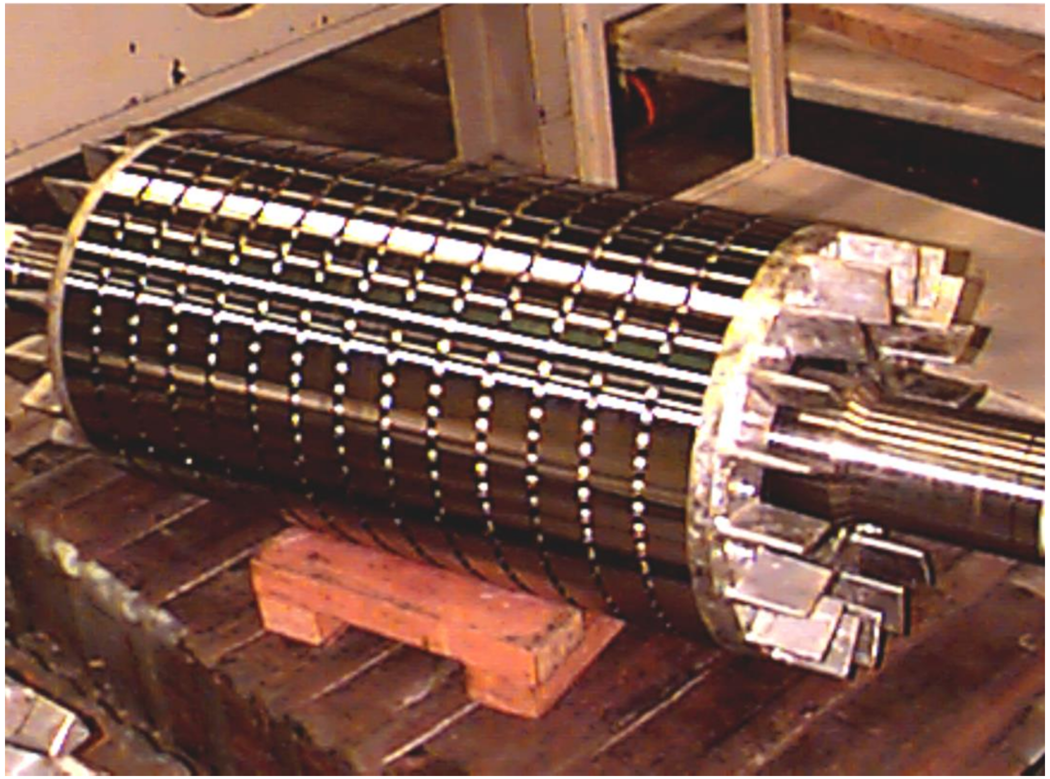
- Larger Cooling Fan
- Optimize Rotor Bar Shape For Inverter
- Bias Loss Distribution to Losses which diminish at lower speeds (core loss)
- Separate Blower
- Addition of RTDs will provide real-time information on the winding temperatures

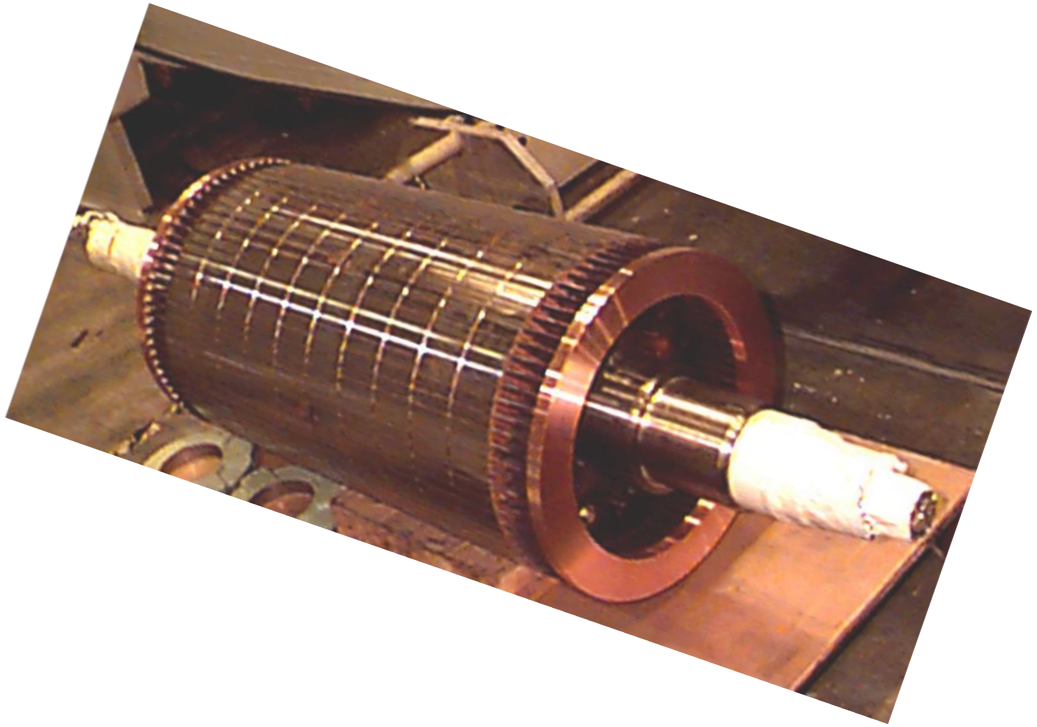


How To Reduce Rotor Temp Rise

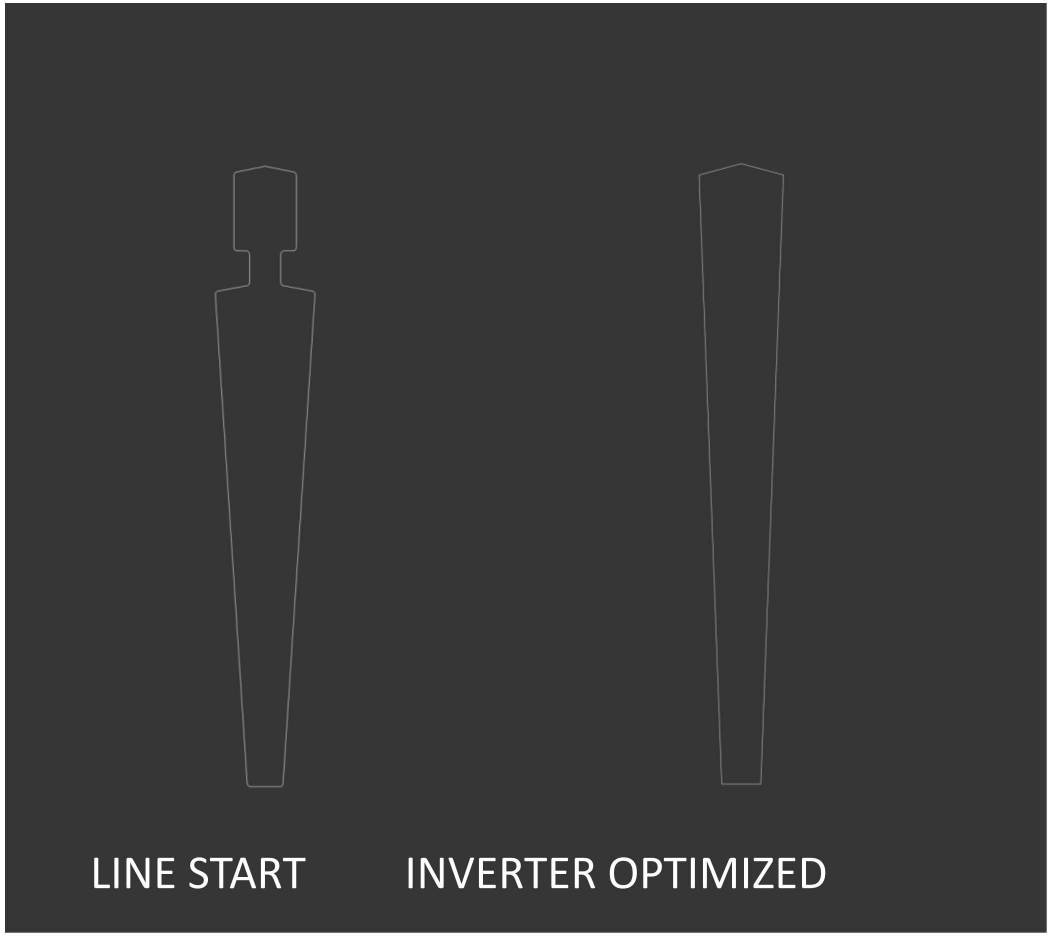
- “Open” Construction
- Higher Number Of Poles
- Copper Bars Rather Than Aluminum
- Optimize Rotor Bar Shape For Inverter
- Ducted Rotor
- Low Slip

Reducing Rotor Temperatures – Ducted and/or Copper Bar Rotor



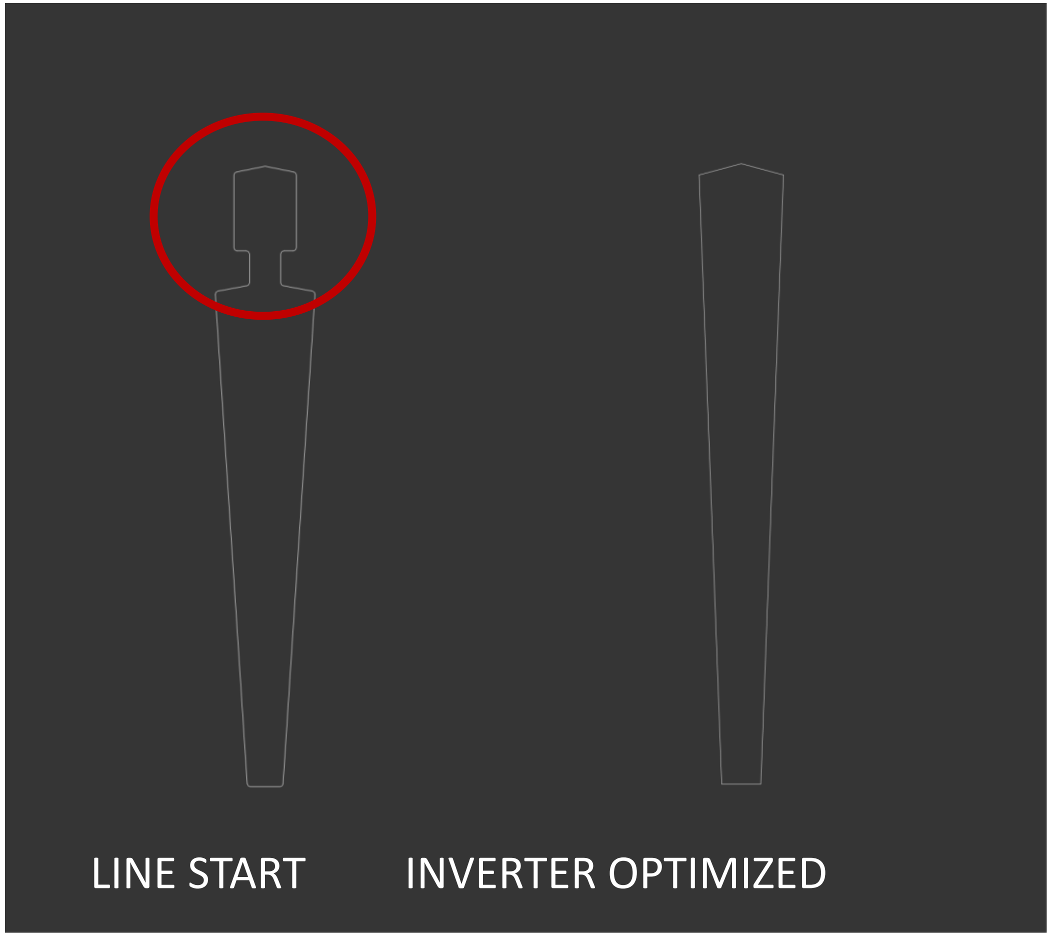


Reducing Rotor Temperatures – Slot Shape for Inverter Power



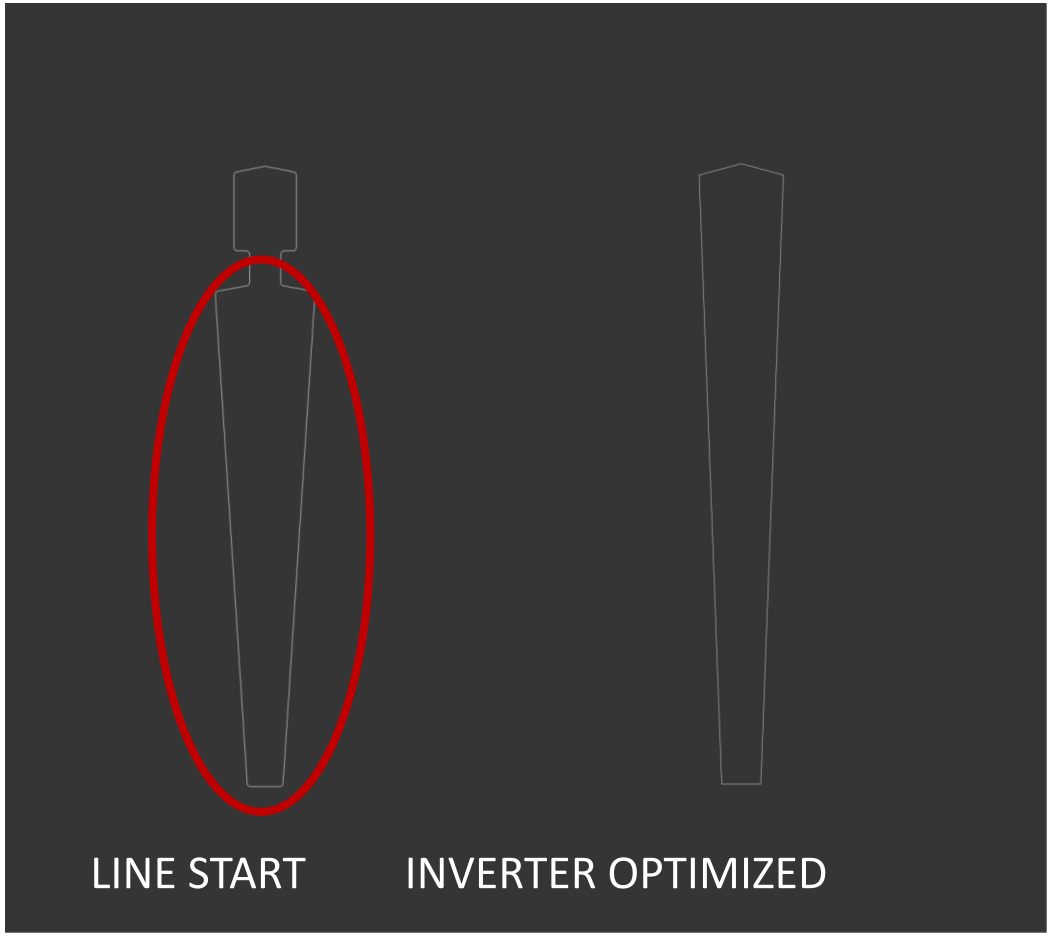
Reducing Rotor Temperatures – Slot Shape for Inverter Power

60Hz slip starting current mostly flows within this section of the rotor bar, creates higher starting torque

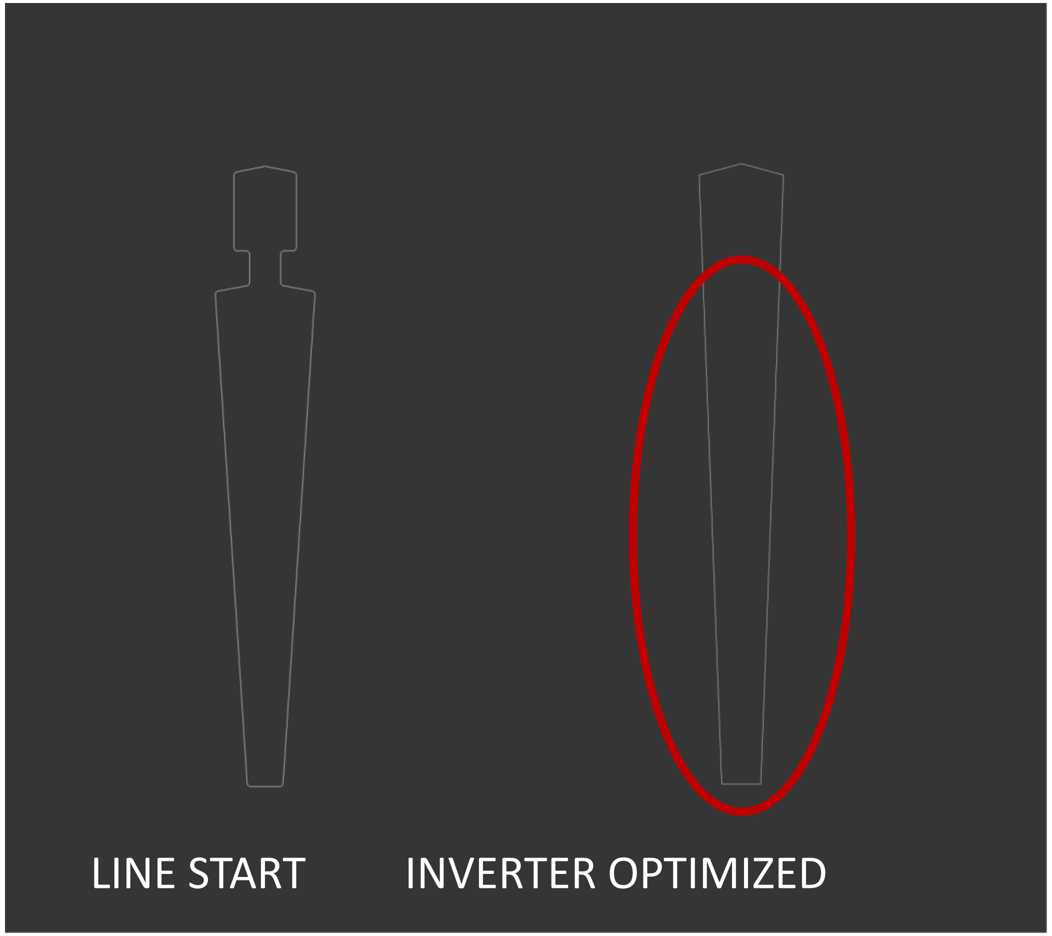


Reducing Rotor Temperatures – Slot Shape for Inverter Power

2Hz slip full load current mostly flows within this section of the rotor bar for rated torque

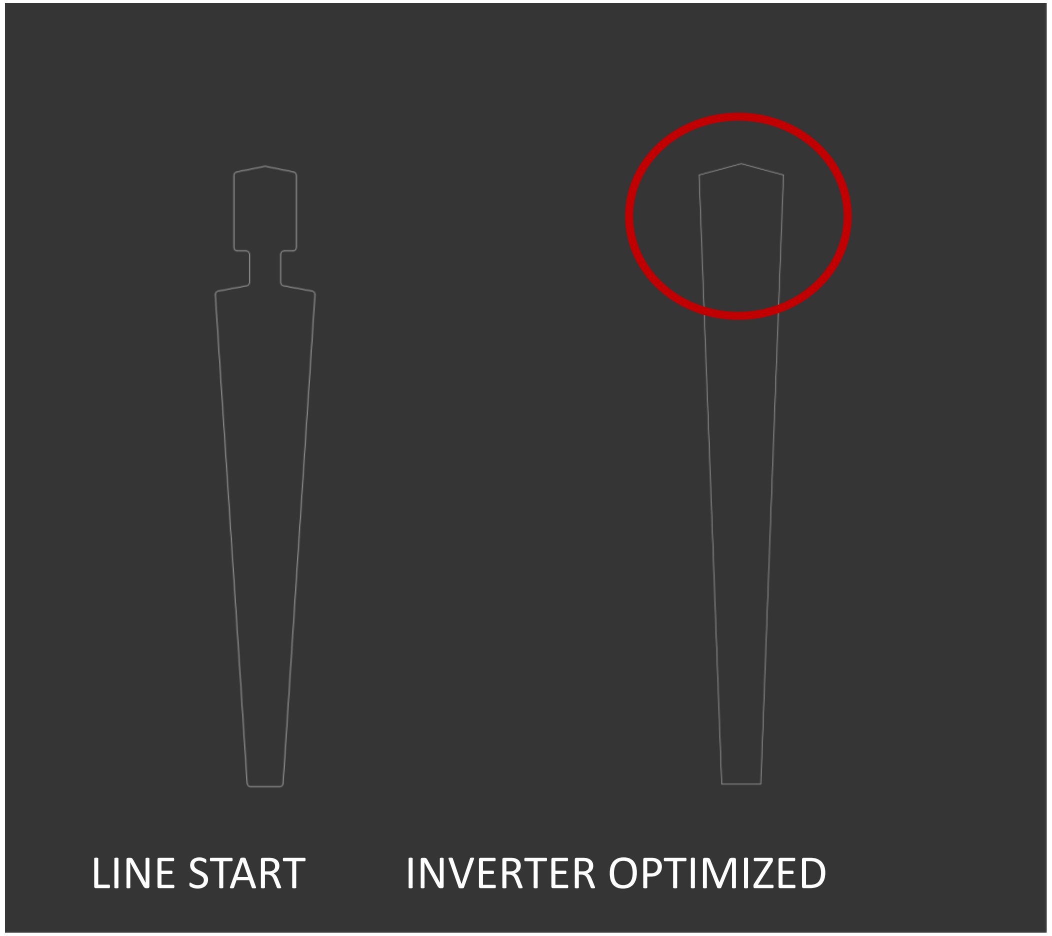


Reducing Rotor Temperatures – Slot Shape for Inverter Power



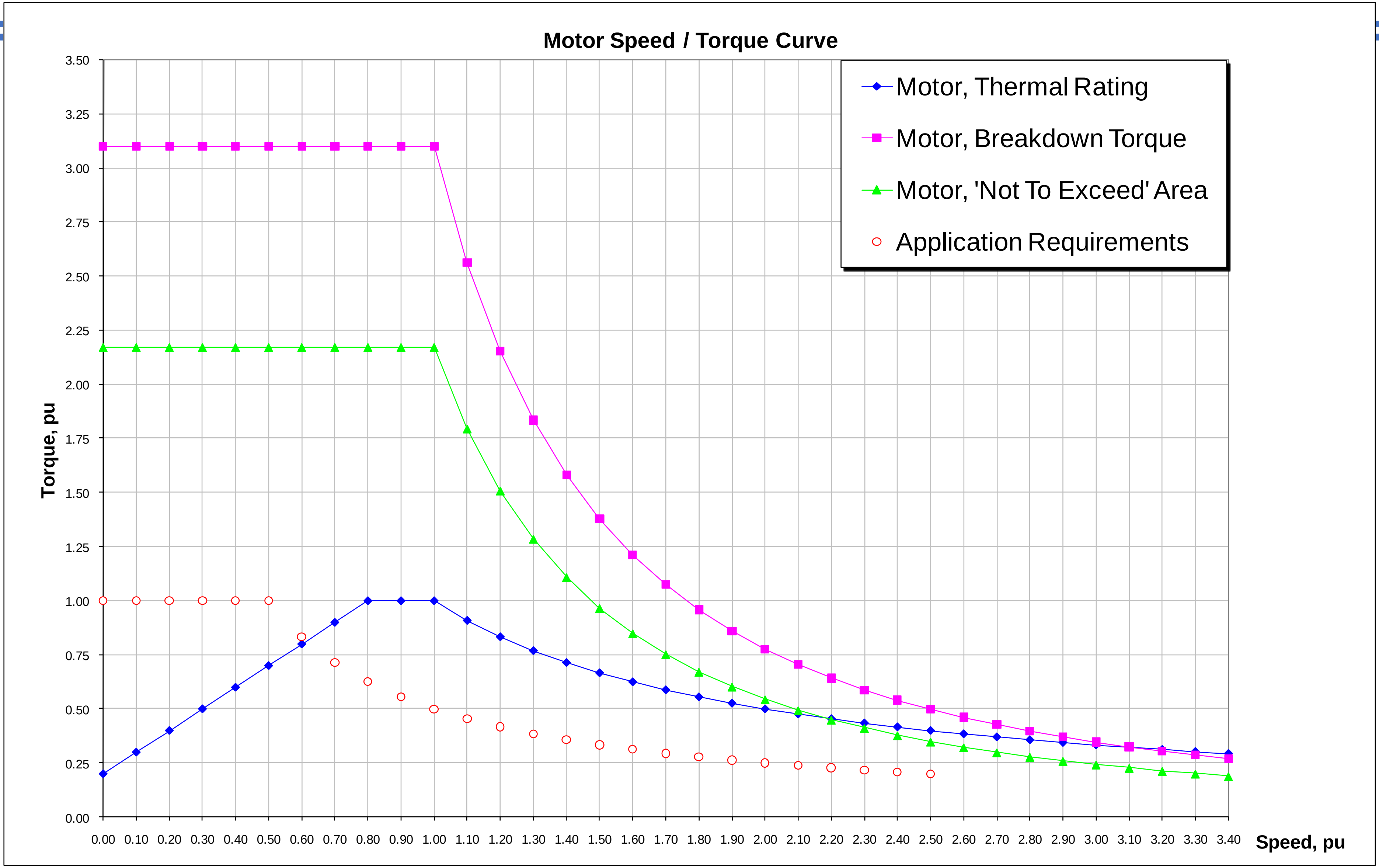
~2Hz slip freq full load current mostly flows within this section of the rotor bar for rated torque throughout the speed range (never operate with 60Hz slip freq)

Reducing Rotor Temperatures – Slot Shape for Inverter Power



Switching freq current mostly flows within this section of the rotor bar, with lower resistance and lower losses

Motor **Torque** and **Thermal** and **Speed** Limitations



Green curve = 70% of Pink curve
~ 150% of rated torque

Overspeed with fans & pumps

Affinity Laws

Applies to Fans, Pumps, Blowers, Compressors

$Q \propto n$

Flow rate (Q) is proportional to speed (n)

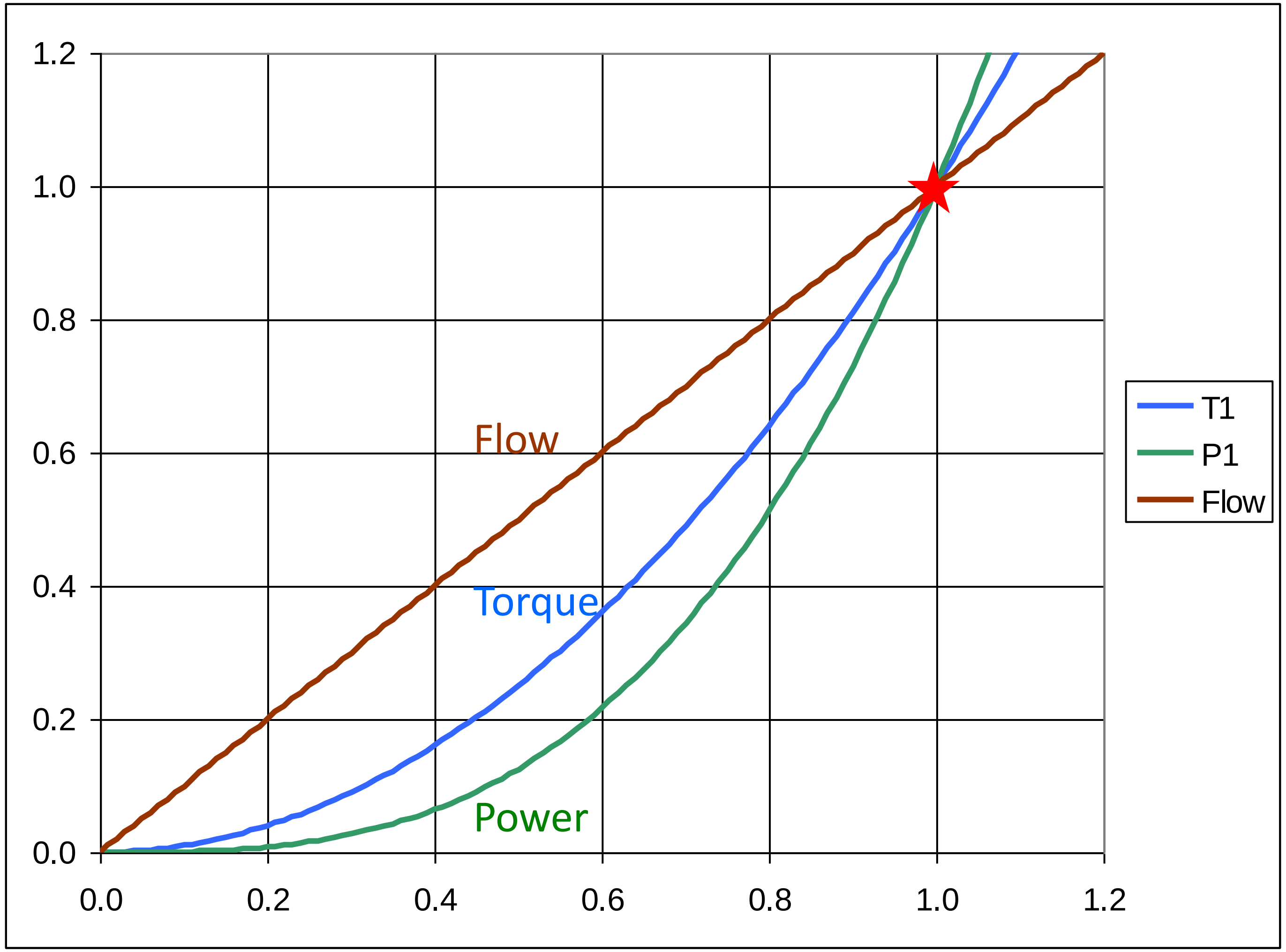
$H \propto n^{2}$

Head or pressure (H) is proportional to speed squared (n^2)

$P \propto n^{3}$

Power (P) is proportional to speed cubed (n^3)

Variable Torque Load



Speed, pu

Flow is proportional to speed
Torque is proportional to speed^2
Power is proportional to speed^3

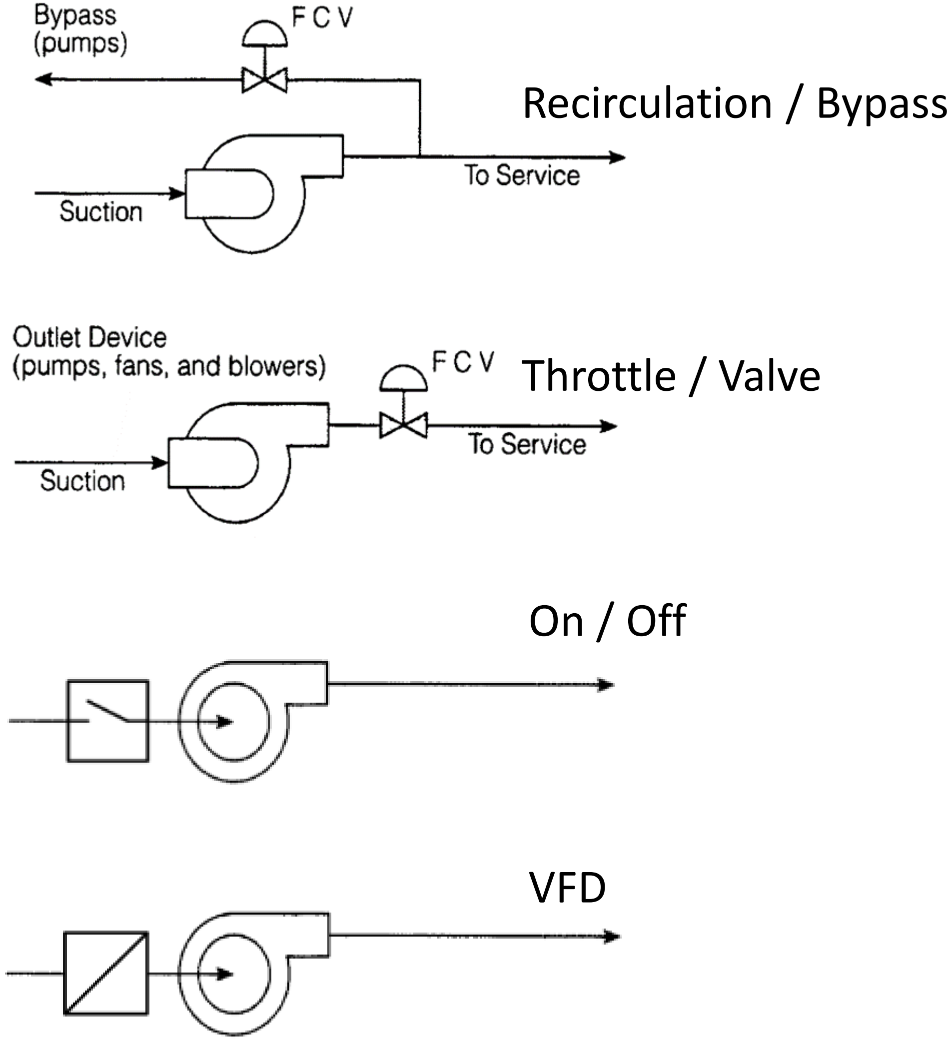
Need 5% more flow, 105%
Torque = 110%
Power = 116%

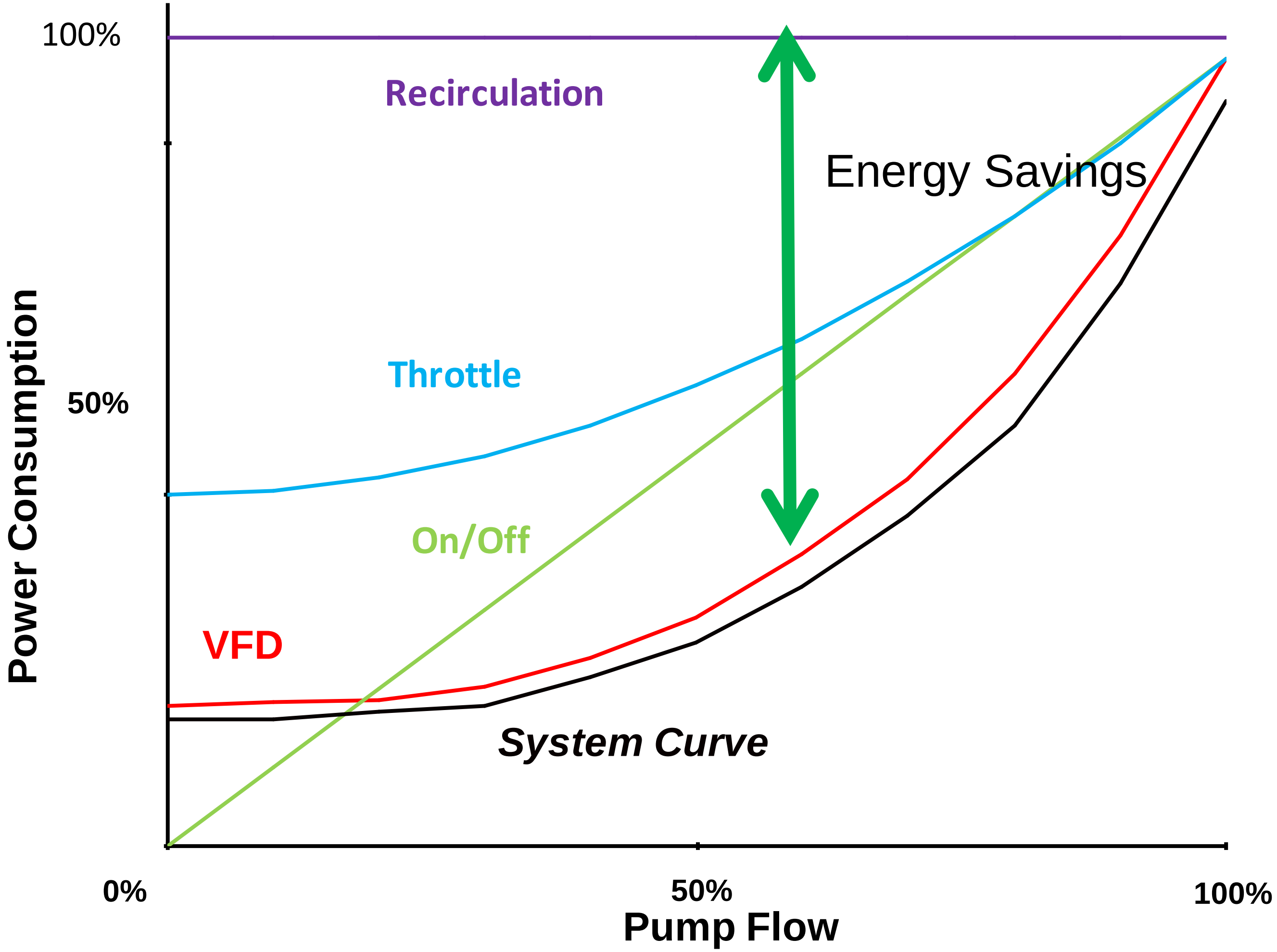
Need 10% more flow, 110%
Torque = 121%
Power = 133%

- Centrifugal fans
- Centrifugal pumps

★ Size for max spd and max tq = max hp

Pump Power Consumption

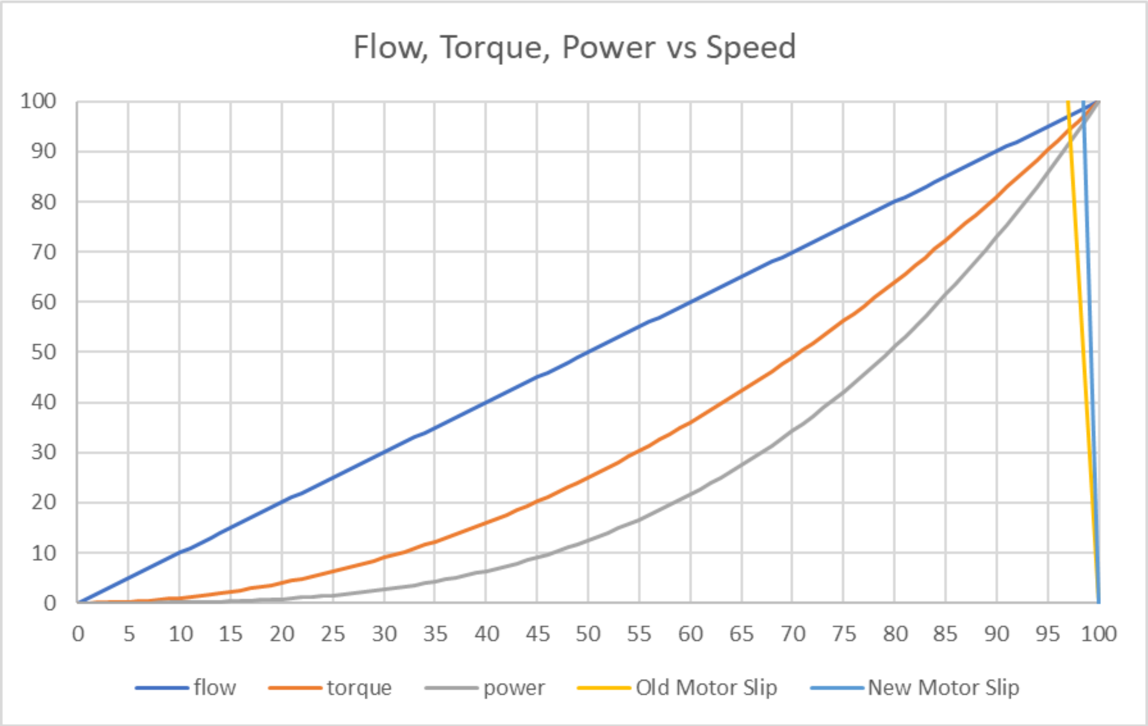


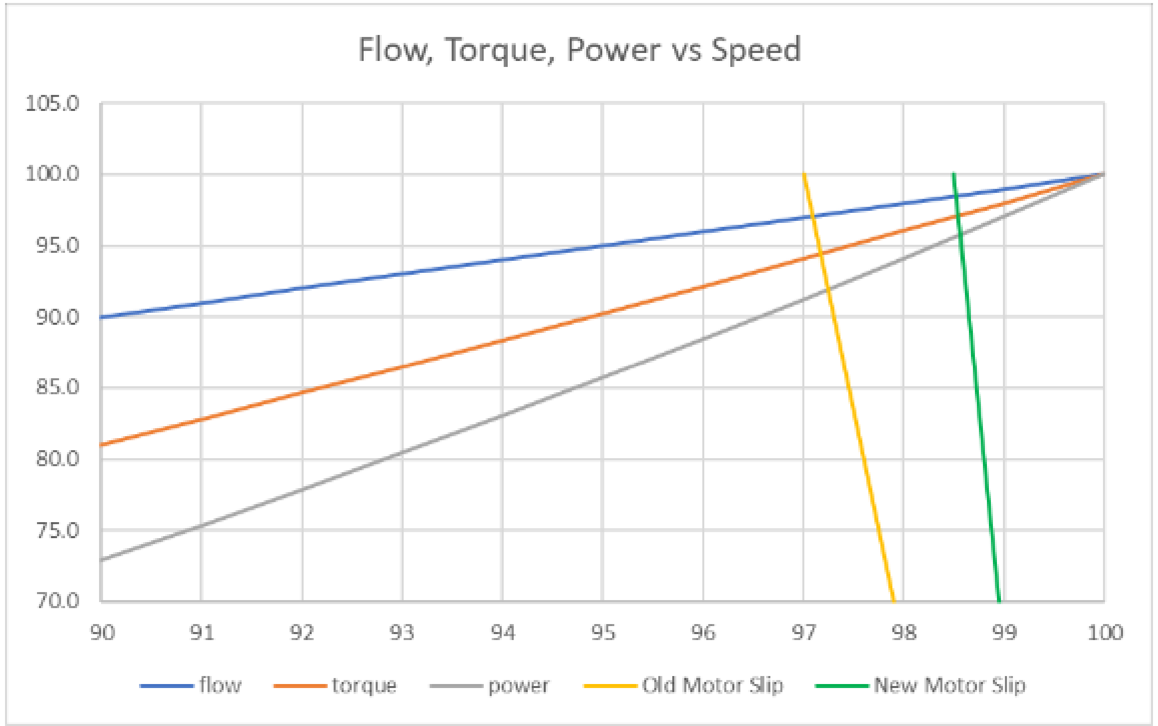


Newer High Efficiency Motors – Be aware!

If you replace an older, higher slip motor with a newer, high efficiency motor, what can you expect?

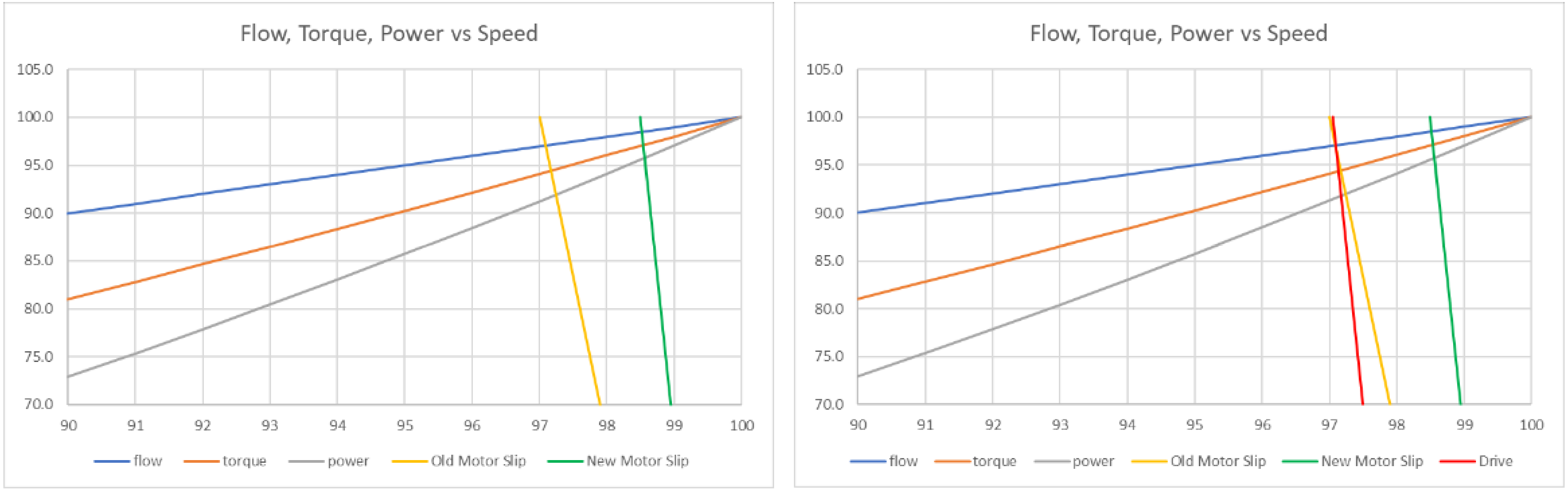
1. When powered from the line (utility or genset), the new motor will consume more power than before! How can that be? It is more efficient – right?





Newer High Efficiency Motors – Be aware!

2. Add a drive to reduce the speed to provide the same flow at reduced torque and reduced power. BUT, adding the drive adds losses!



Min speed with fans & pumps

Min speed with fans & pumps

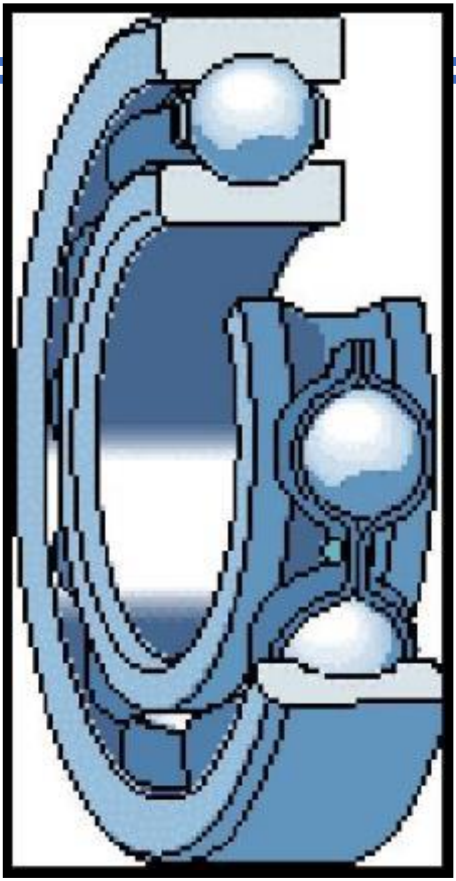
- Key issues for min speed:
  - Typically, not a cooling issue for a motor without a separate blower. It would be if the load was a constant torque type, such as a conveyor.
  - Can be a bearing issue for the motor if using sleeve bearings. Should not be a problem with ball or roller bearings.
  - In the past, with 6-step inverters, the motors would cog. This is not a problem with PWM inverters.
  - If holding torque at zero speed is required, there may be current limitations for the inverter since only three IGBTs would be providing all of the current. Some inverters might actually supply a very low output frequency (1Hz) so the current (and heat) would be shared among the 6 IGBTs.
  - Most fans and pumps are not operated below about 50% of rated speed since the flow would be so low.
  - The bearings of the fan and pump also need to be considered. For some down-hole pumps, a minimum speed must be maintained for cooling the pump and motor bearings, and for cooling the motor itself.

Bearing Systems

BEARING TYPE	**HORIZONTAL MOUNTED MOTORS**	**VERTICAL MOUNTED MOTORS**
Anti Friction	Available	Available
Sleeve	Available	Available as a guide bearing.
Angular Contact	Available for high axial thrust applications	Available
Spherical Roller		Available
Tilting Pad	Available	Available

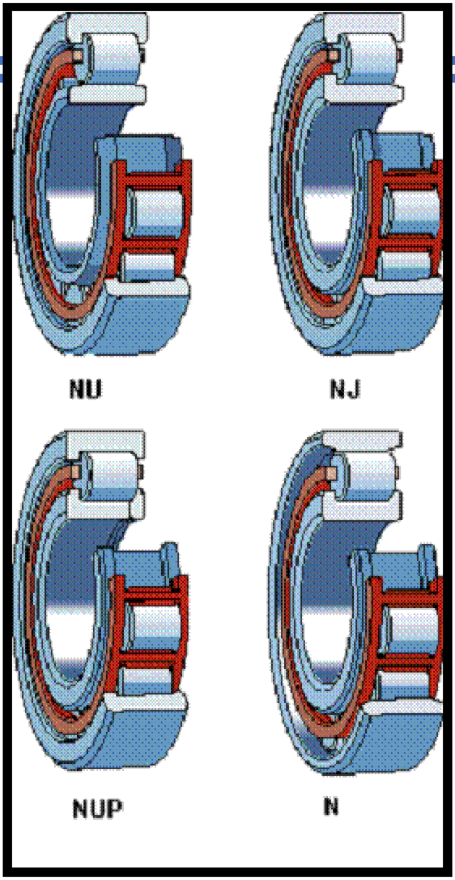
Lubrication Systems Available:
Grease.
Oil - Forced Flood or Mist.
- Self lubricated.

Cooling Systems Available:
Air.
Water.
Re-circulating oil.



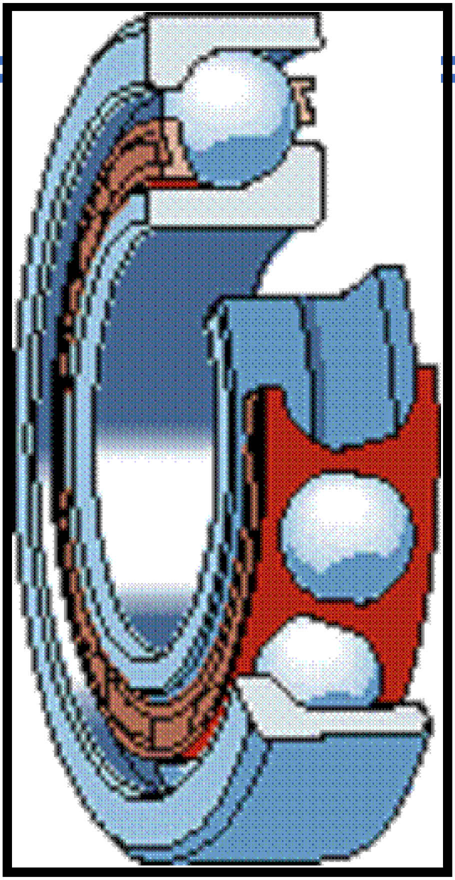
Ball Bearings

- Moderate Radial Loads
- Moderate Thrust Loads



Cylindrical Roller Bearings

- Heavy Radial Loads
- No Thrust Loads



Angular Contact Bearings

- Heavy Thrust Loads
- No Radial Loads Unless Duplex Mounted.

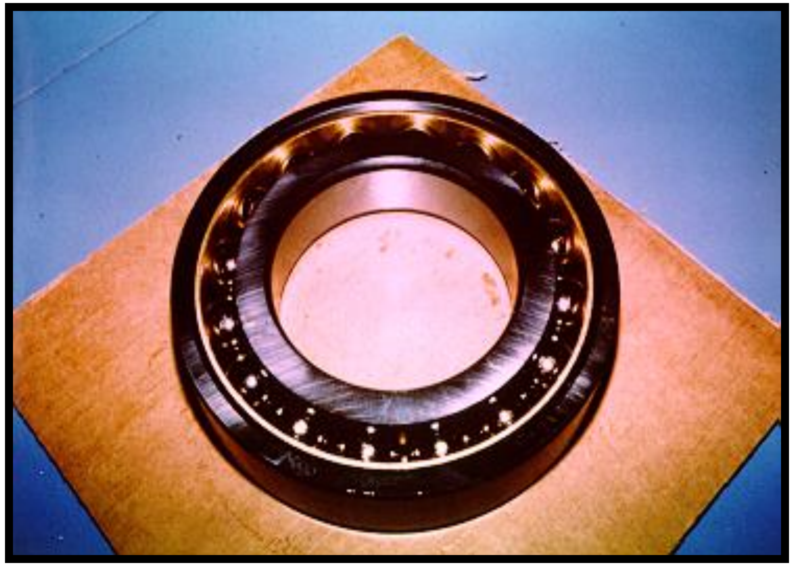
Anti-Friction Bearing Criteria

1. Speed Limitations
2. Bearing Load Limitations
3. Application
    1. Radial Load
    2. Thrust Load
4. Bearing Life Design Standards:
    1. Coupled Duty L_{10} Life = 100,000 Hours
    2. Belted Duty L_{10} Life = 17,500 Hours

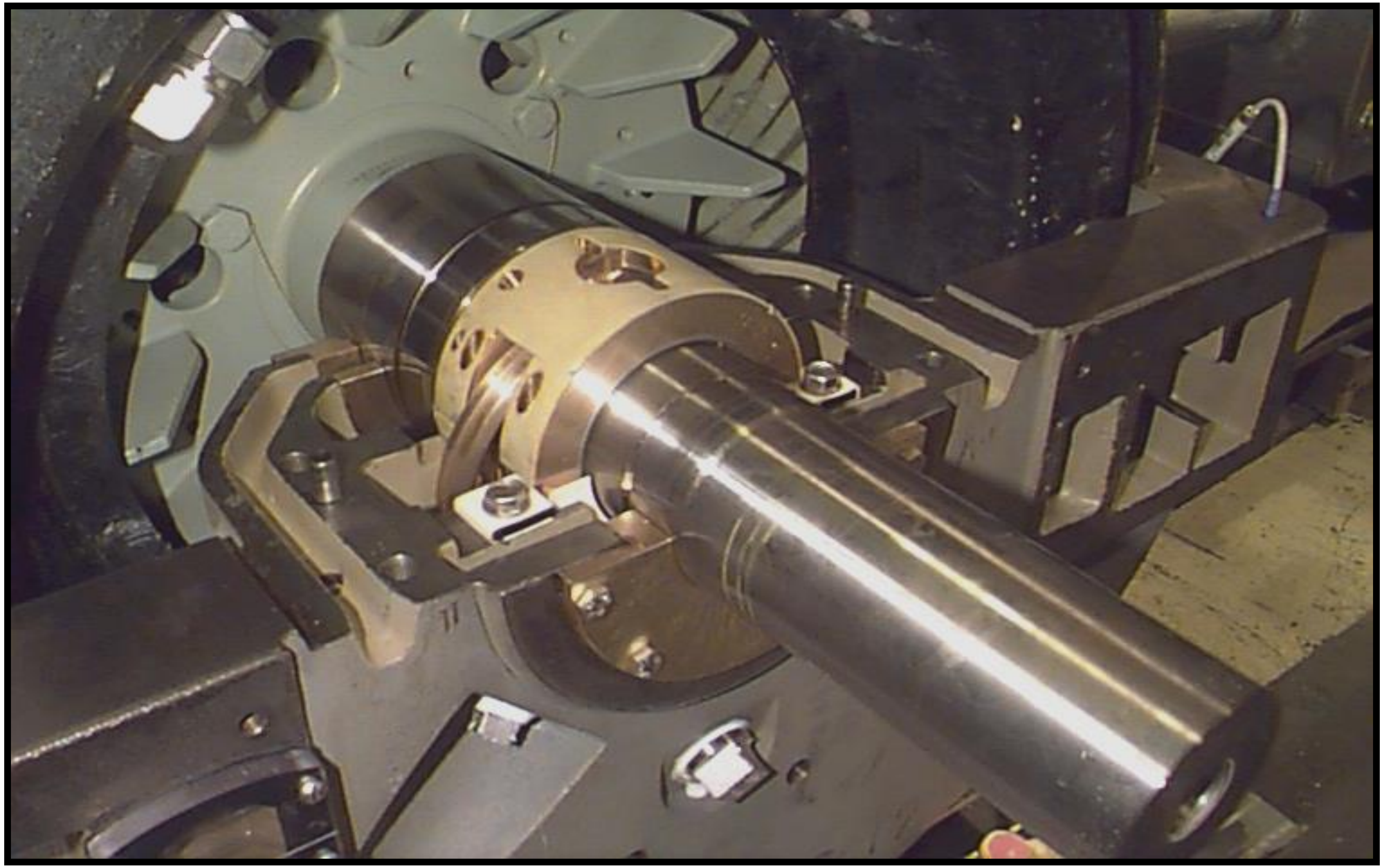
Bearing L_{10} Life

The L_{10} Life represents the life that 90% of an identical group of bearings will achieve before failure.

- Finite Life
- Factors Affecting Life
  - Contamination
  - Improper Lubrication
  - Application
  - Misalignment
  - Installation
  - Excessive Temperatures



Sleeve Bearings



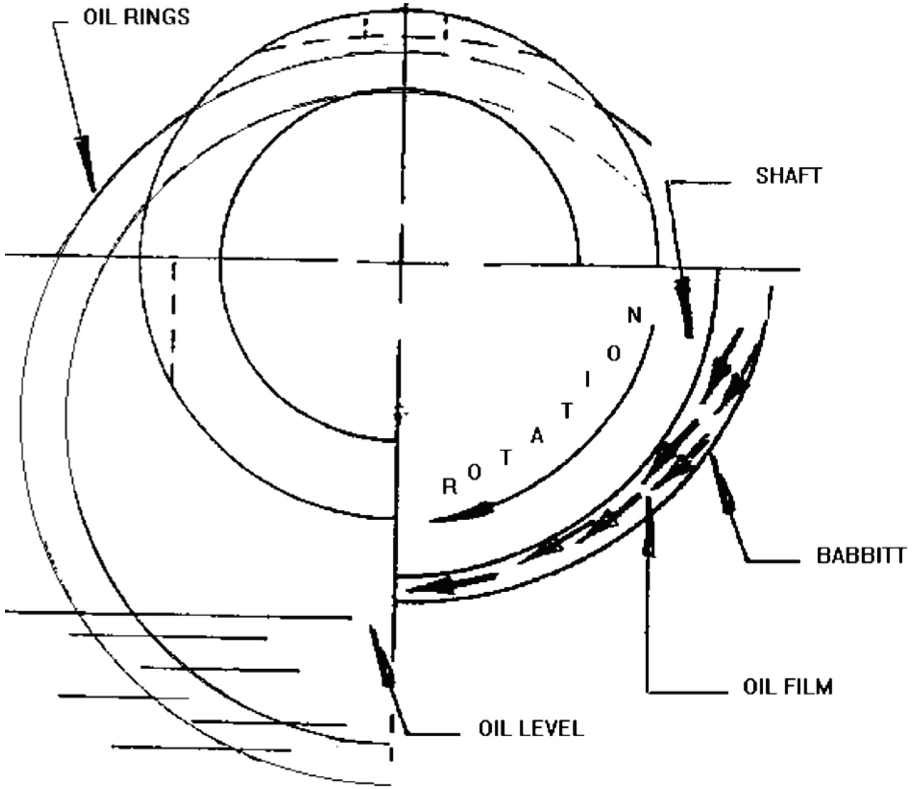
Sleeve Bearings

Journal Bearings

- Cylinder Seat
- - Thick Wall
- - Thin Wall
- Spherical Seat
- Horizontally Split
- Bronze Alloy Shell
- Steel Alloy Shell
- Tin Based Babbitt
- Theoretical Infinite Life

Sleeve Bearing Lubrication

- Oil Lubricated: Light Turbine Oil, 150 SSU.
- Self Lubricating: Oil Ring Feed Oil Film.
- Hydrodynamic Fluid Film Lubrication: Shaft rotation builds an oil wedge to float the shaft, riding on an oil film- No metal to metal contact.



SCCR for Drives

SCCR for drives

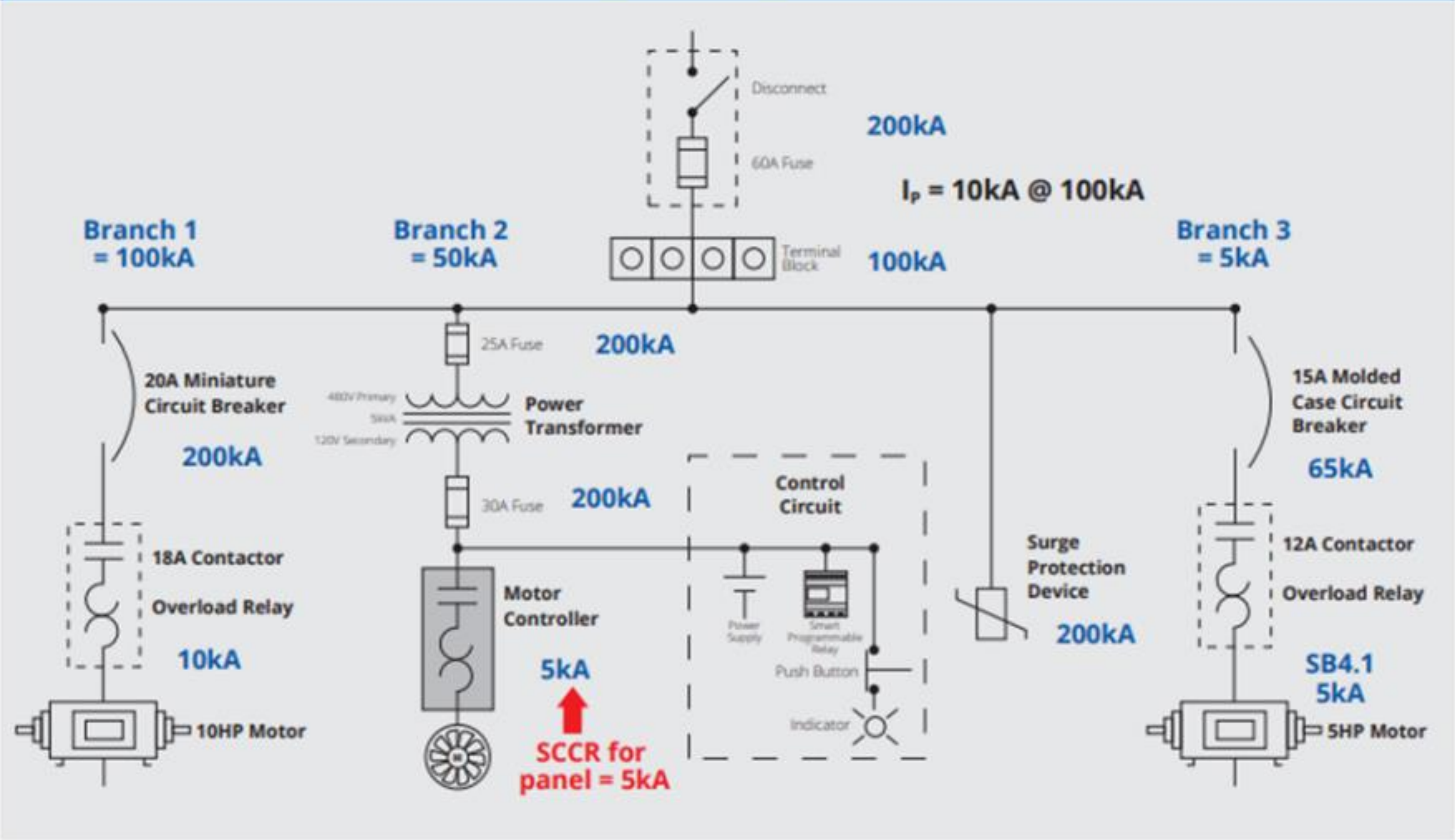
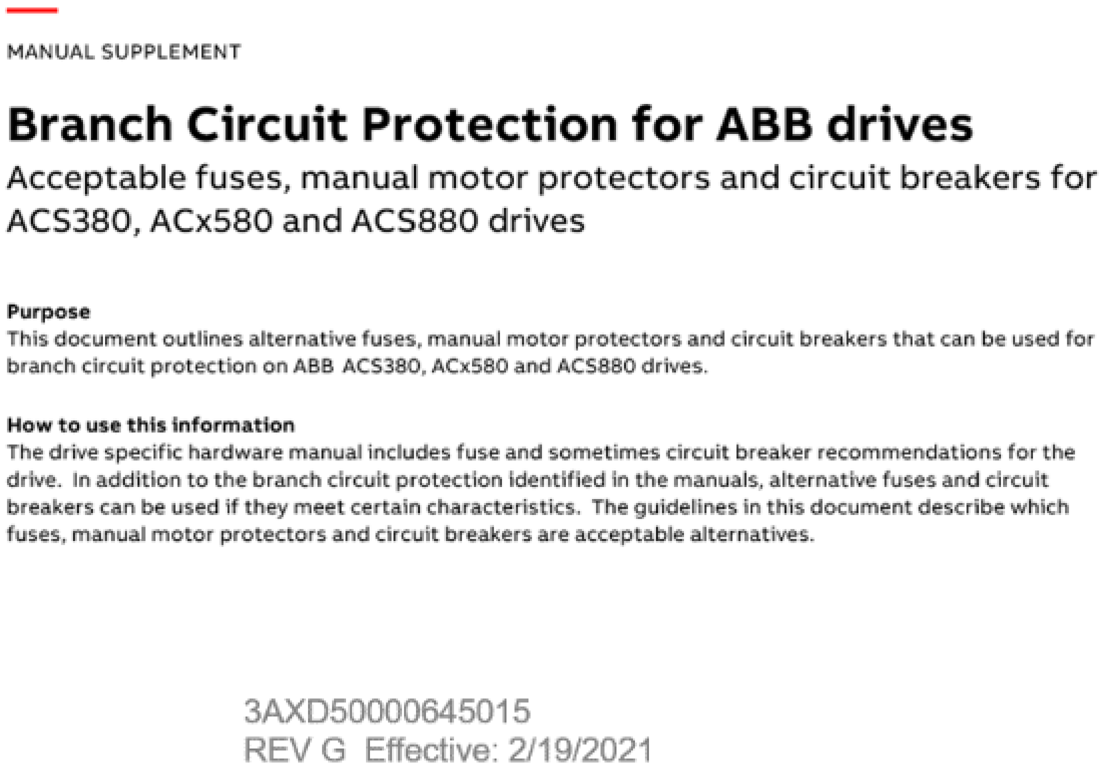


Figure 3: Example SCCR

SCCR for drives



MANUAL SUPPLEMENT

Branch Circuit Protection for ABB drives

Acceptable fuses, manual motor protectors and circuit breakers for ACS380, ACx580 and ACS880 drives

Purpose

This document outlines alternative fuses, manual motor protectors and circuit breakers that can be used for branch circuit protection on ABB ACS380, ACx580 and ACS880 drives.

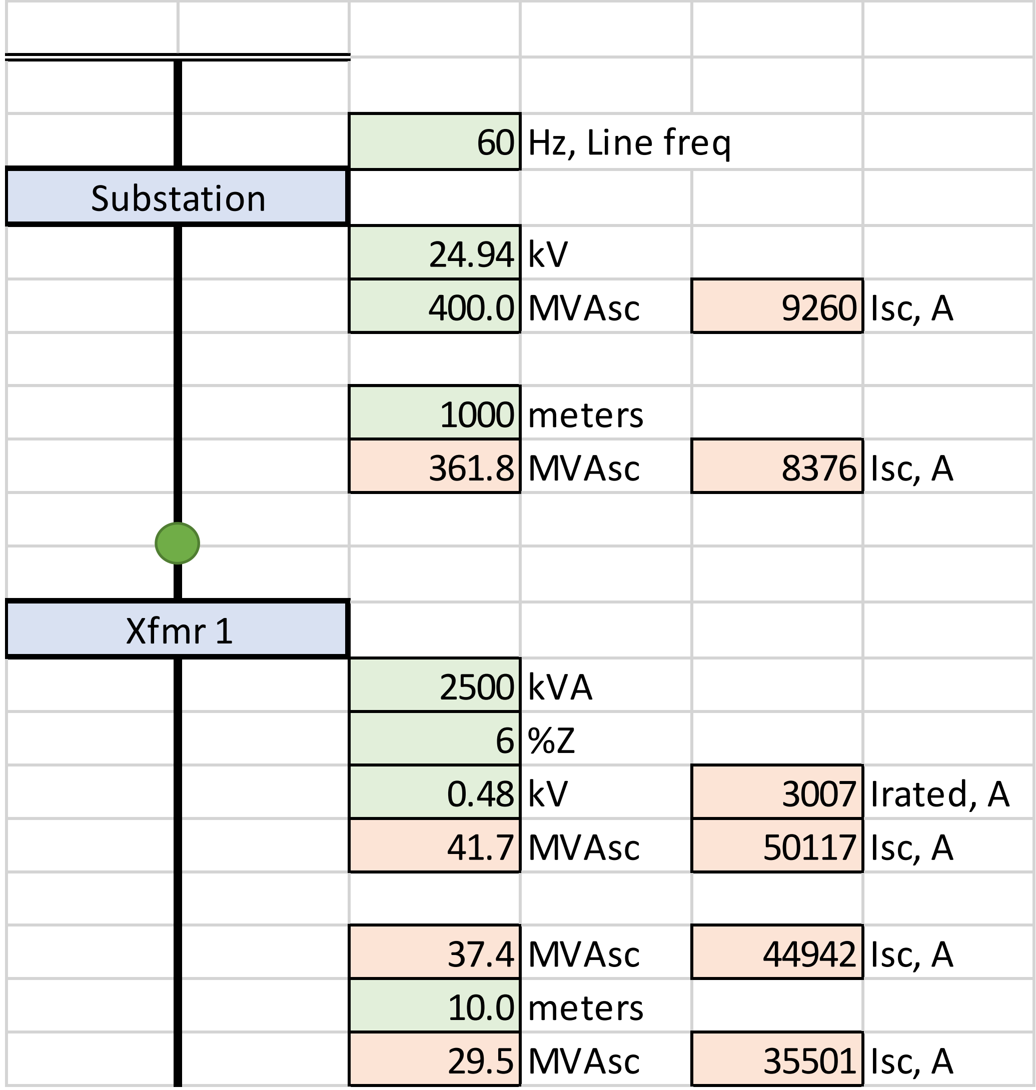
How to use this information

The drive specific hardware manual includes fuse and sometimes circuit breaker recommendations for the drive. In addition to the branch circuit protection identified in the manuals, alternative fuses and circuit breakers can be used if they meet certain characteristics. The guidelines in this document describe which fuses, manual motor protectors and circuit breakers are acceptable alternatives.

3AXD50000645015
REV G Effective: 2/19/2021

- Manual lists:
  - UL 248-15 Fast Acting Class T Fuses
  - UL 248-8 Fast Acting Class J Fuses
  - UL 248-8 Time Delay Class J Fuses
  - UL 248-8 High Speed Class J Fuses
  - UL 248-4 Fast Acting Class CC Fuses
  - UL 248-17 Time Delay Class CF Cube Fuses
  - UL 248-17 Fast Acting Class CF Cube Fuses
  - MMP Type E Manual Motor Protectors
  - UL 248-10 Fast Acting Class T Fuses
  - UL 248-10 Fast Acting Class L Fuses
  - UL 248-10 Time Delay Class L Fuses
  - UL 248-13 Semiconductor Fuses
  - UL 489 Current Limiting Circuit Breakers

A more realistic scenario for Isc at the drive



	60	Hz, Line freq		
Substation				
	24.94	kV		
	400.0	MVAsc	9260	Isc, A
	1000	meters		
	361.8	MVAsc	8376	Isc, A
Xfmr 1				
	2500	kVA		
	6	%Z		
	0.48	kV	3007	Irated, A
	41.7	MVAsc	50117	Isc, A
	37.4	MVAsc	44942	Isc, A
	10.0	meters		
	29.5	MVAsc	35501	Isc, A

Available at the Substation

Available 1000m from the Substation

Calculations for Xfmr 1

Available at Xfmr 1 secondary terminals

Available 10m from Xfmr 1

How does that work?

Effect of x meters of cable on Isc

- 3ph cable ~ 0.435 uH / m
  - Some use 1 uH / m (seems high)
- At f = 60 Hz, 0.435 uH for d = 1 m
  - XL = 2 x pi x f x L x d = 1.64×10^{-4} Ohms
- MVAsc of cable = kV^2 / XL

- When you have <u>two</u> MVAsc items in series, the sum of the two = MVAsc total =
  - (MVAsc1 x MVAsc2) / (MVAsc1 + MVAsc2)

- Isc = MVAsc / (√3 x kV), kA

Example

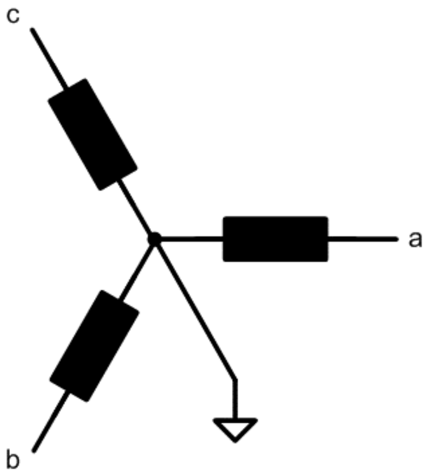
2500 kVA, 0.48 kV, 6%Z with 10 m of cable

- MVAsc at primary of xfmr = 400
- MVAsc of xfmr =
  - 2500 / 0.06 / 1000 = 41.7 MVA (50.1 kA)
- MVAsc total =
  - (400 x 41.7) / (400 + 41.7) = 37.4 MVA
  - This is the actual MVAsc at the xfmr secondary terminals

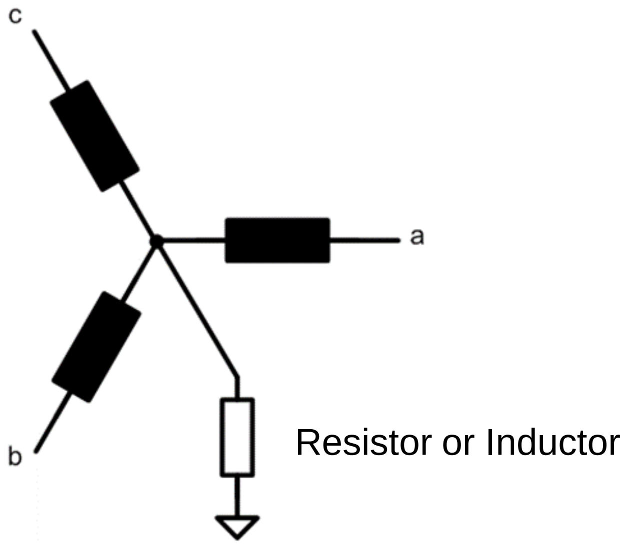
- XL of 10m of cable = 1.64×10^{-3} Ohms
- MVAsc of cable =
  - 0.48^2 / 1.64×10^{-3} = 140.5 MVA
- MVAsc at the end of 10m of cable =
  - 37.4 x 140.5 / 37.4 + 140.5 = 29.5 MVA
  - Isc = 35.5 kA NOT 50.1 kA

HRG vs Solid Ground

Grounding the Wye Secondary

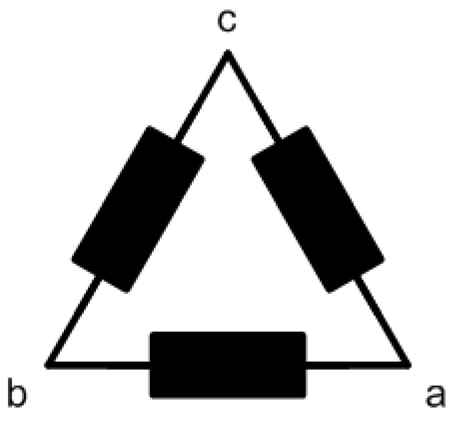


Solidly Grounded

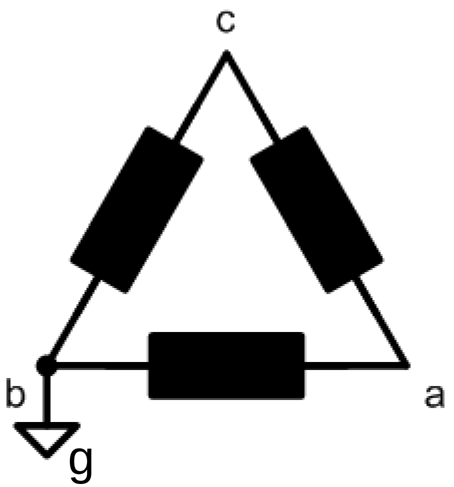


High or Low Resistive Grounding
or Inductive Grounding
This limits ground fault current

Grounding the Delta Secondary

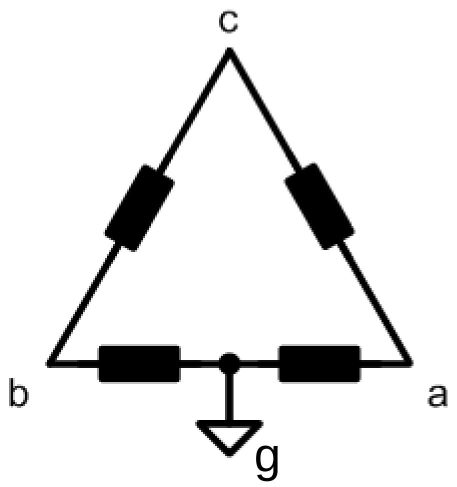


Floating



Corner Grounded
or
B-Phase Grounded

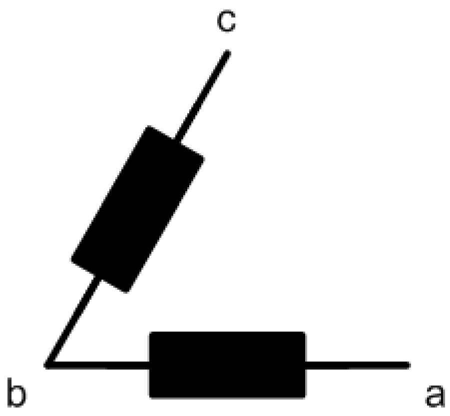
Vab=Vbc=Vca=Vag=
Vcg=480 V
Vbg=0 V



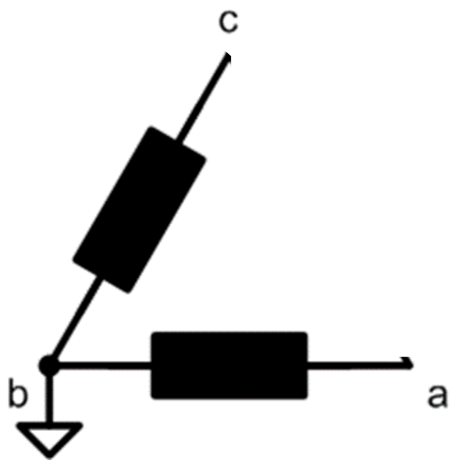
Center Grounded
or
Stinger Leg

Vab=Vbc=Vca=240 V, 3ph
Vag=Vbg=120 V, 1ph
Vcg=208 V, 1ph

Grounding the Open Delta (Vee) Secondary



Floating



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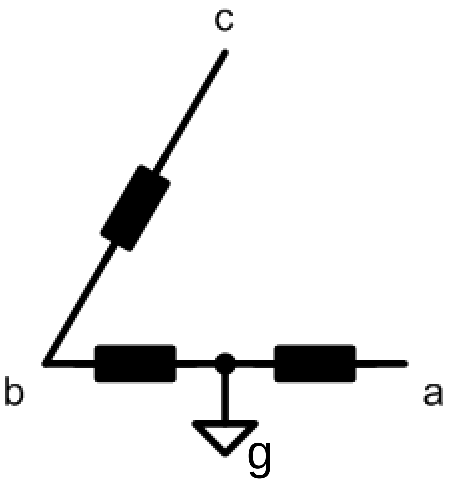

Center Grounded
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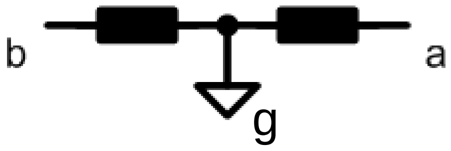


Center Tapped
Single Phase

Vab=240 V, 1ph
Vag=Vbg=120 V, 1ph
Usually seen in homes

Ground Faults

Let Rngr = 0.0 Ω

IL = 480/(1.732 * $\sqrt{0.00^2 + 0.014^2}$)

IL = ~19.8 kA

Let Rngr = 2.61 Ω

IL = 480/(1.732 * $\sqrt{2.16^2 + 0.014^2}$)

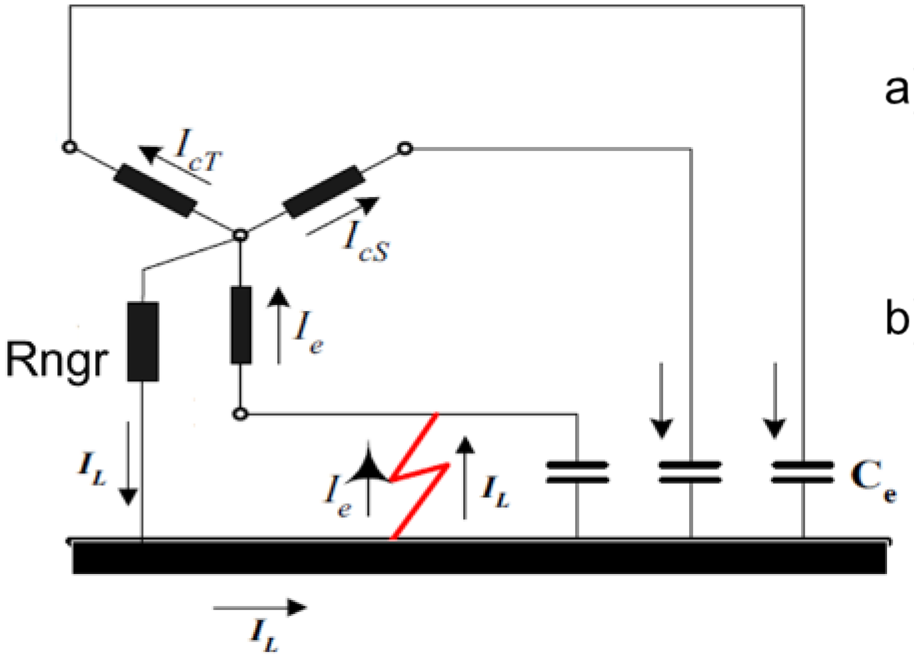
IL = 106 A

Let Rngr = ∞ Ω

IL = 480/(1.732 * $\sqrt{\infty^2 + 0.014^2}$)

IL = ~0 A

IL = V/($\sqrt{3}$ * $\sqrt{(Rngr^2 + Z^2)}$)



SLGF (single line ground fault) fault current, IL, is limited by:

a) Impedance of transformer winding, Z, = 0.014Ω (1000kVA, 480V, 6%Z)

b) Impedance of neutral grounding resistor, Rngr = 0 or 2.61Ω

Typical Resistance Grounded Systems

- Low Voltage Systems
    - 5A
    - 10A
    - 100A

- Medium Voltage Systems
    - 400A

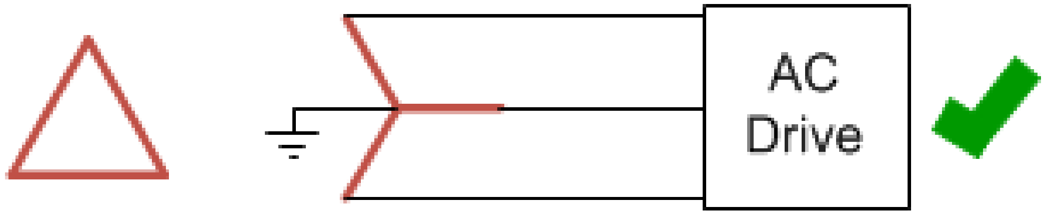
Drive / Transformer Combinations

Preferred Configuration

✓ Good

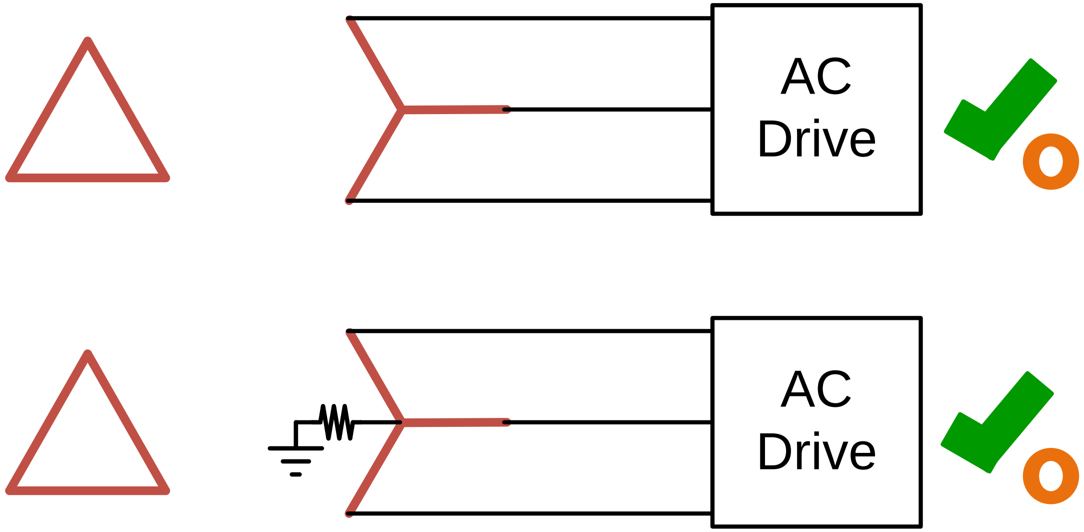
✓o Good, check manual

✗ Avoid



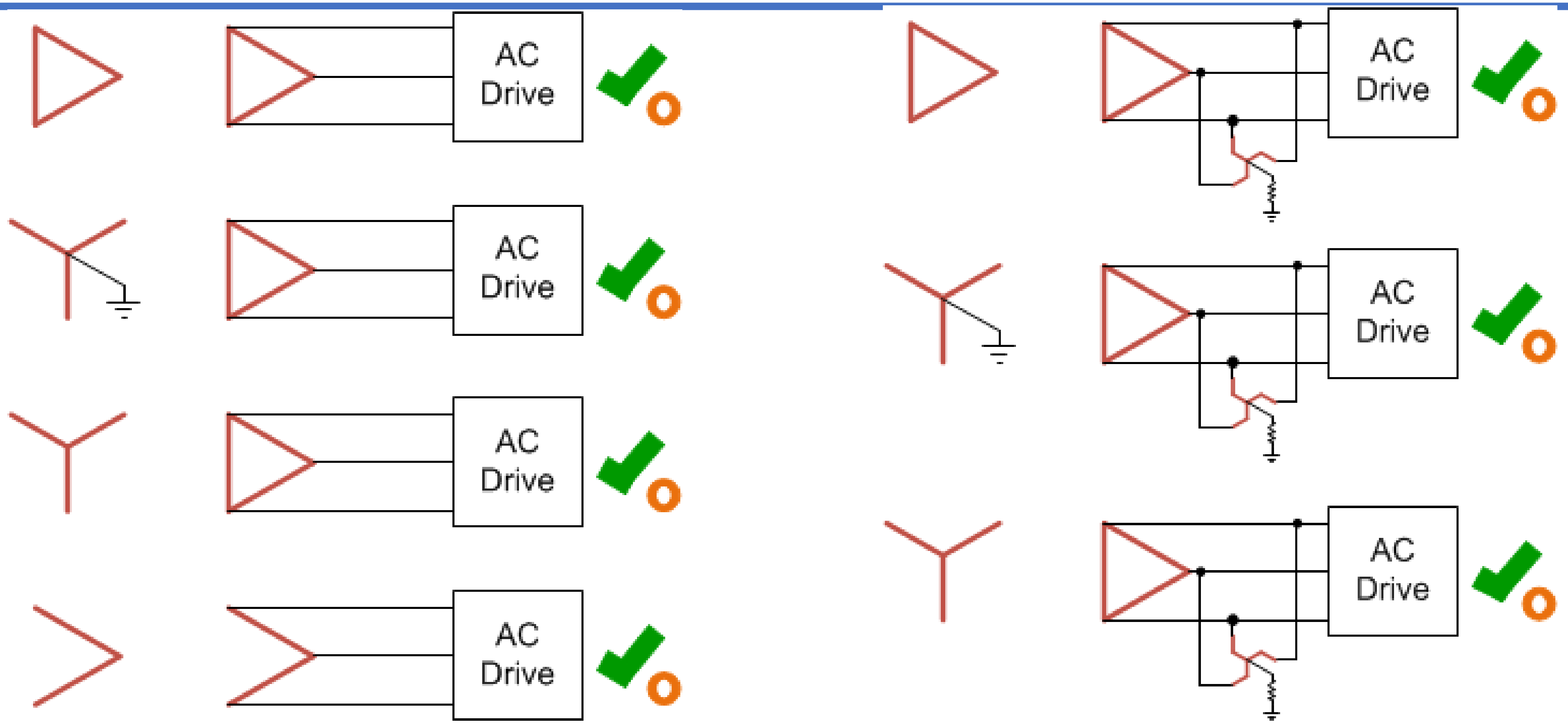
LV Drives

Acceptable Configurations



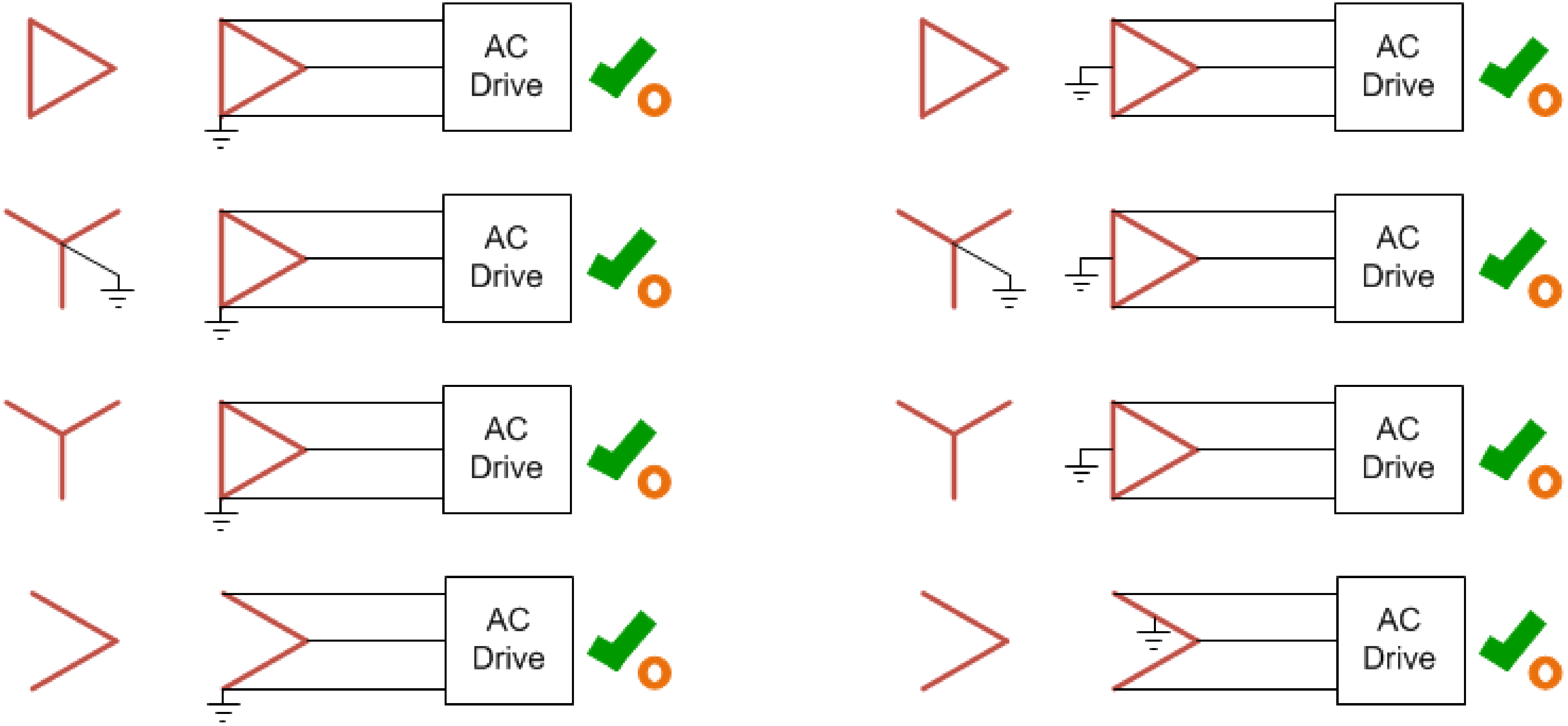
LV Drives

Acceptable Configurations



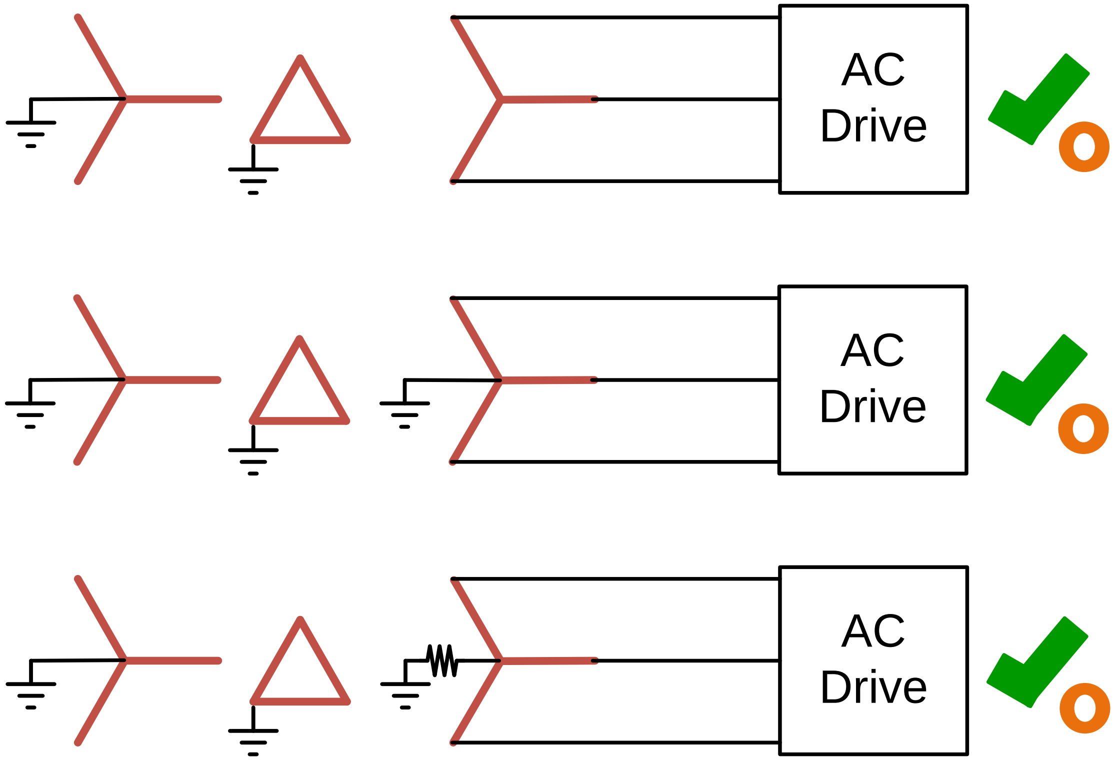
LV Drives

Acceptable Configurations



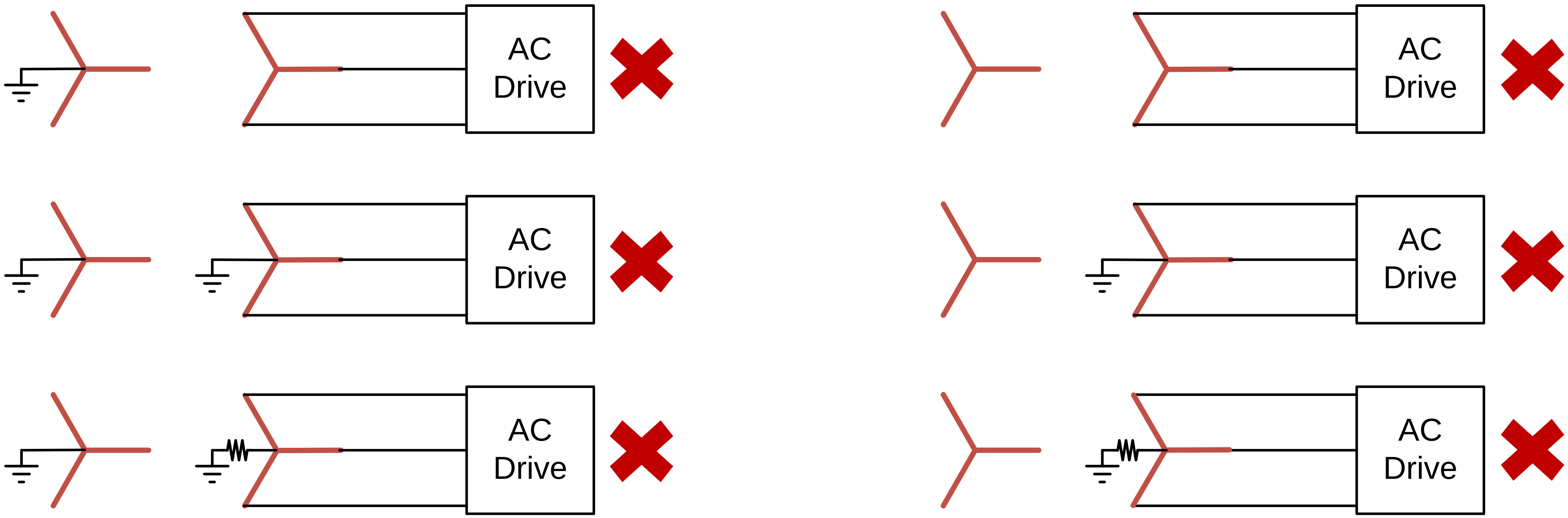
LV Drives

Should-Work Configurations



LV Drives

Not Acceptable Configurations



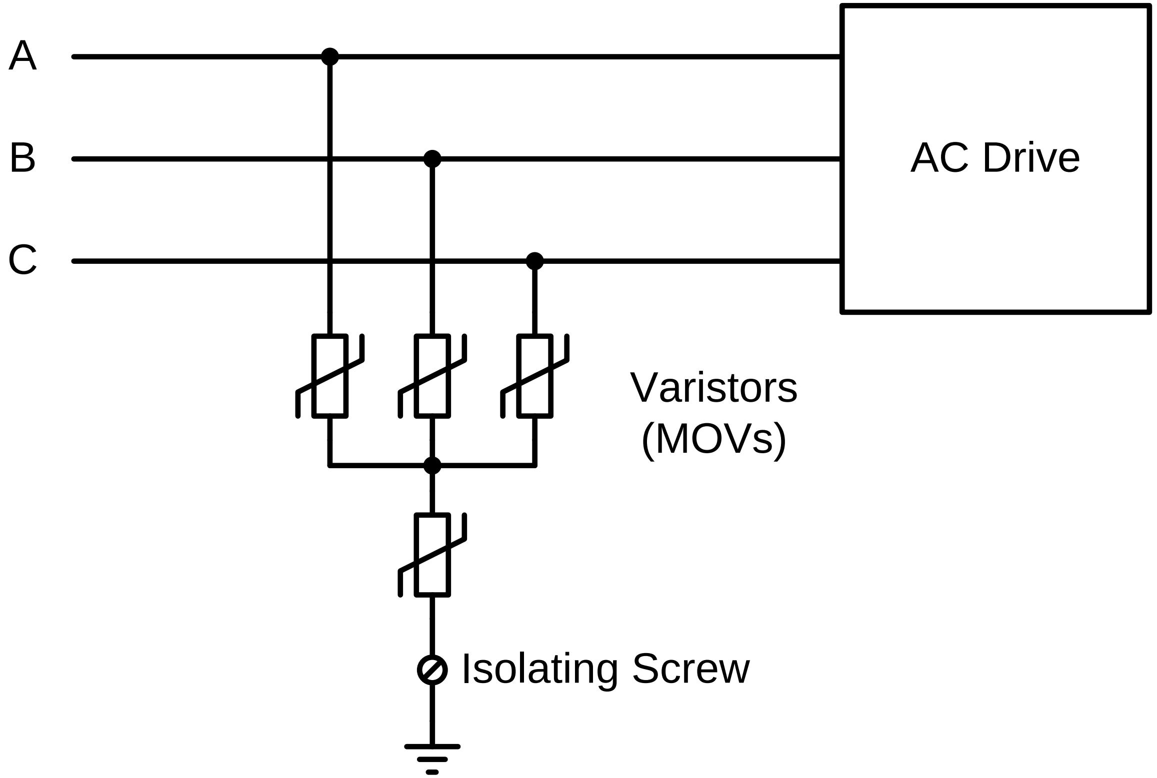
LV Drives

Important Note:

- If the secondary is floating or has a high resistance ground, check the LV drive manual for changing the ground connections to the EMC AC caps, EMC DC caps and the Varistors (MOVs)!
- Why?

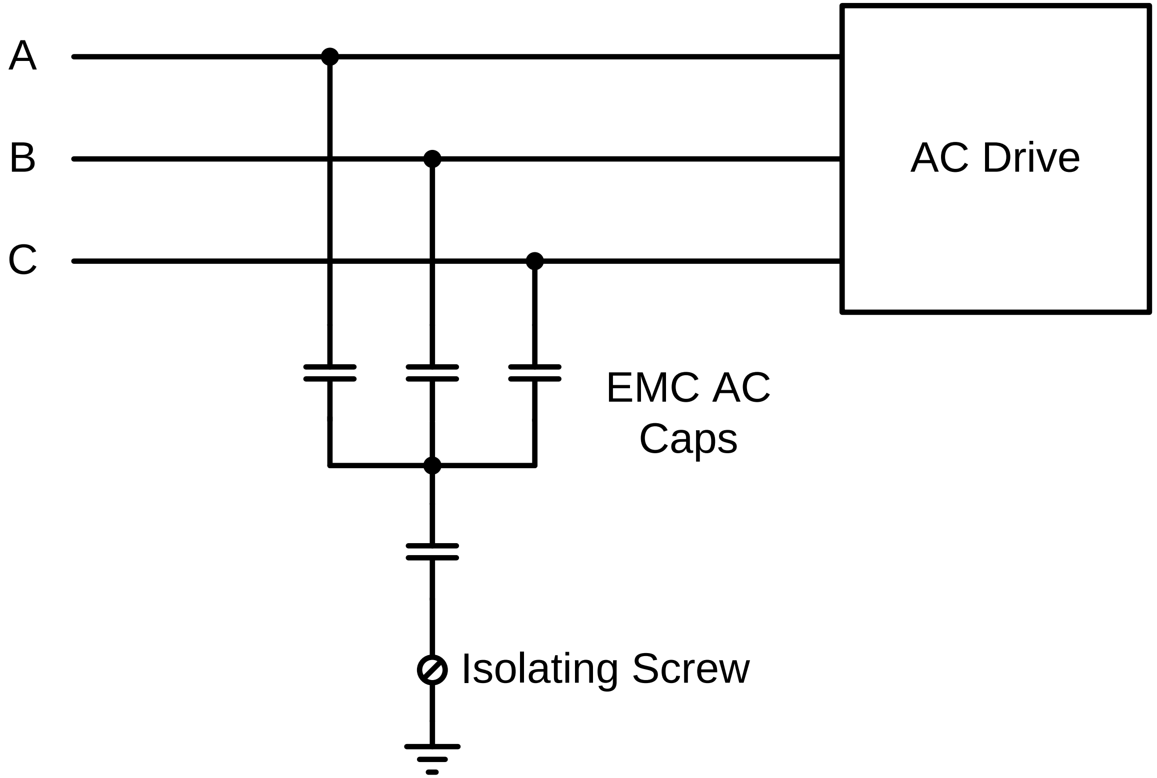
Varistors (MOVs)

- If a line to ground fault occurs on a floating or HRG system, or if there is an unknown impedance between the chassis and building steel, the MOV connected from midpoint of the "trident" configuration to ground can see a voltage that exceeds its MCOV rating (Maximum Continuous Operating Voltage). If it does, the MOV will quickly fail (with a bang!).



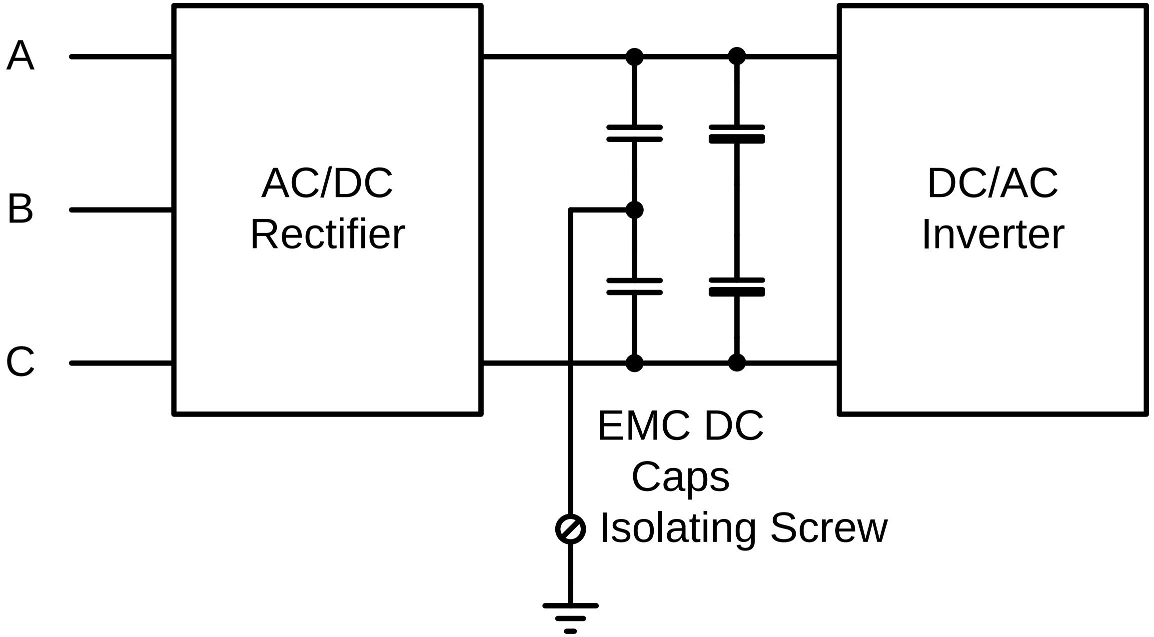
EMC AC Caps

- If a line to ground fault occurs on a HRG system, or if the unit is connected to a corner grounded system or an arcing fault appears on a floating system, the EMC AC cap connected from midpoint of the “trident” configuration to ground can see a voltage that exceeds its voltage rating. If it does, the cap could fail (with a bang!).

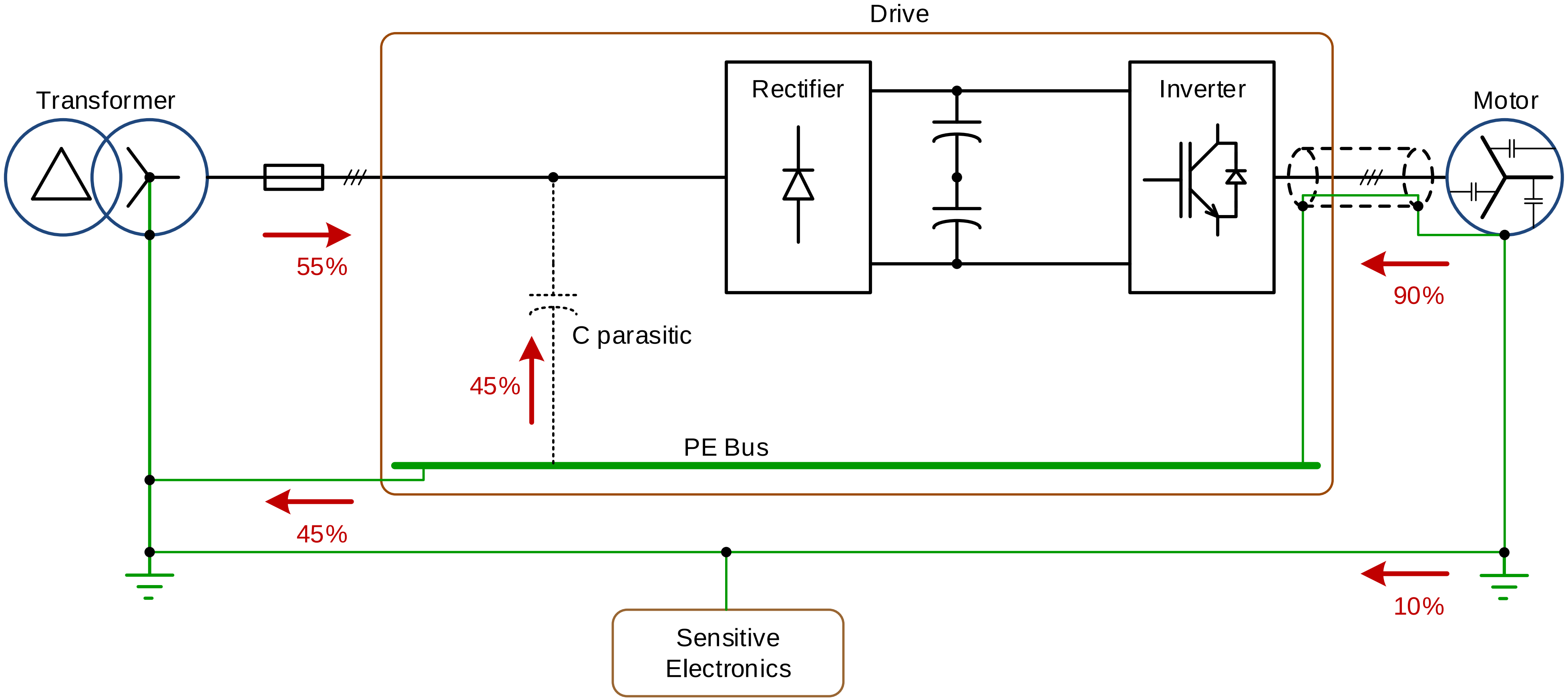


EMC DC Caps

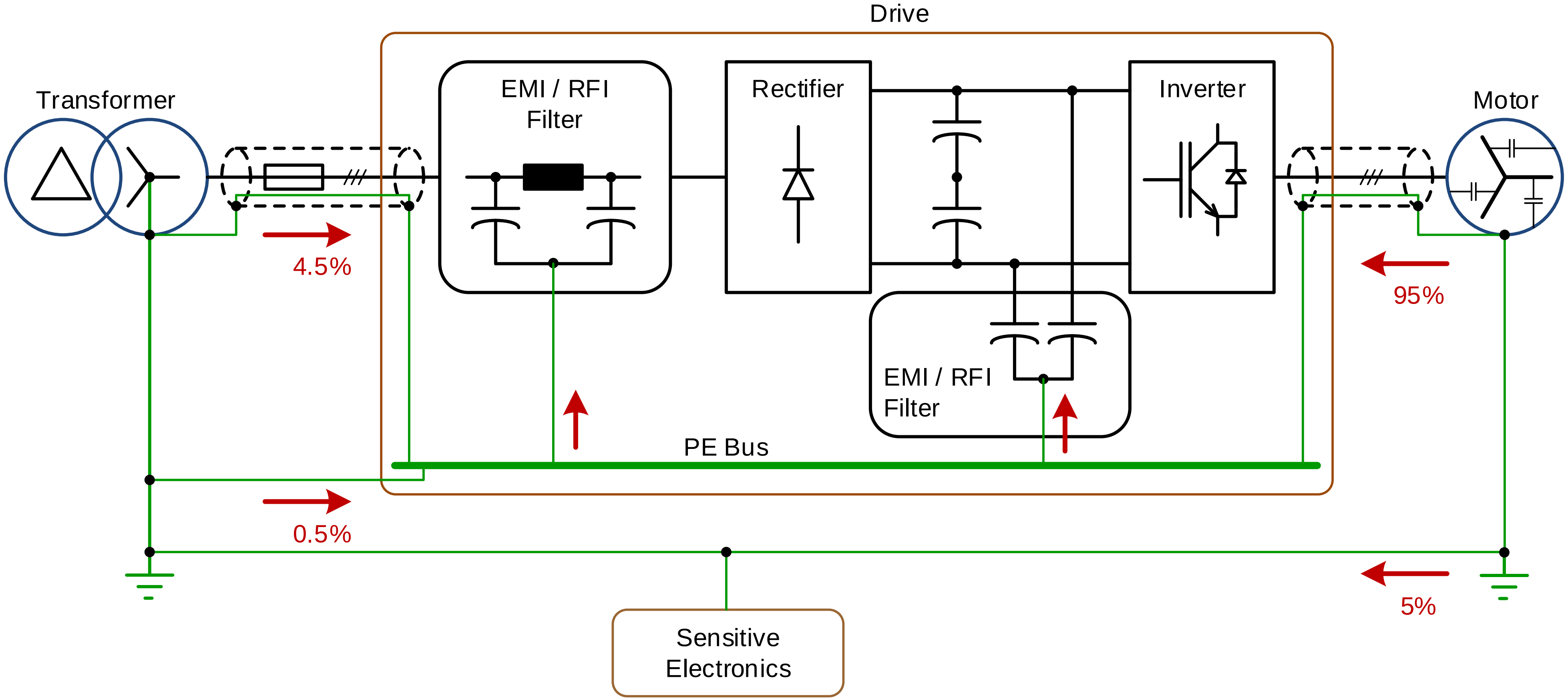
- If an arcing fault occurs within the drive system, the EMC DC caps connected from midpoint of DC bus to ground can allow current to charge the DC bus caps. If it does, the DC bus caps can fail (also with a bang!). The screw needs to be removed for floating, HRG and corner grounded systems.



Path for CM Current, No EMC Caps



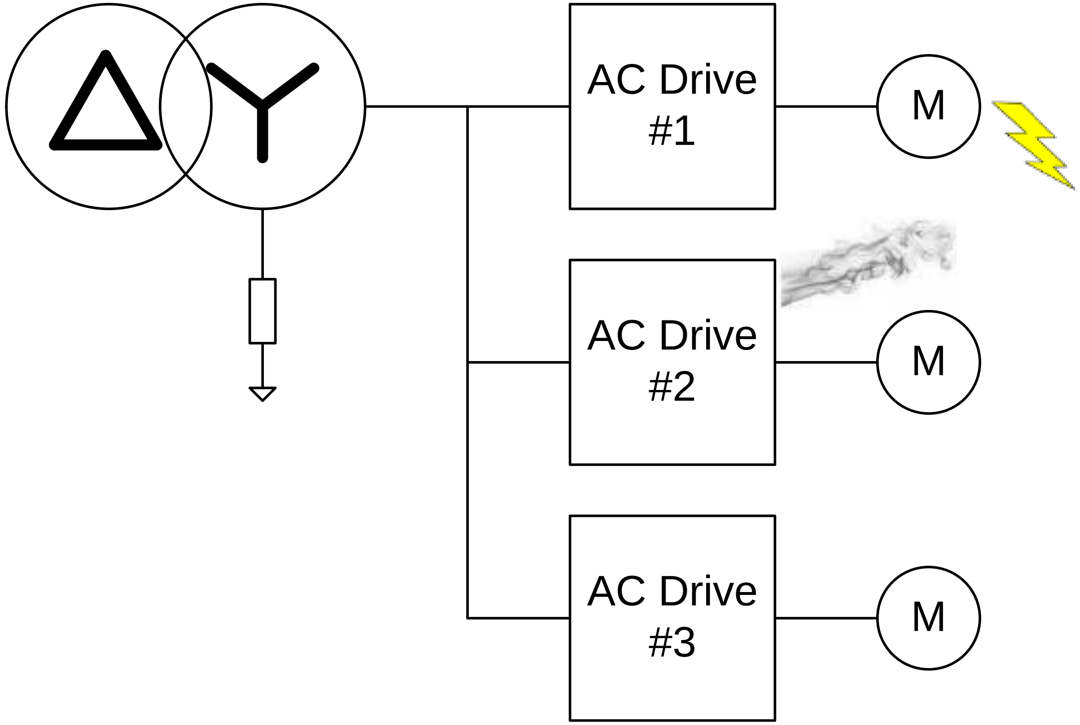
Path for CM Current, with AC and DC EMC Caps



NOTE: a fuse does not belong inside the cable ☺

Drive Failure Case Study

- The situation:
  1. HRG system
  2. Drive #1 was running its motor, which had a phase to ground fault within the motor. It did not trip off.
  3. Drive #2 was connected to the AC bus, and charged up, but was not modulating.
  4. Drive #3 was also connected to the AC bus, and charged up, but was not modulating.
  5. The DC Bus Caps in Drive #2 ruptured.



RM Tallam, DW Schlegel, FL Hoadley, Failure Mode for AC Drives on High Resistance Grounded Systems, IEEE APEC, 2006

Drive Failure Case Study

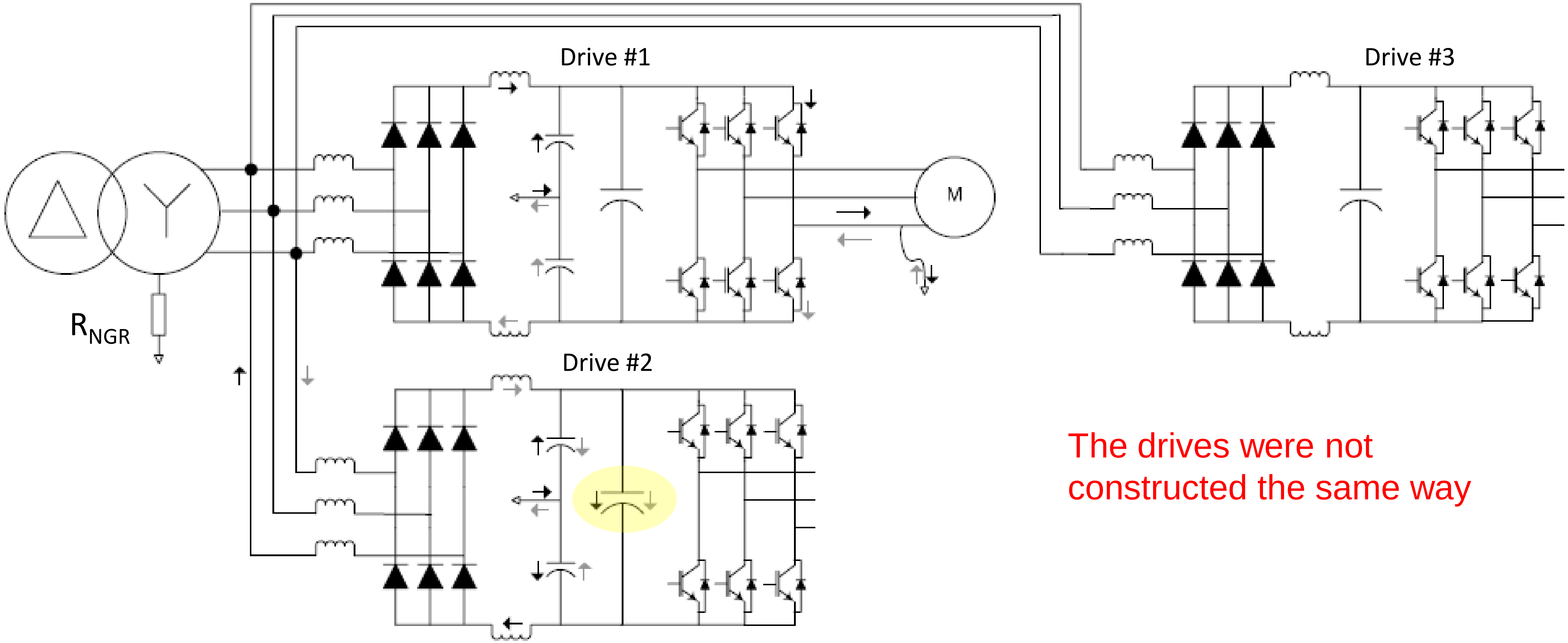


Fig. 3. AC drives on HRG system. Drive #1 and drive #2 have DC CM capacitors. The circulating path for fault current through drive #2 is shown, when a phase-ground fault occurs at the output of drive #1.

The drives were not constructed the same way

RM Tallam, DW Schlegel, FL Hoadley, Failure Mode for AC Drives on High Resistance Grounded Systems, IEEE APEC, 2006

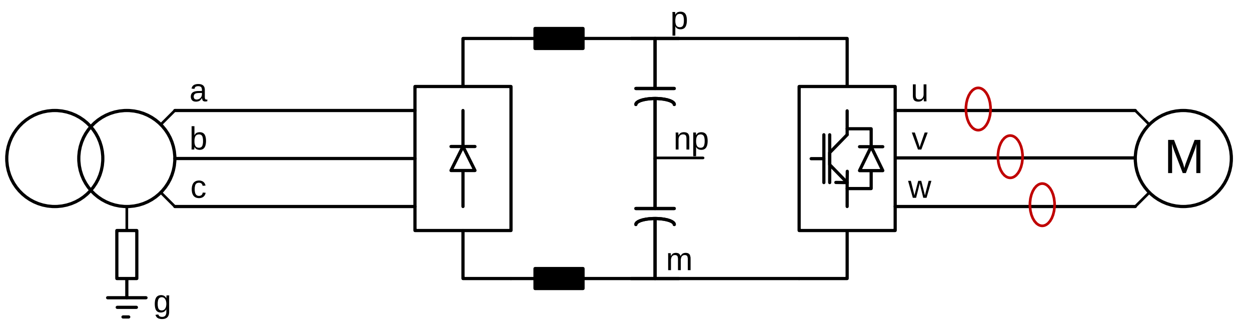
Drive Failure Case Study

- Note:
    - Drive #1 had the short on the output, which acts like an arcing fault due to PWM waveform.
    - The fault current followed a path through the EMC DC caps in Drive #2, further charging its DC bus caps, and on out through its diode bridge back to Drive #1
    - Drive #2 was not running, so no significant load on the DC bus, and its voltage kept rising until they ruptured. Its OV trip did nothing to stop this from happening.
    - Drive #3 did not have EMC DC caps, so it was not affected.

RM Tallam, DW Schlegel, FL Hoadley, Failure Mode for AC Drives on High Resistance Grounded Systems, IEEE APEC, 2006

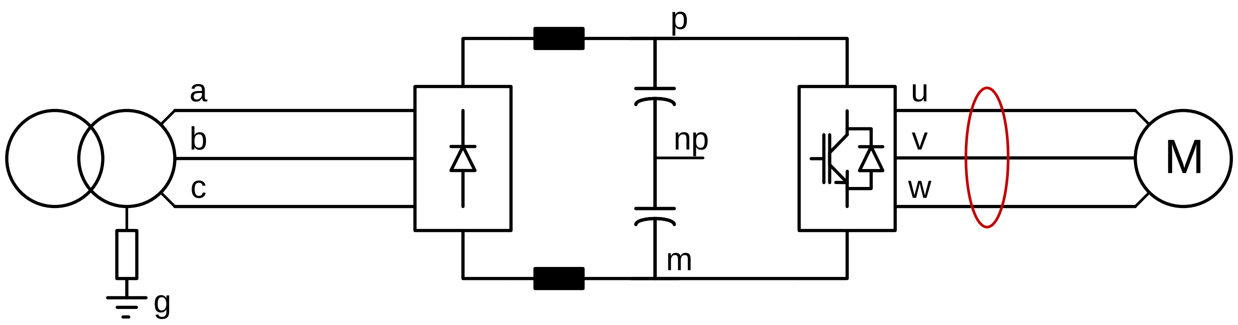
Ground Fault Detection

Ground Fault Detection Methods



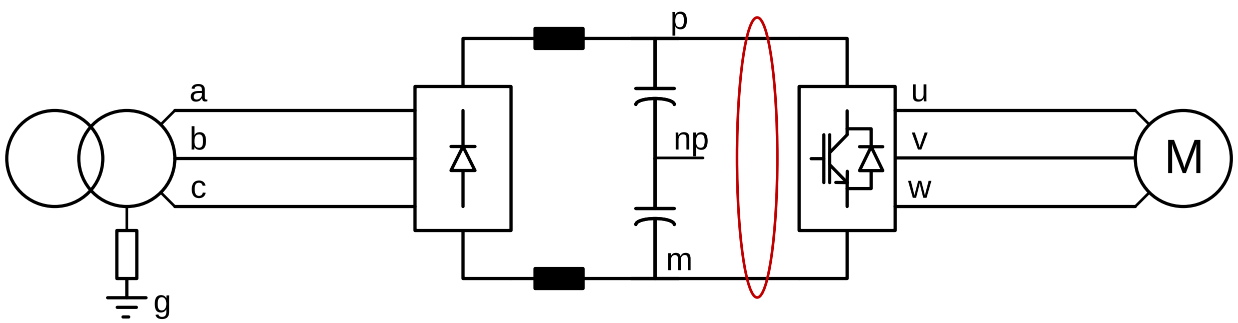
If the sum of the three currents exceeds x amount, it trips on a ground fault.
Or, if the unbalance exceeds some amount, it will trip. Could be a ground fault.

Ground Fault Detection Methods



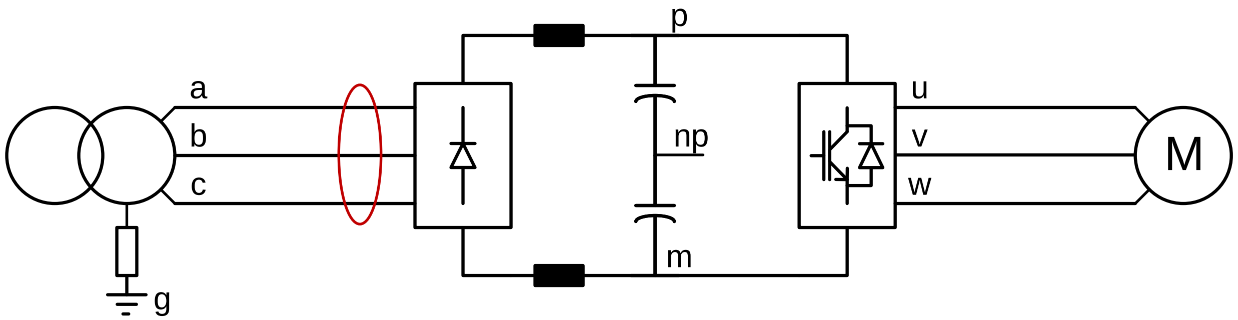
If the sum of the three currents (zero-sequence) exceeds x amount, it trips on a ground fault.

Ground Fault Detection Methods



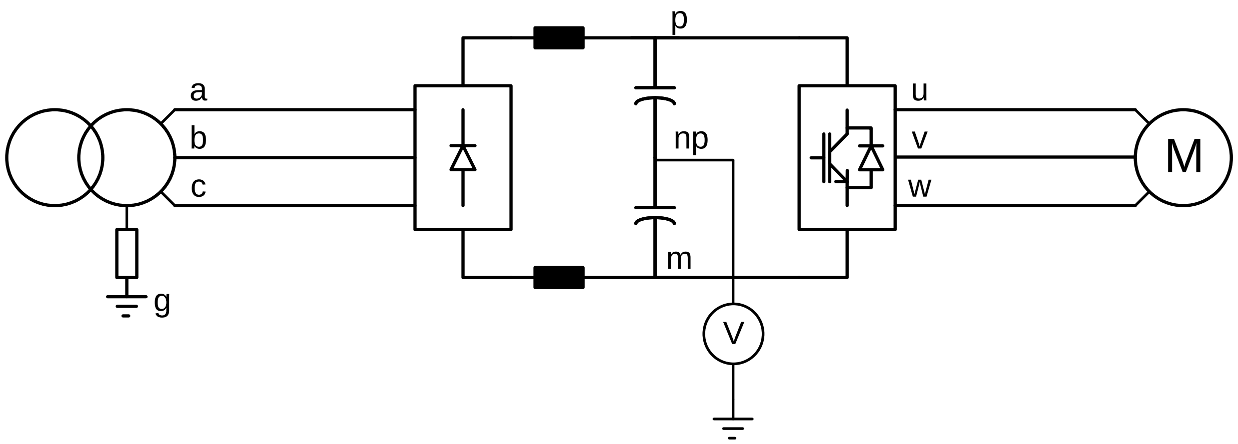
If the zero-sequence current exceeds x amount, it trips on a ground fault.

Ground Fault Detection Methods



If the zero-sequence current exceeds x amount, it trips on a ground fault.
The ground fault could be within the drive or downstream from the drive.

Ground Fault Detection Methods



If the Neutral Point-to-ground voltage exceeds x amount, it trips on a ground fault.
The ground fault could be upstream from the drive, within the drive,
or downstream from the drive.

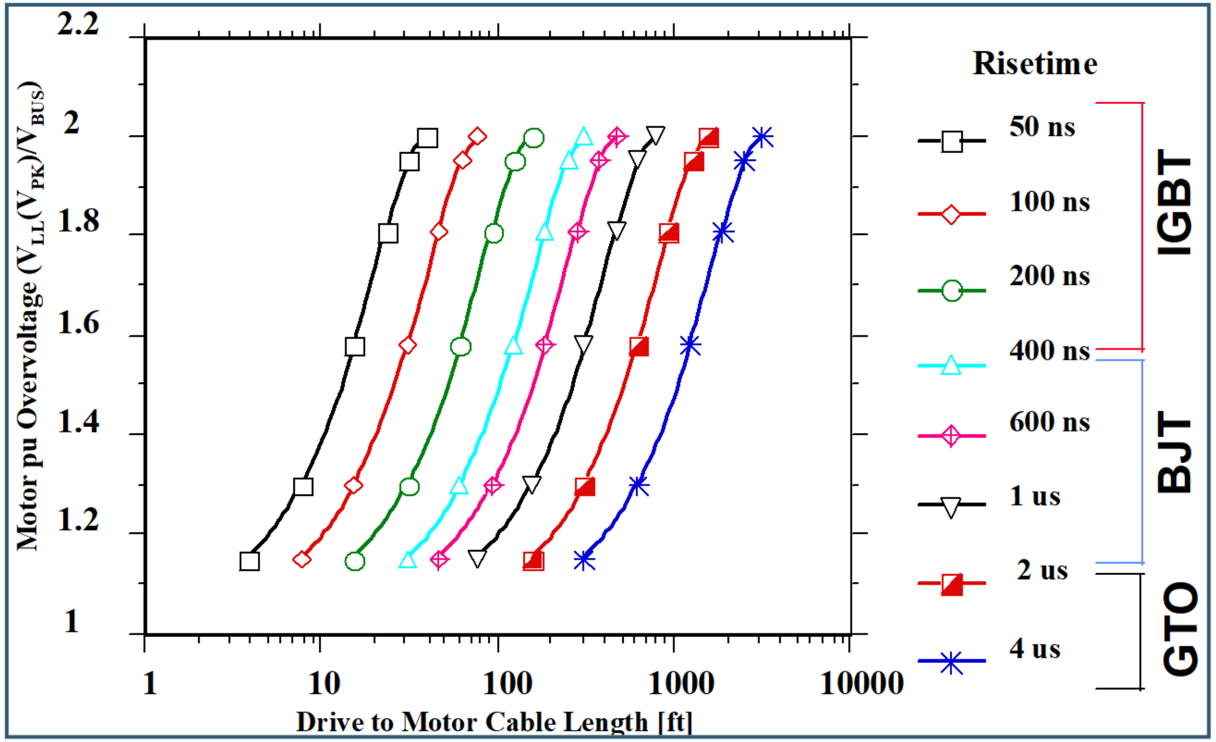
Load Reactors

Reflected Waves

- For many years, there was no real concern about the type of cable or the length of cable between the drive and motor.
- This was because the switching speed of the power semiconductors used in the drives were slow, and most of the AC drives were for 230V motors. Also, distances were usually less than 400ft.
- However, as the semiconductors became faster, and as the bus voltage increased, motors started to fail. Why?
- Peak voltage at the motor terminals was exceeding a value that caused premature motor insulation failure
- At the drive terminals, peak voltage is 1x the DC bus voltage
- At a critical cable length, the peak voltage is 2x the DC bus voltage
- This is a problem

Motor Insulation System

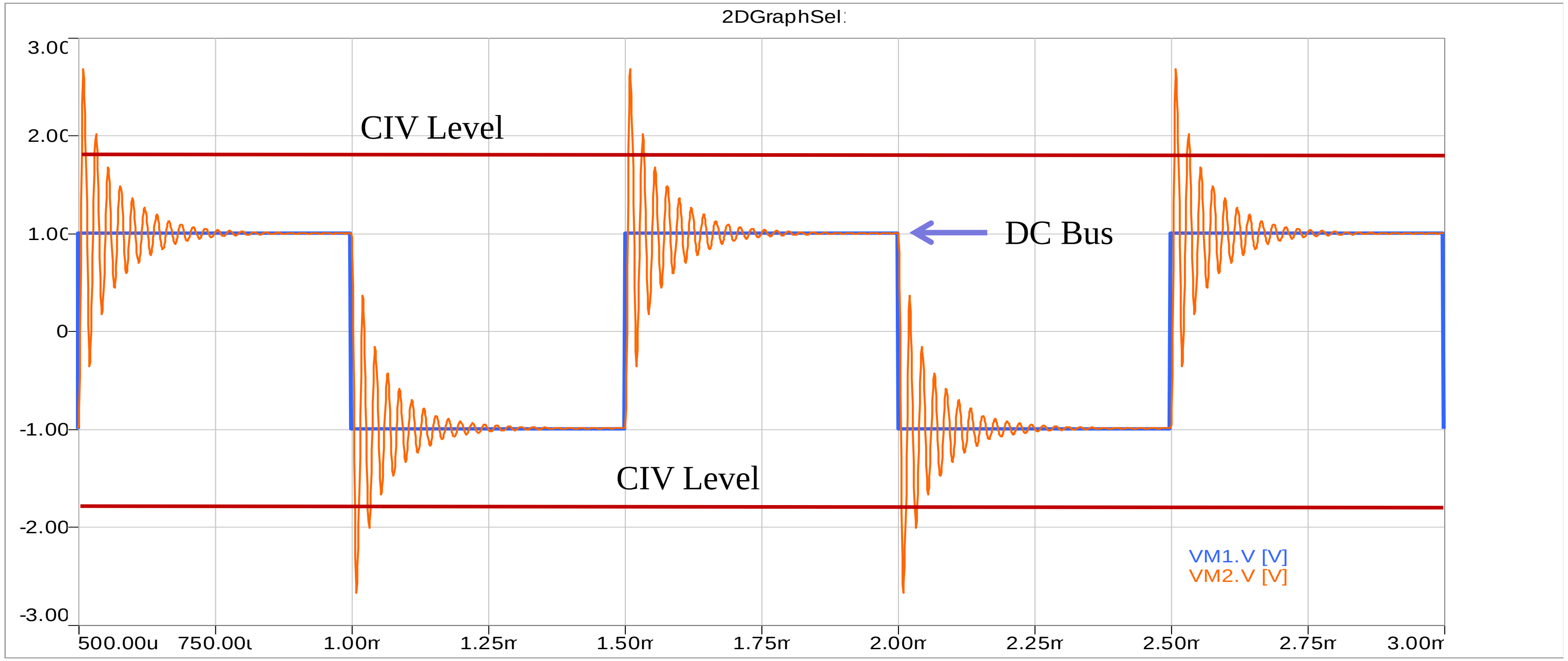
- Peak withstand voltage for slow risetimes (for example, > 6 us) was determined by the breakdown strength of the magnet wire
- Peak withstand voltage for fast risetimes and higher carrier frequency causes corona failure mechanism of the magnet wire insulation
- IGBT technology creates greater stresses on the motor's insulation system than previously seen with older style switching devices



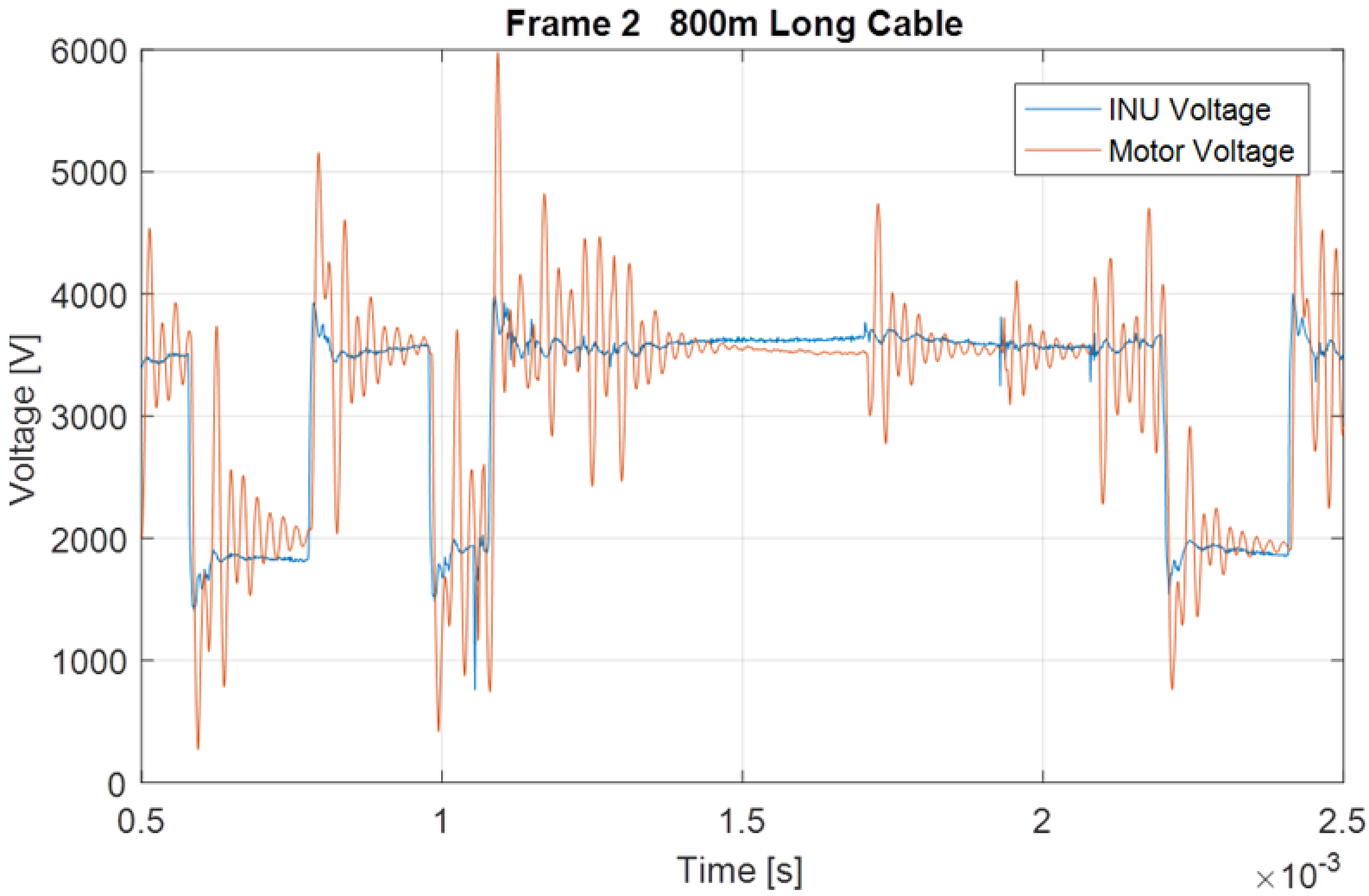
Z Liu, GL Skibinski, *Method to Reduce Overvoltage on AC Motor Insulation from Inverters with Ultra-Long Cable*, IEEE IEMDC Conference, 2017

When does PD (Corona) occur?

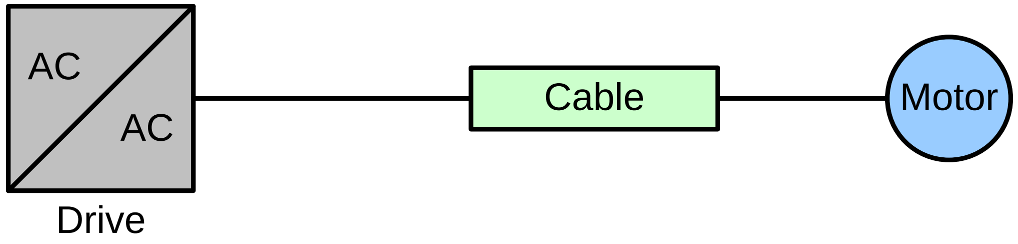
- Reflected wave produces voltage peaks at the motor terminals
- Terminal voltage in excess of the insulation system CIV level will begin the PD / CORONA process
- Excessive voltage causes partial discharges / corona that attacks insulation materials



Example, Medium Voltage Drive and Motor



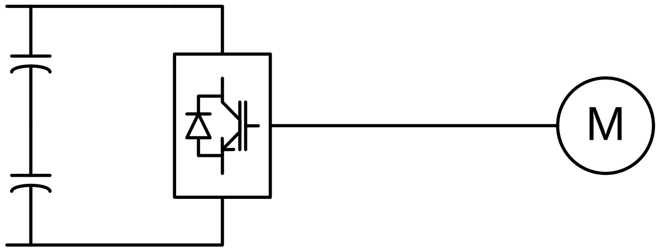
Reflected Waves



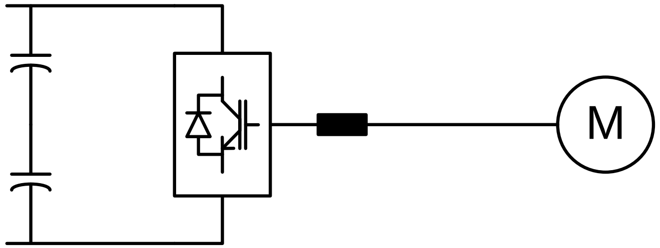
- Why can this be a problem?
  - Partial Discharge
  - First-Turn Failures
- Affected by:
  - Length of cable between drive and motor
  - Magnitude of PWM voltage pulses (DC bus voltage)
  - Rate of rise of PWM voltage pulses (dV/dt)
  - PWM minimum spacing between pulses
  - Motor and cable surge impedance mismatch
  - Motor load

L Saunders, G Skibinski, S Evon, D Kempkes, *Riding the reflected wave – IGBT drive technology demands new motor and cable considerations*, IEEE PCIC Conf, Sept 1996

How can we reduce the dV/dt? Filtering

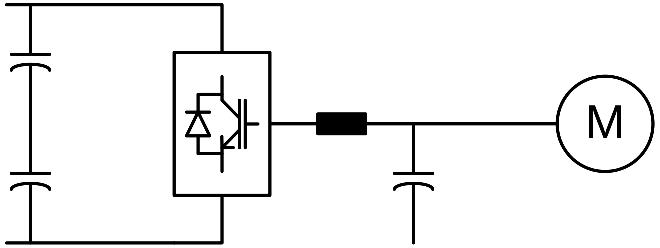


Basic Inverter and Motor

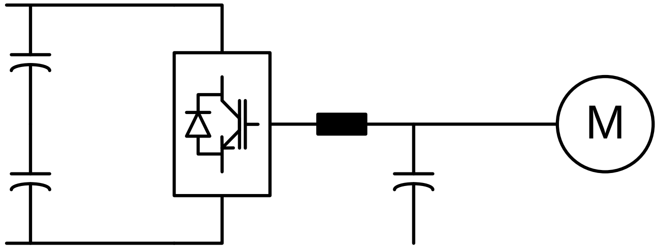


Output Load Reactor

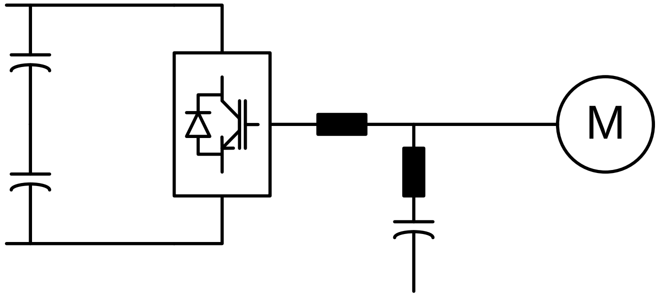
Helps a little, but may cause more oscillations. Better to go with a dV/dt filter or SW filter. It will also introduce a voltage drop to the motor.



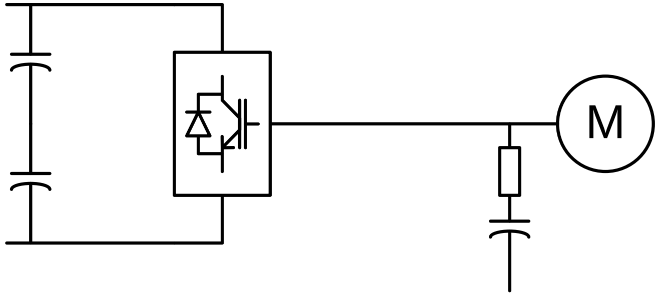
*dV/dt Filter



*Broadband Sinewave Filter



Sinewave Filter



RC Terminator

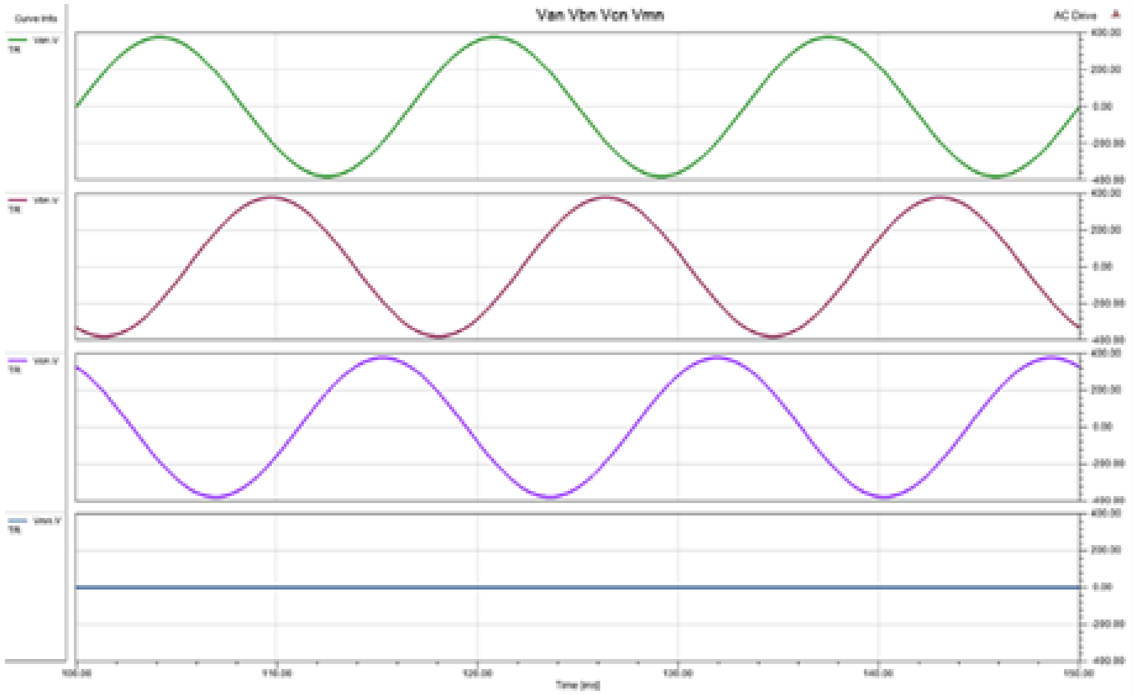
* Used in MV drives

Shaft Grounding Brushes and Bearing Currents

What is Common Mode Voltage (CMV)?

CMV = (Van + Vbn + Vcn) / 3

3ph Sinusoidal Voltages



CMV = (Van + Vbn + Vcn) / 3 = 0

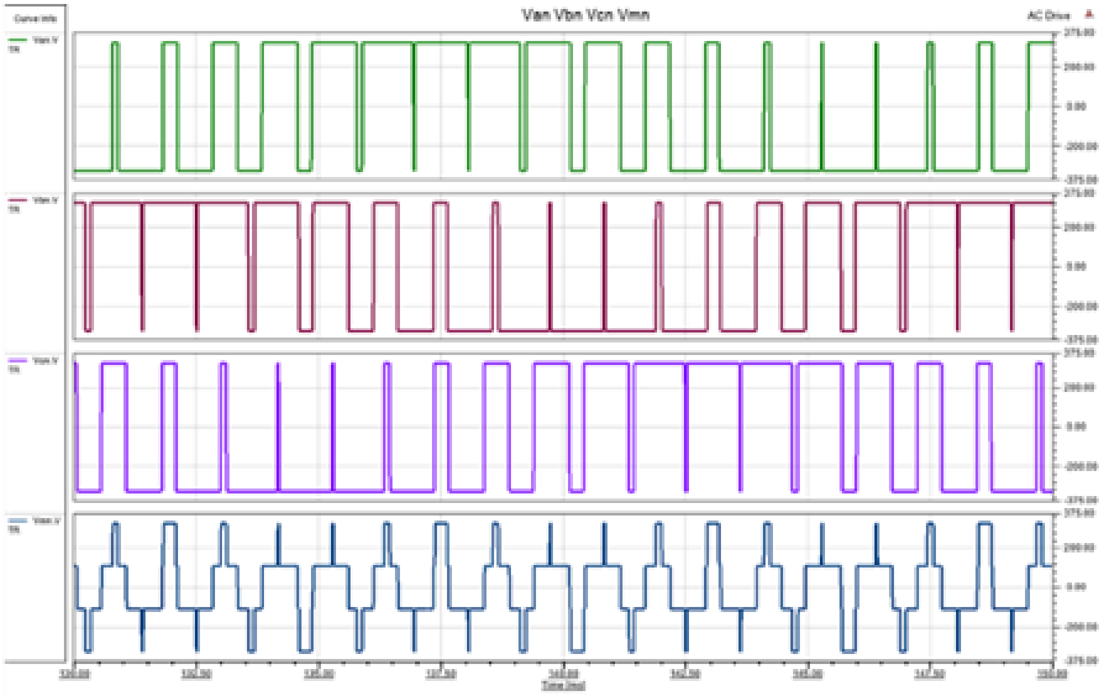
Van

Vbn

Vcn

CMV

3ph PWM Voltages

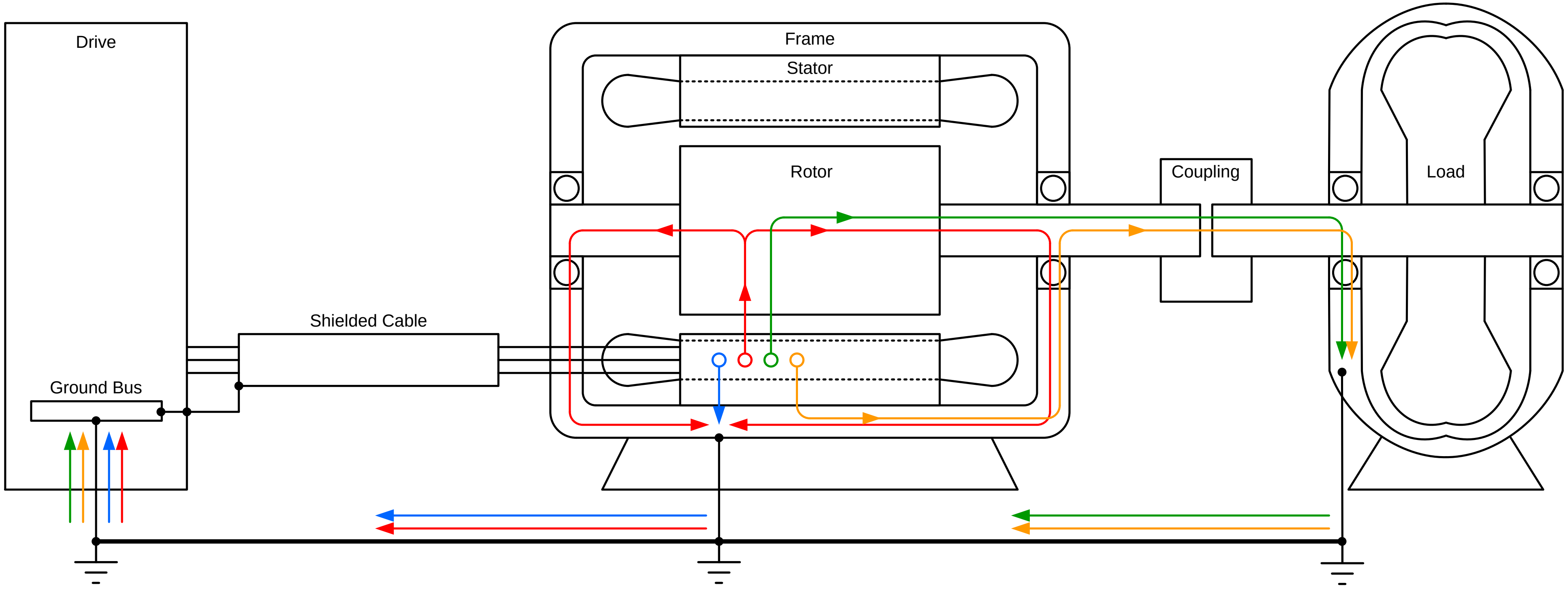


CMV = (Van + Vbn + Vcn) / 3 ≠ 0

High dV/dt = high common mode current

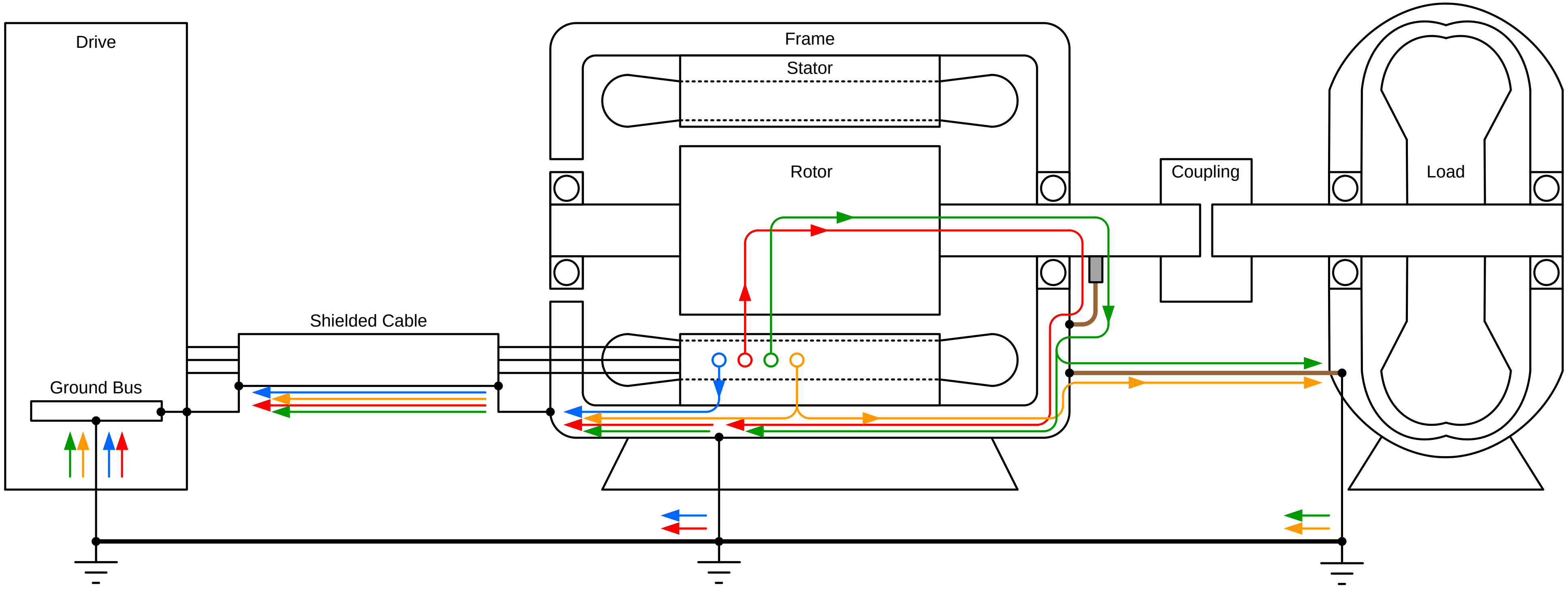
Icm = C x dV/dt

Currents within a motor and load



Cable shield not connected to motor frame
Paths of common mode currents from stator to ground back to drive

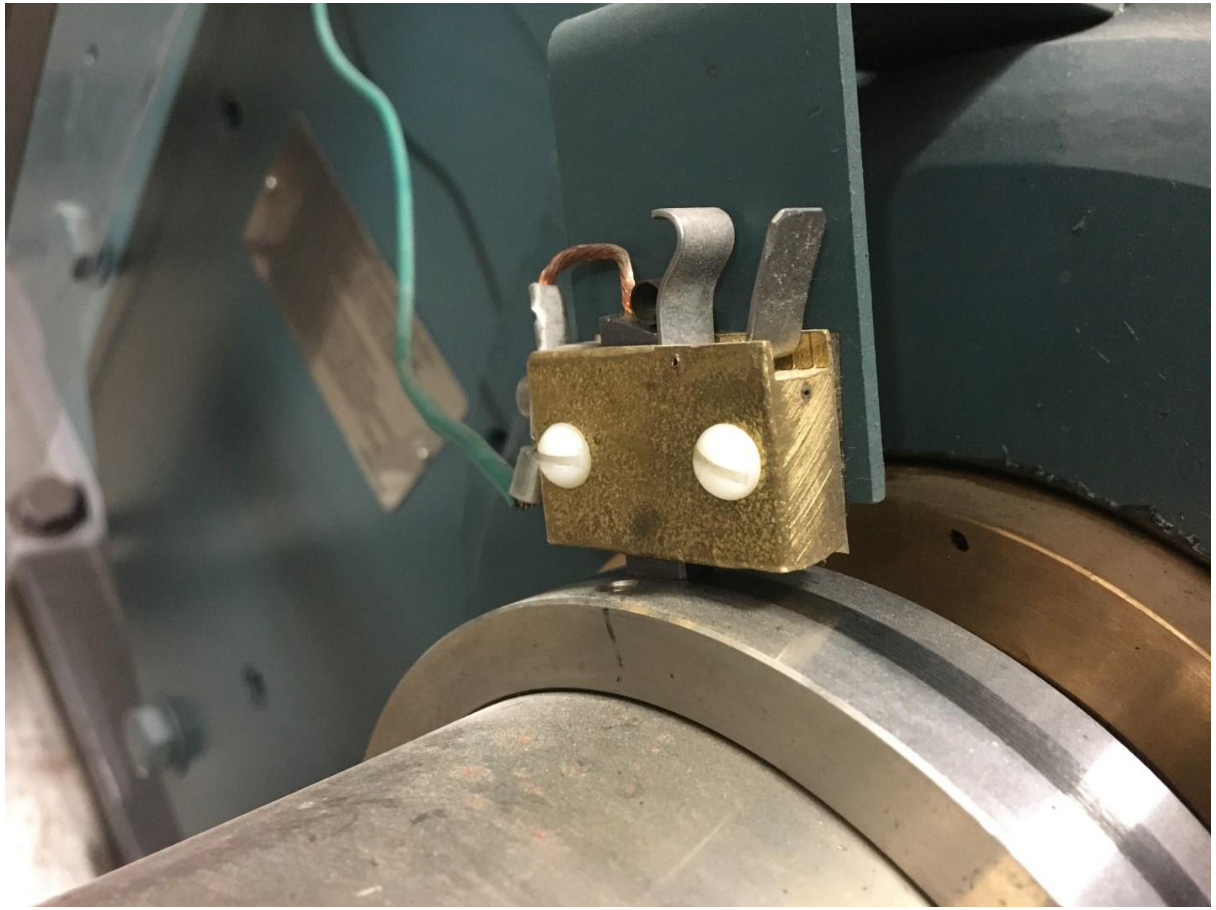
Currents within a motor and load

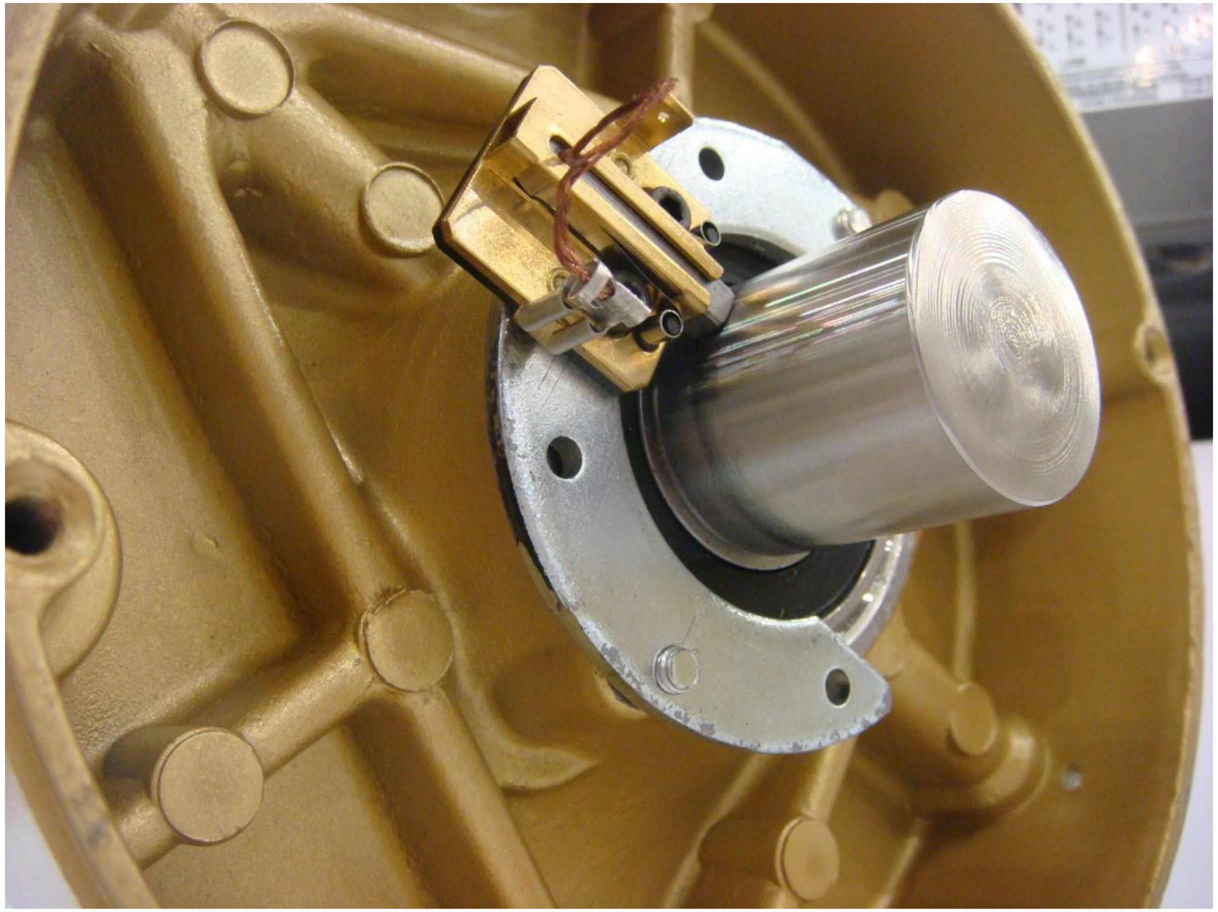


Cable shield is connected to motor frame

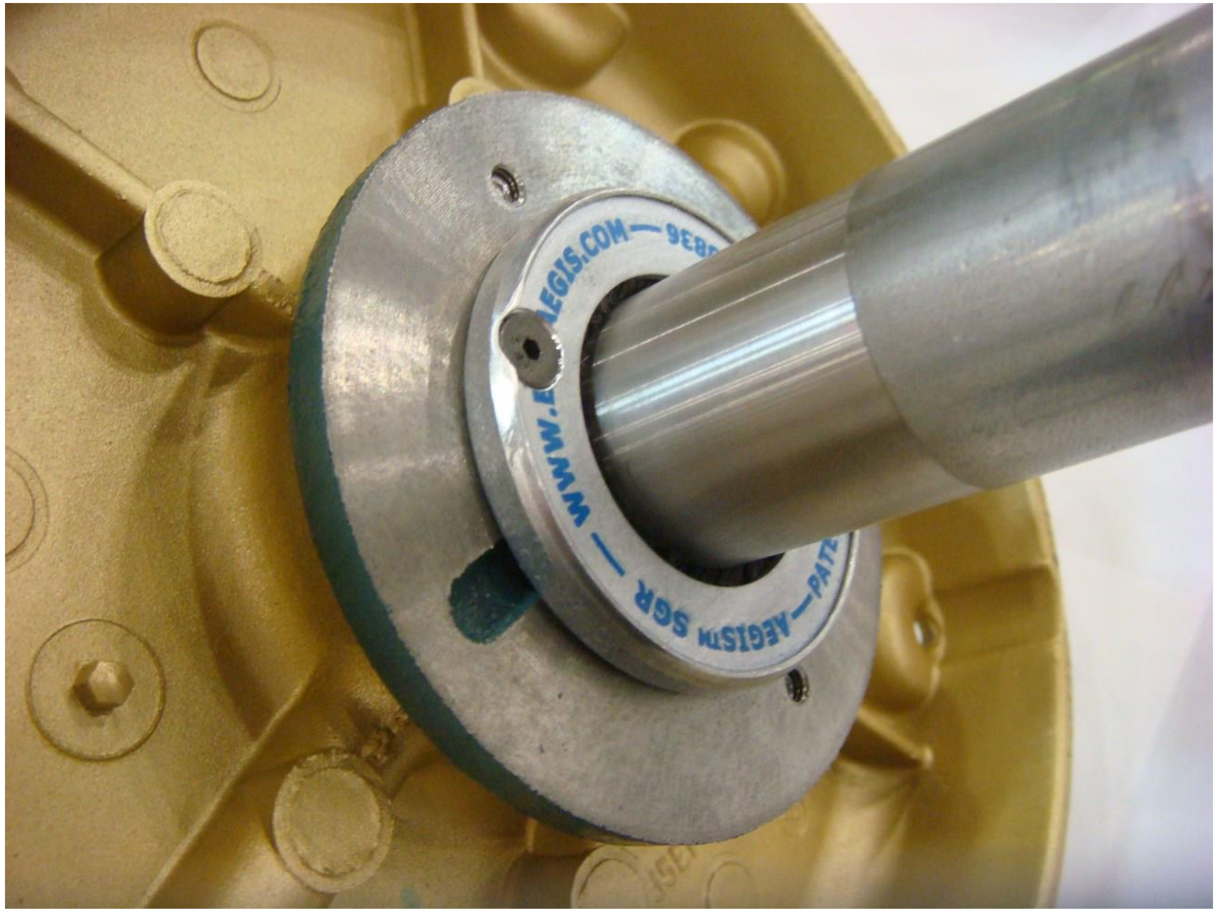
Paths of common mode currents from stator to ground back to drive through the cable shield

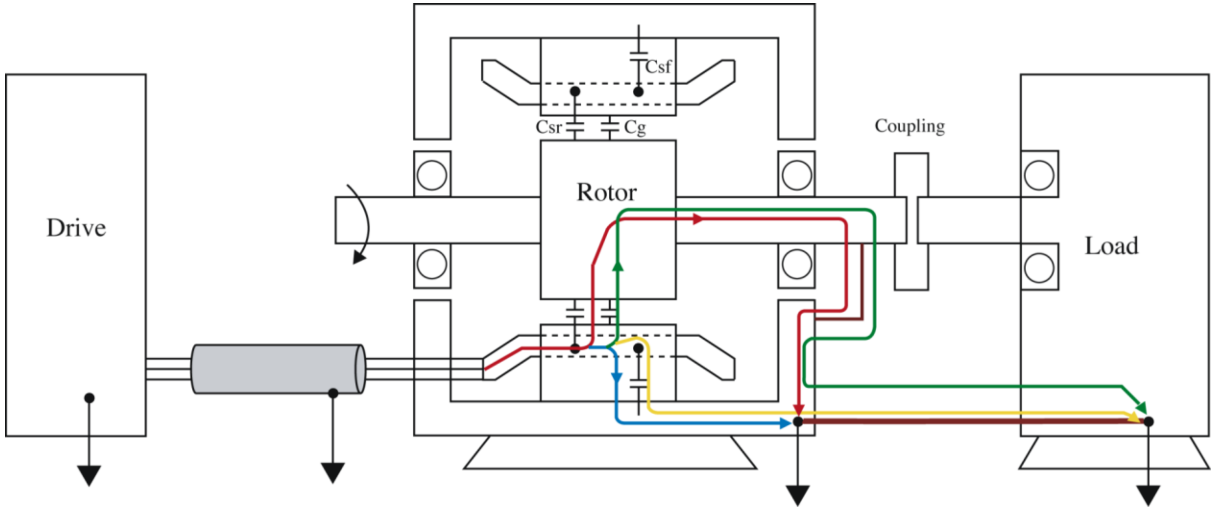
Shaft Ground Brush





Shaft Ground Brush





Bearing Current Remediation

- Proven results include:
  - Improving the high-frequency ground connection from the motor to the drive and from the motor to the driven equipment
  - Insulate the bearing on the opposite drive end of motor
  - Two insulated motor bearings
  - Shaft grounding brush across the drive end motor bearing which could be mounted inside the motor housing or outside
  - An important ground path is the connection between the motor and inverter. Cables should be used that provide continuous, low resistivity shielding around the three phase conductors. The termination of the cable shield should be made by landing these connections on a ground surface free of paint at both the drive ground bus and at the motor frame.

R.F. Shiferl, M.J. Melfi, "Bearing Current Remediation Options“, *IEEE Industry Applications Magazine,* August 2004
R. McElveen, F. Hoadley, “Best Practices for Mitigating Bearing Currents”, *Pumps & Systems*, June 2019, pp 51-55
M. Laufik, “The Need for Shaft Grounding on VFD-Driven Motors”, *Pumps & Systems*, June 2019, pp 44-45

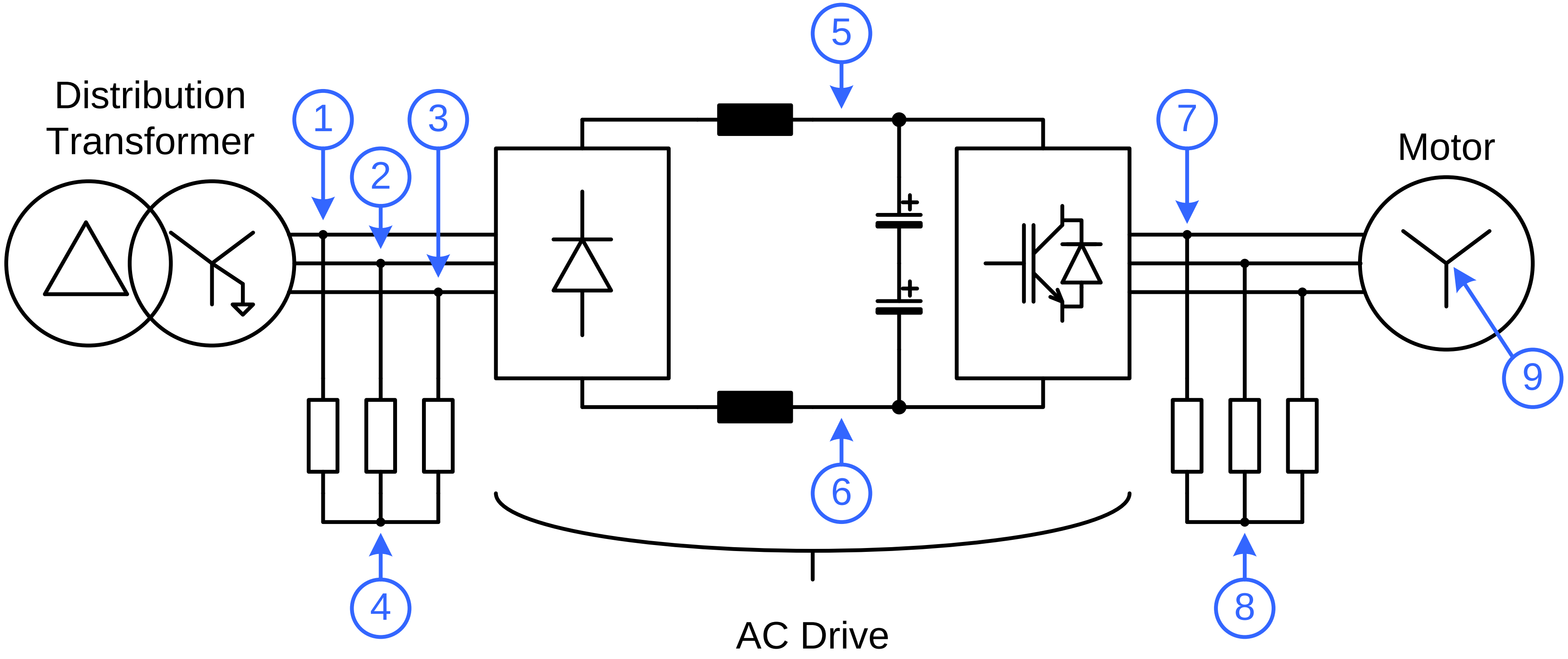
VFD Wiring, Common Mode

Common Mode Voltage / Current

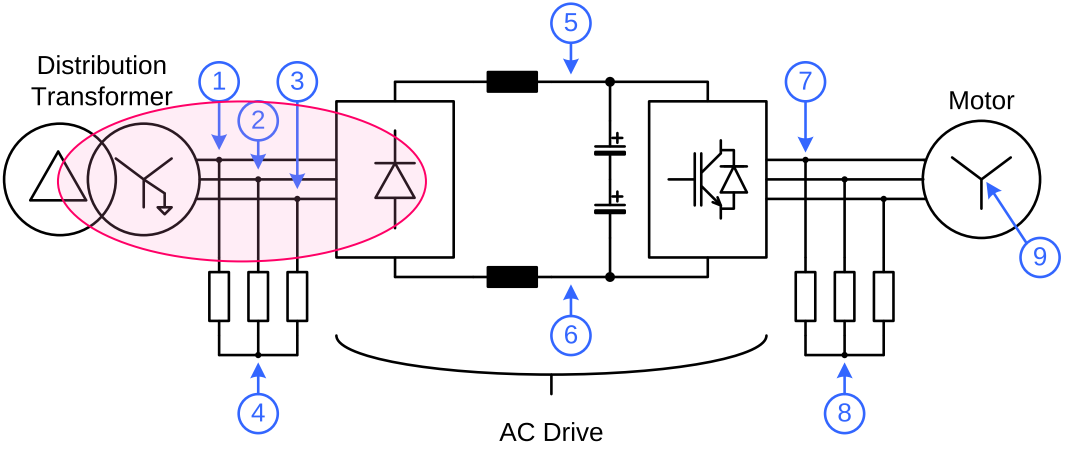
- Modern PWM drives create switching patterns where instantaneous average voltage to ground is not zero.
- Voltage has a rapid change of magnitude with respect to time (dV/dt)
- High dV/dt results in capacitively coupled currents from motor windings to ground through several paths

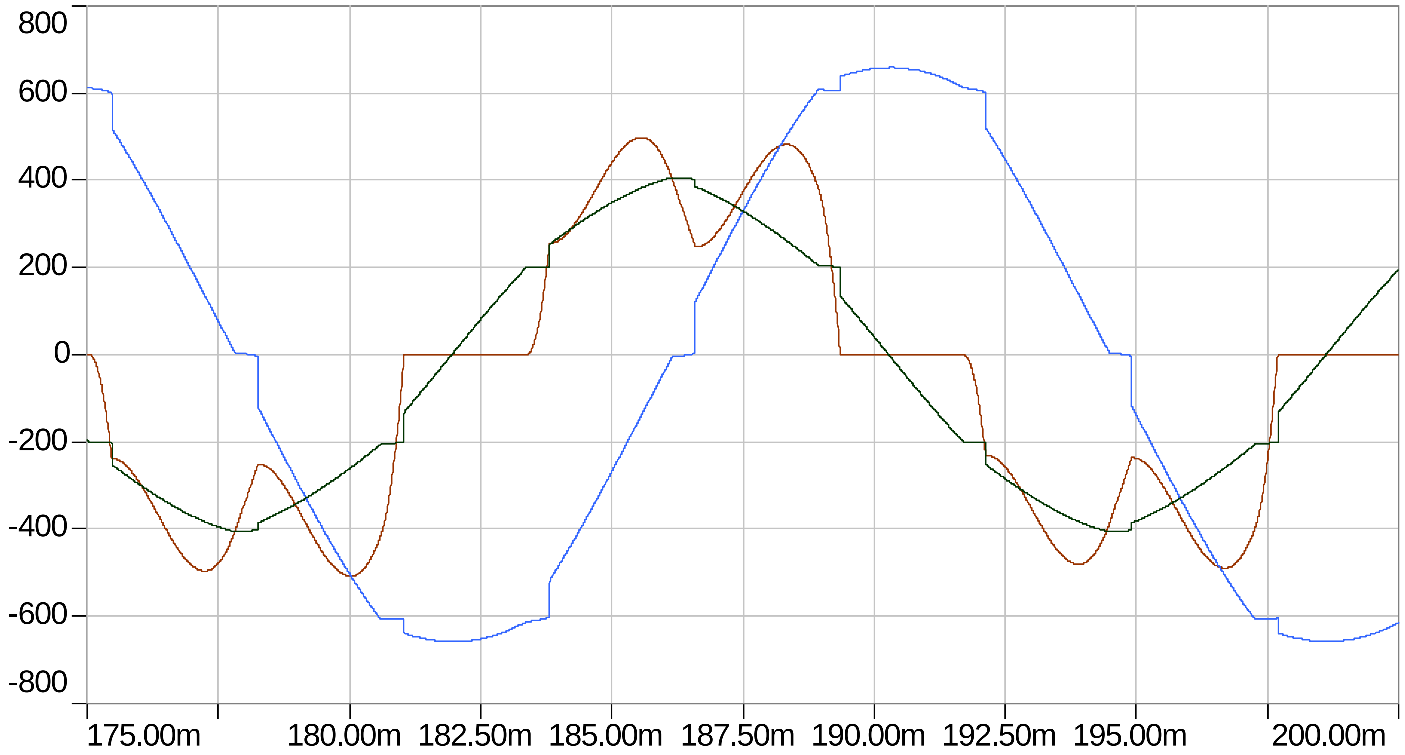
$$I = C \times dV/dt$$

Voltage Probe Sites (Voltages with respect to ground)



Vin and I in


Distribution Transformer
① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨
Motor
AC Drive


800
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0
-200
-400
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-800
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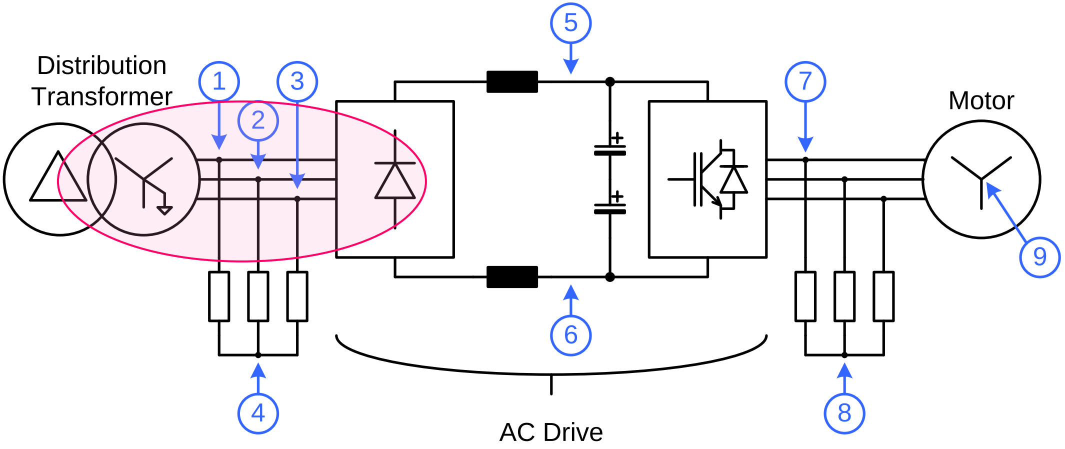
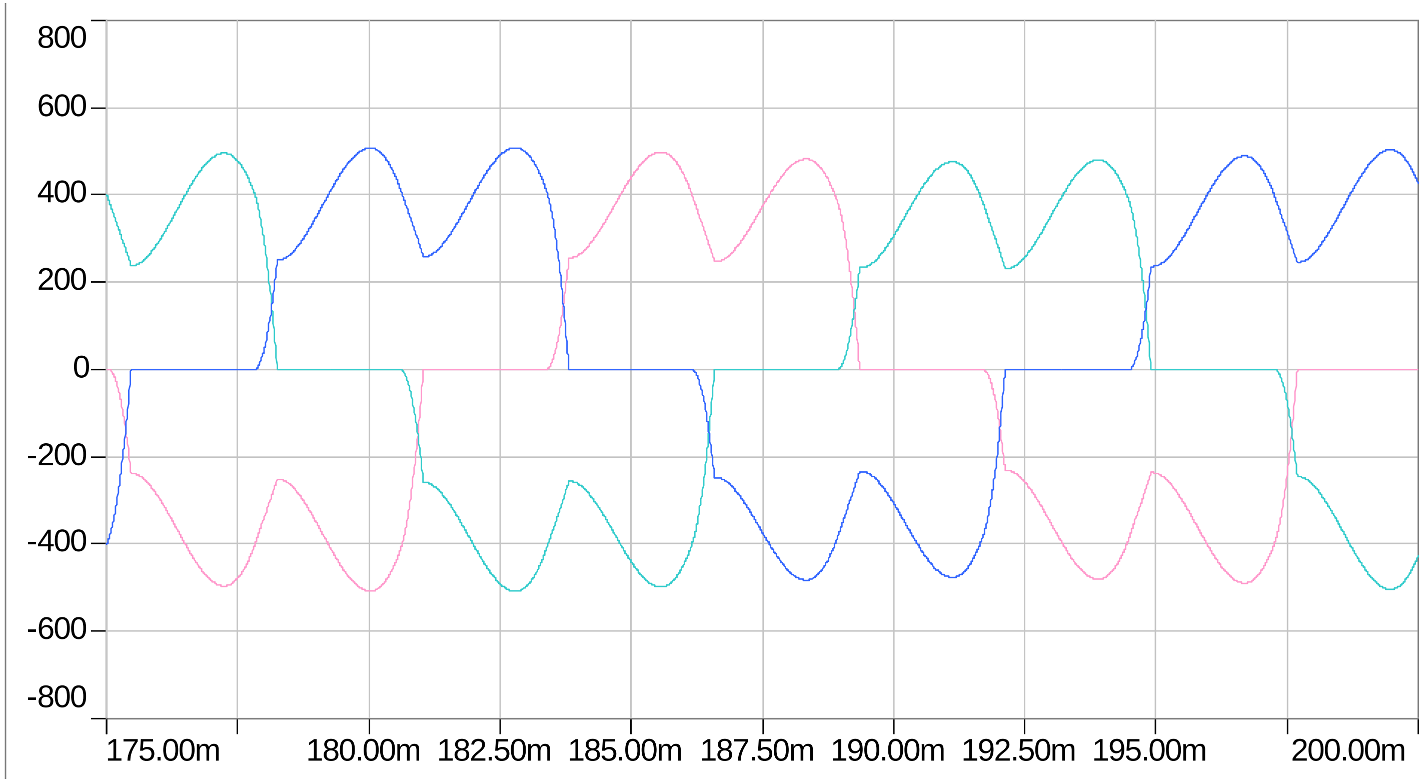
180.00m
182.50m
185.00m
187.50m
190.00m
192.50m
195.00m
200.00m

Iin – a,b,c


Distribution Transformer
1
2
3
4
5
6
7
8
9
Motor
AC Drive


800
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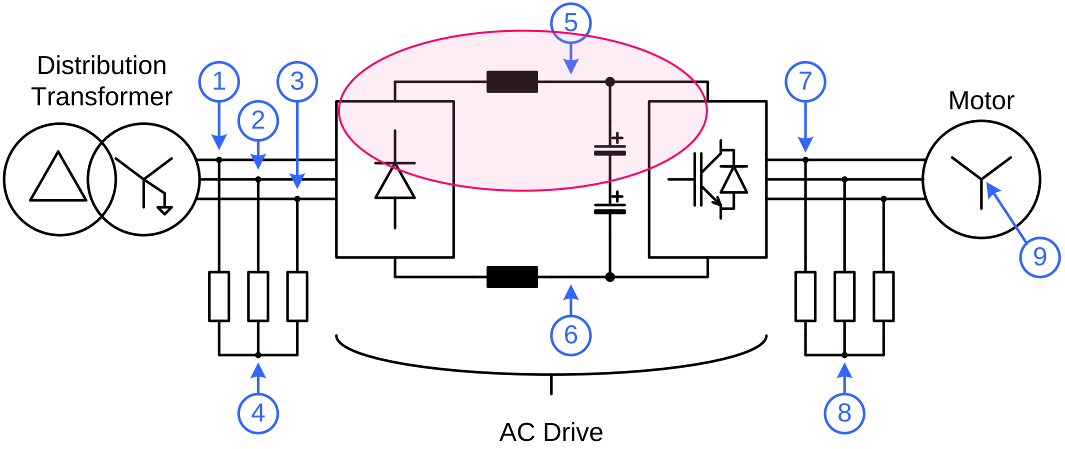
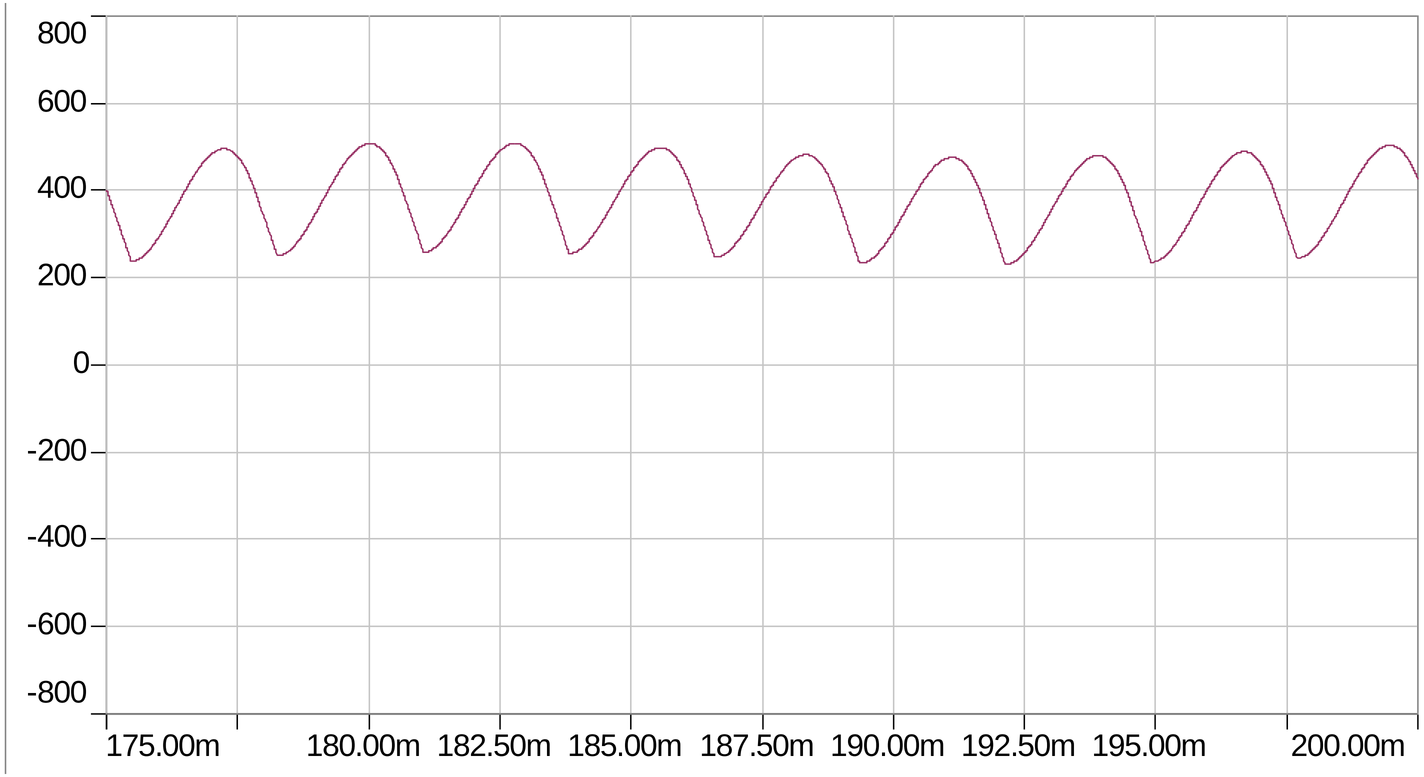
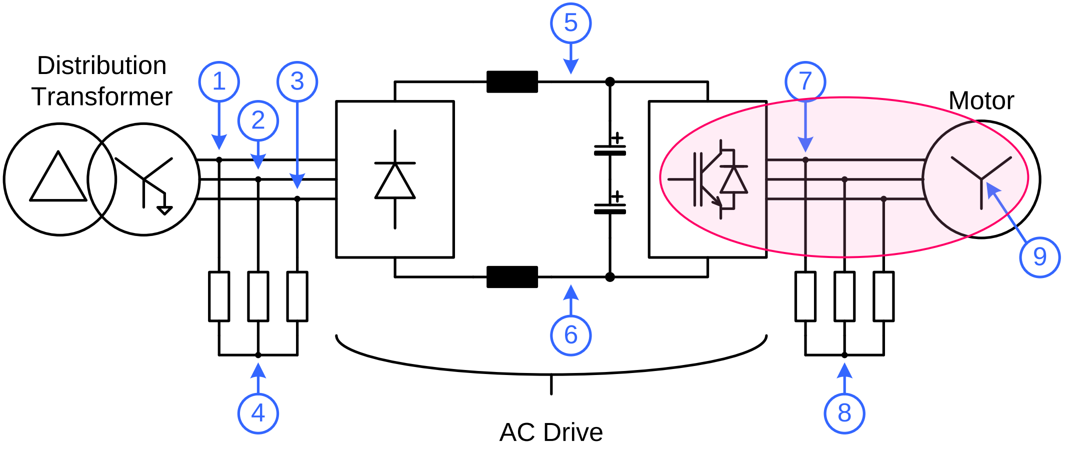
190.00m
192.50m
195.00m
200.00m

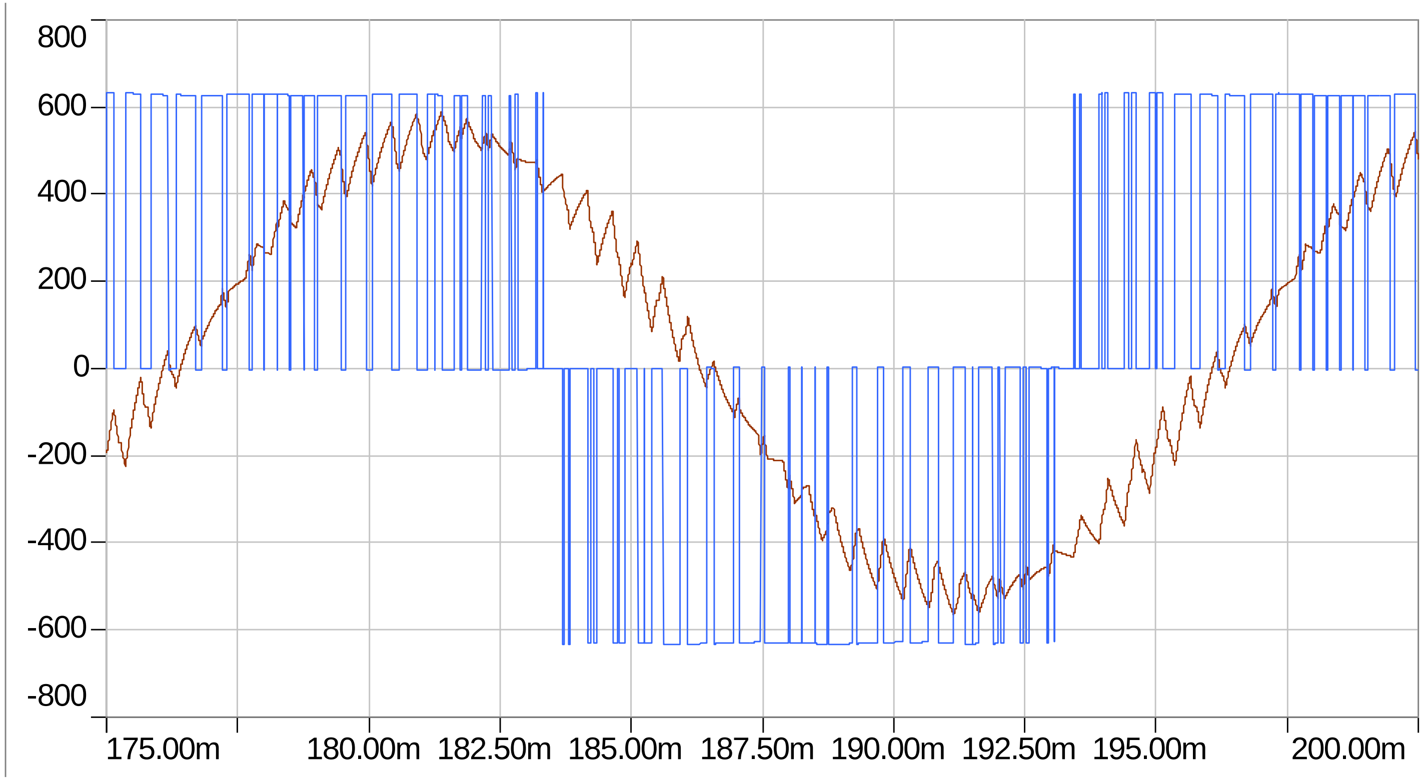
I dc link choke



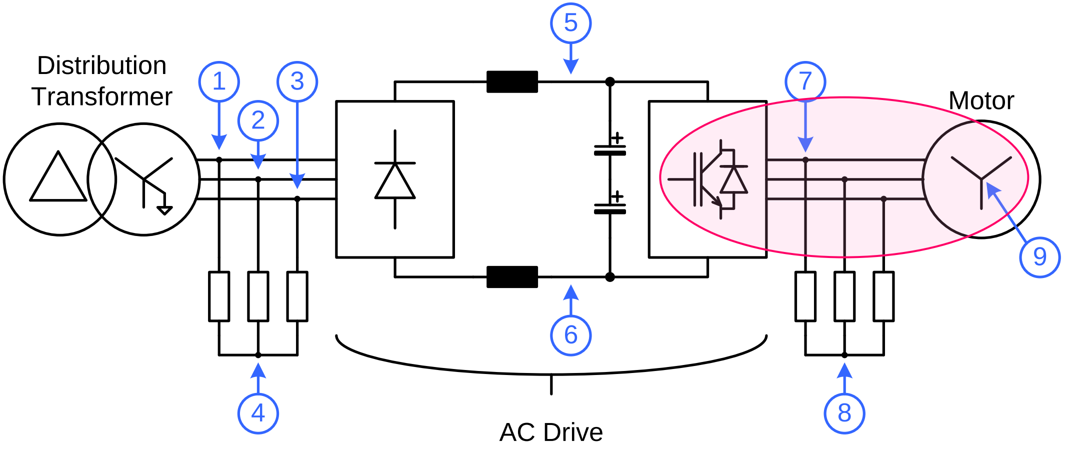


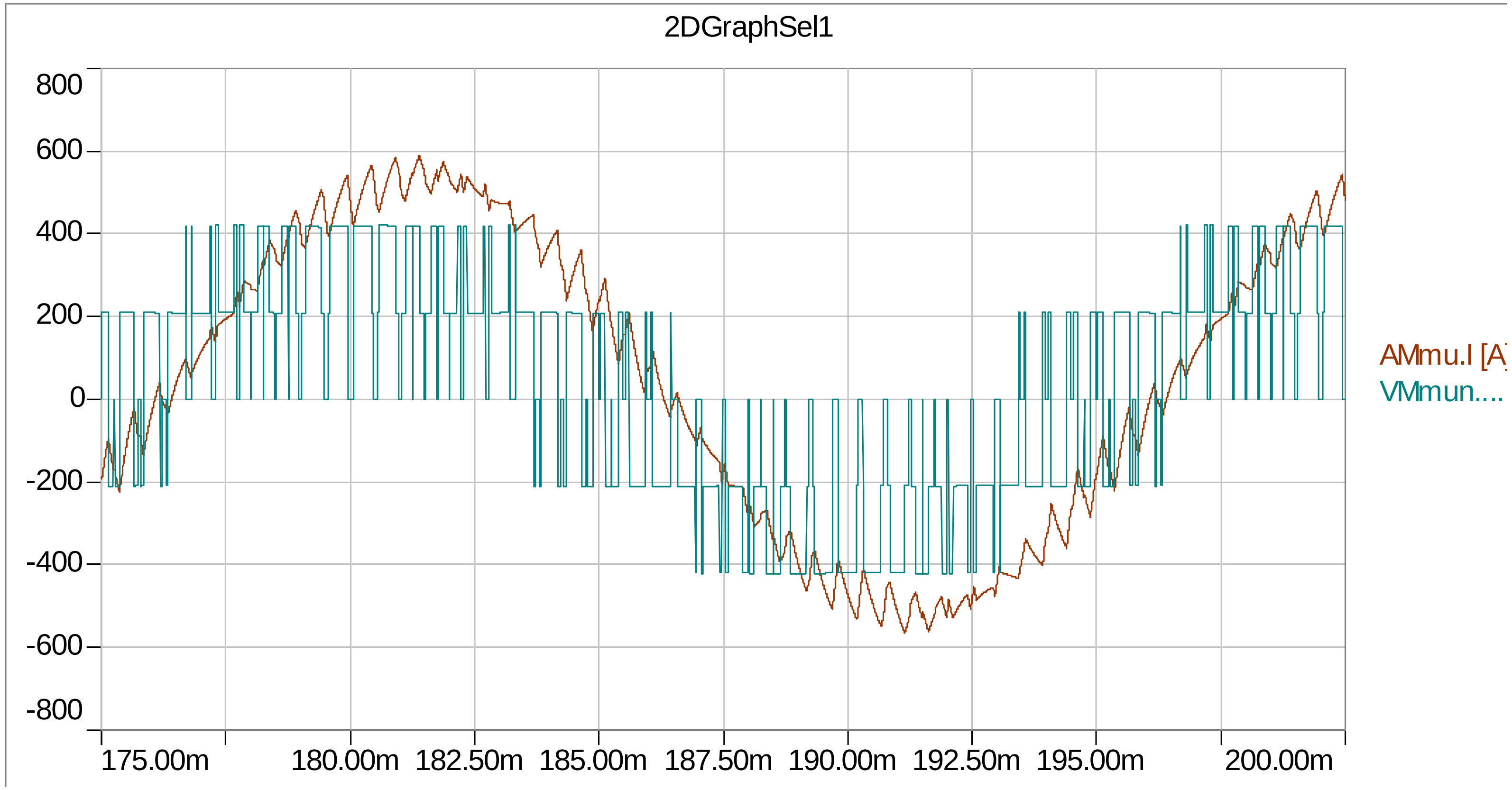
Vph-ph and I out



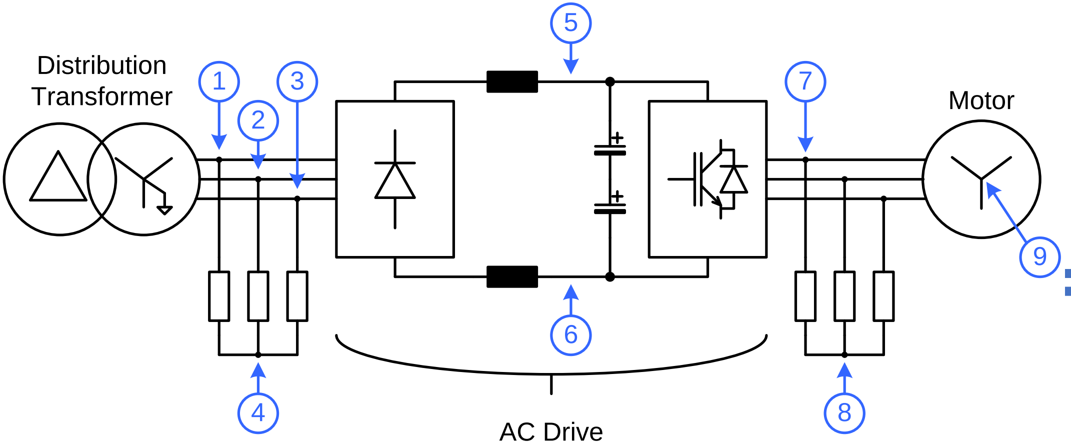


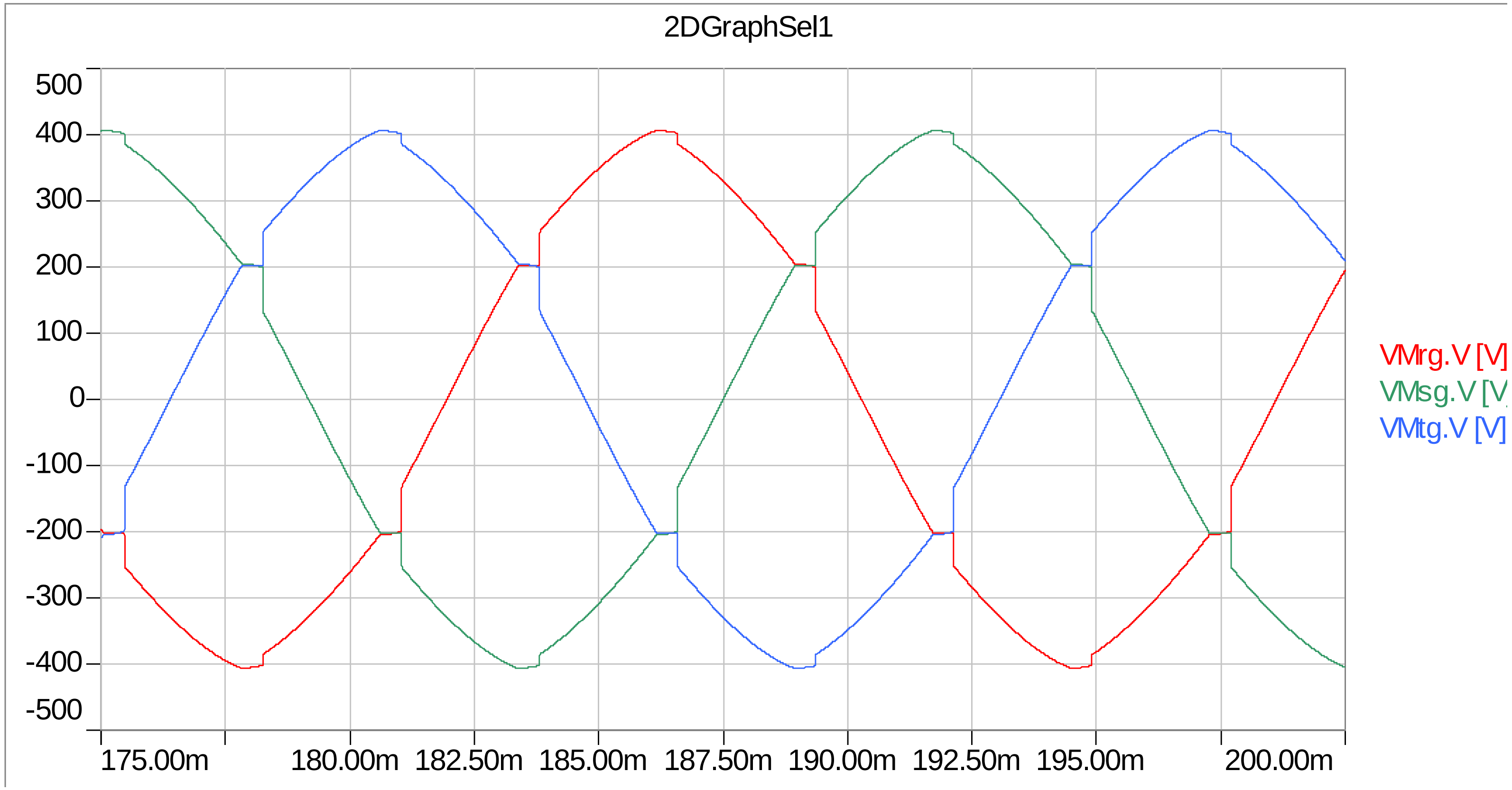
Vph-n and I out



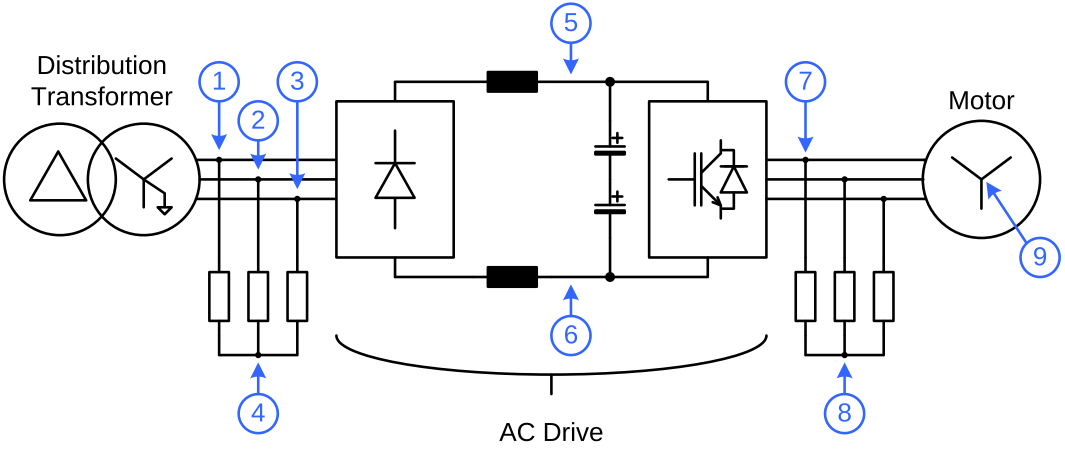


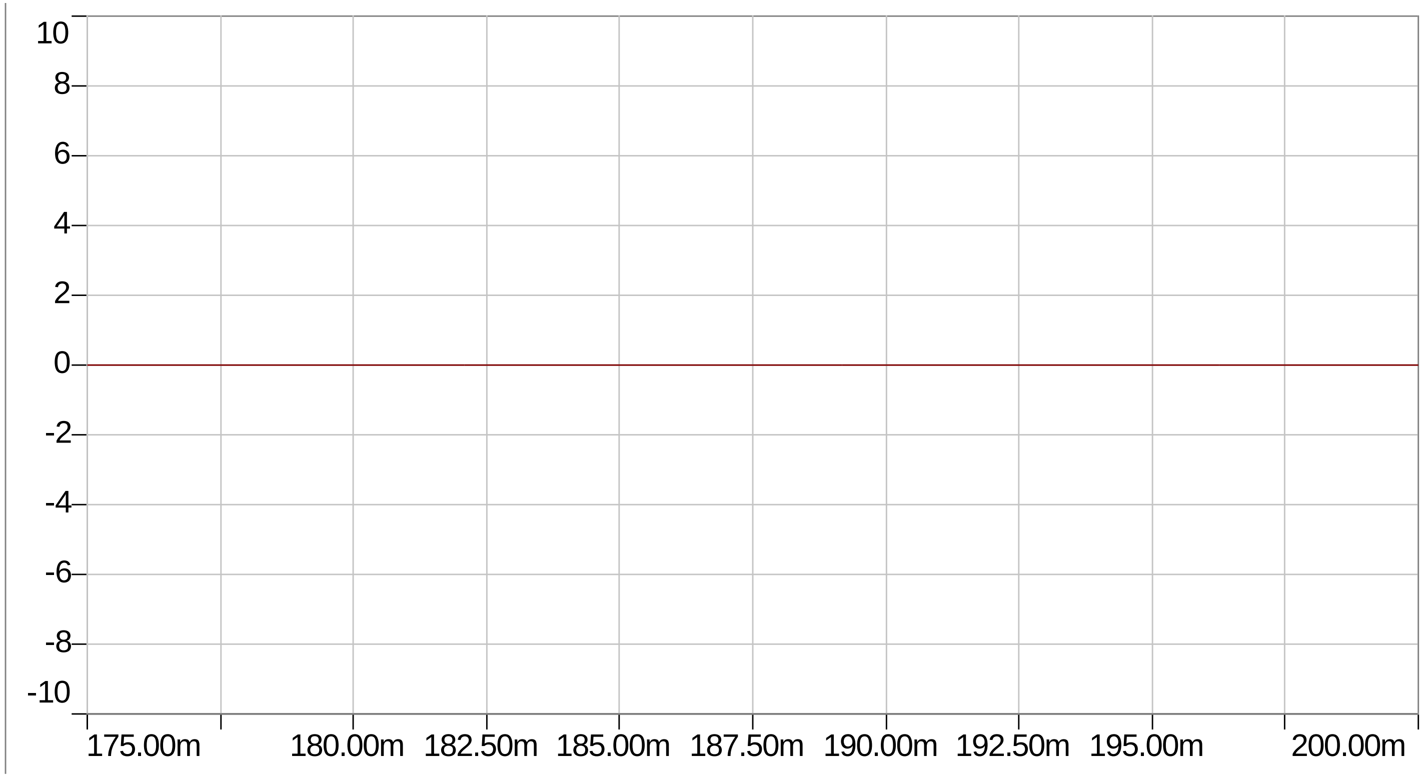
Probes 1,2,3 to gnd



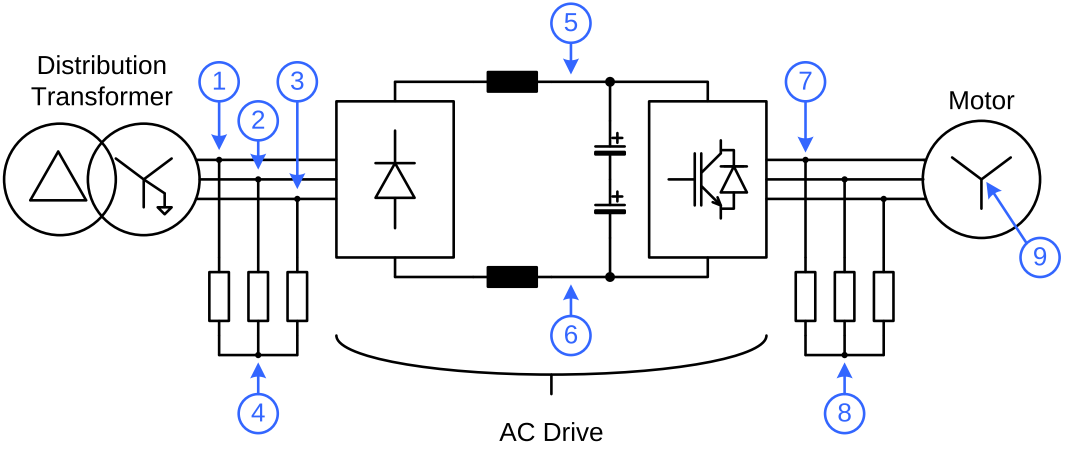


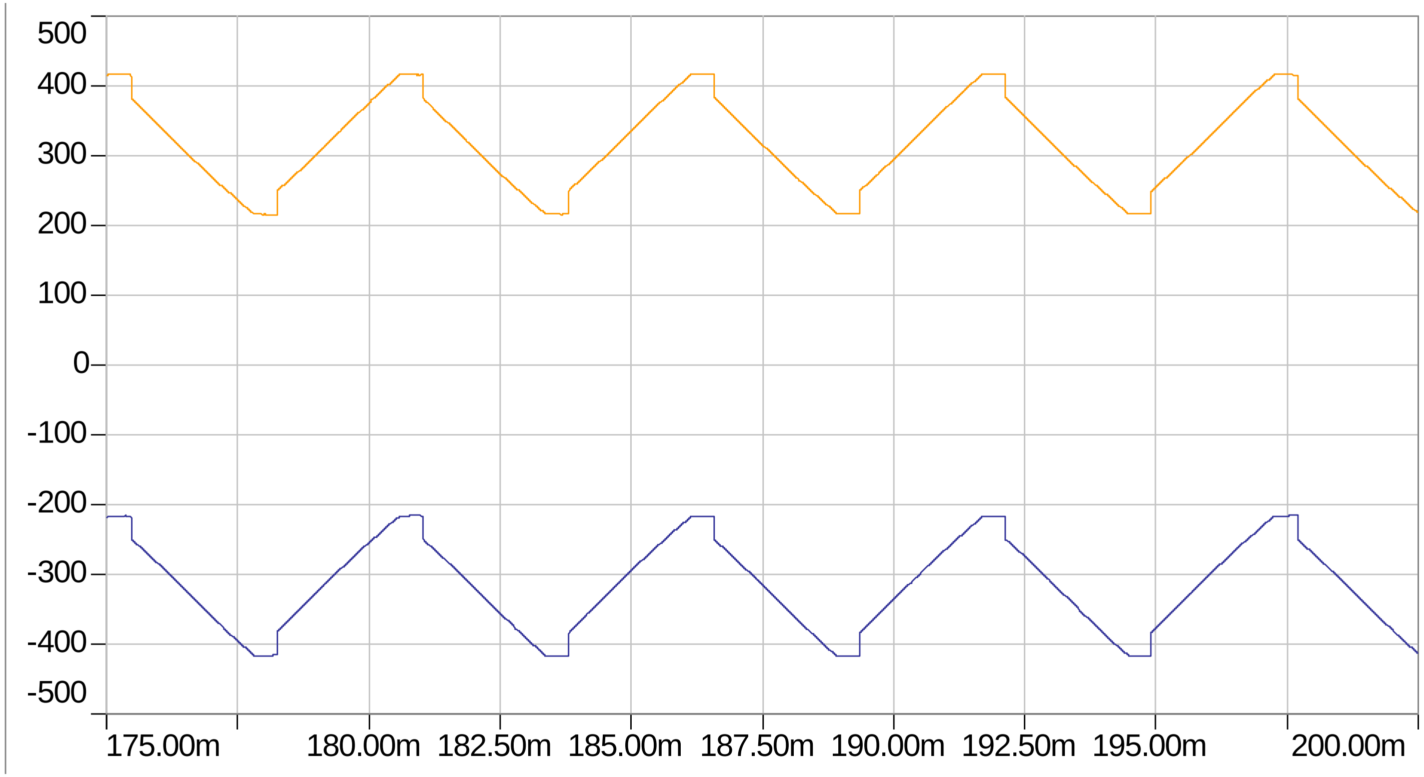
Probe 4 to gnd



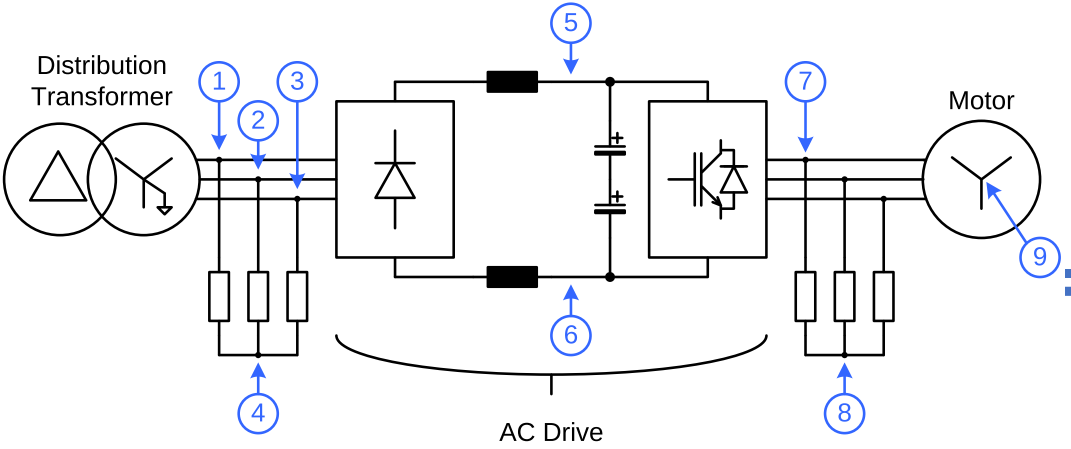


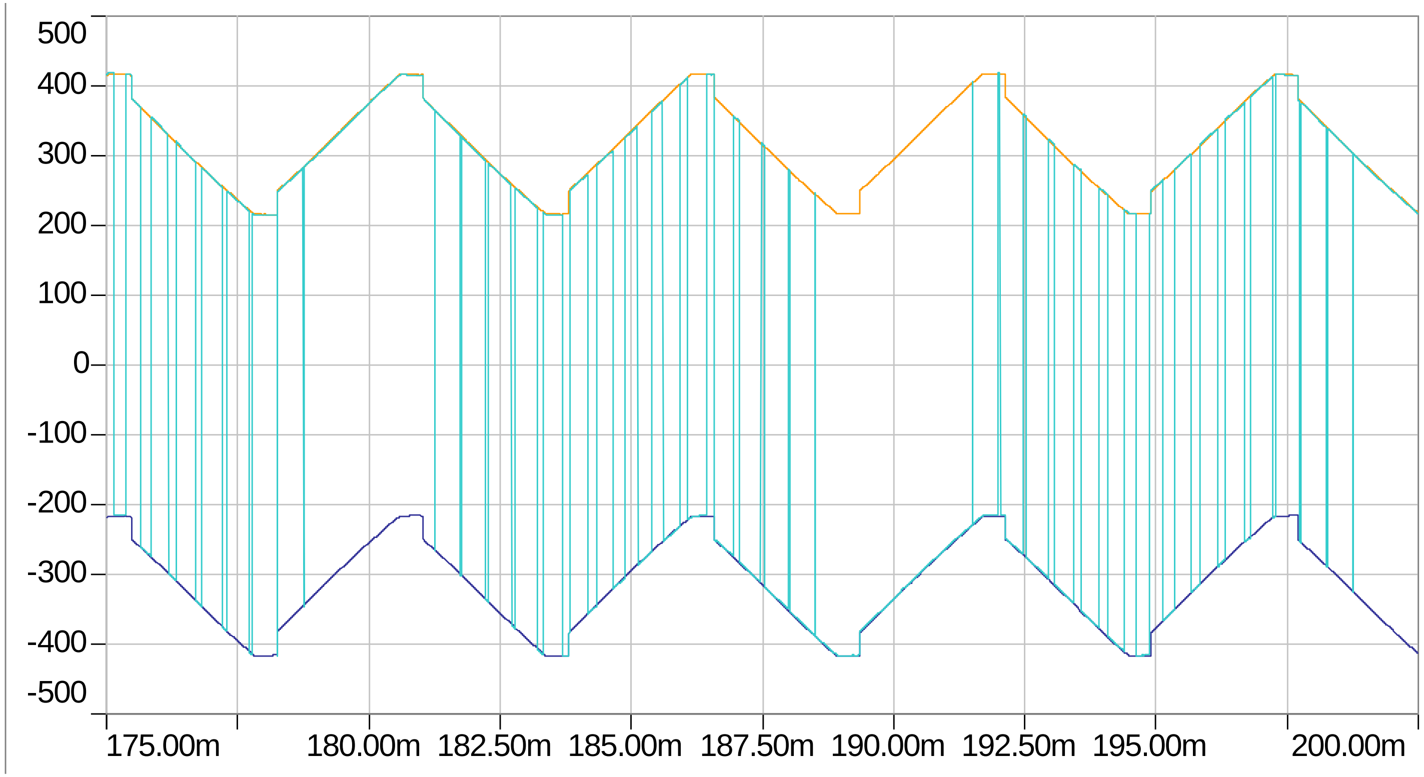
Probes 5,6 to gnd



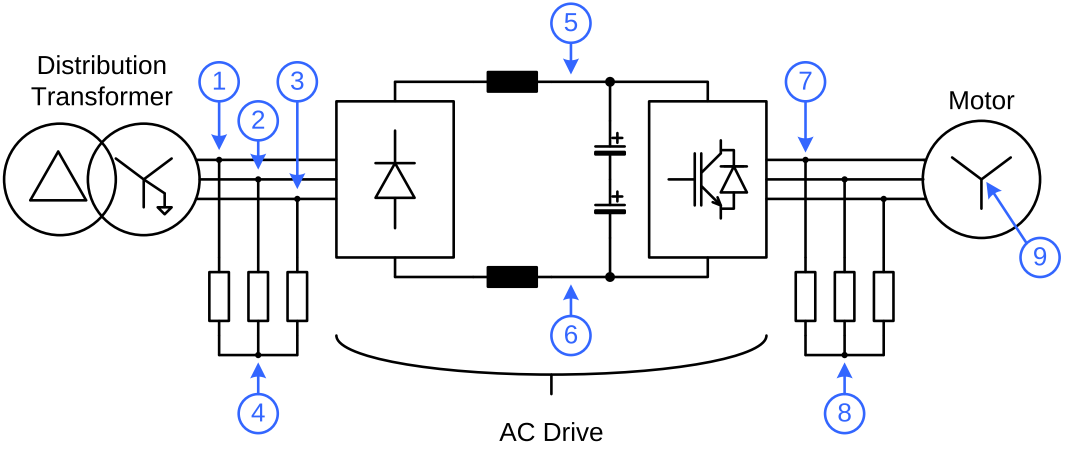


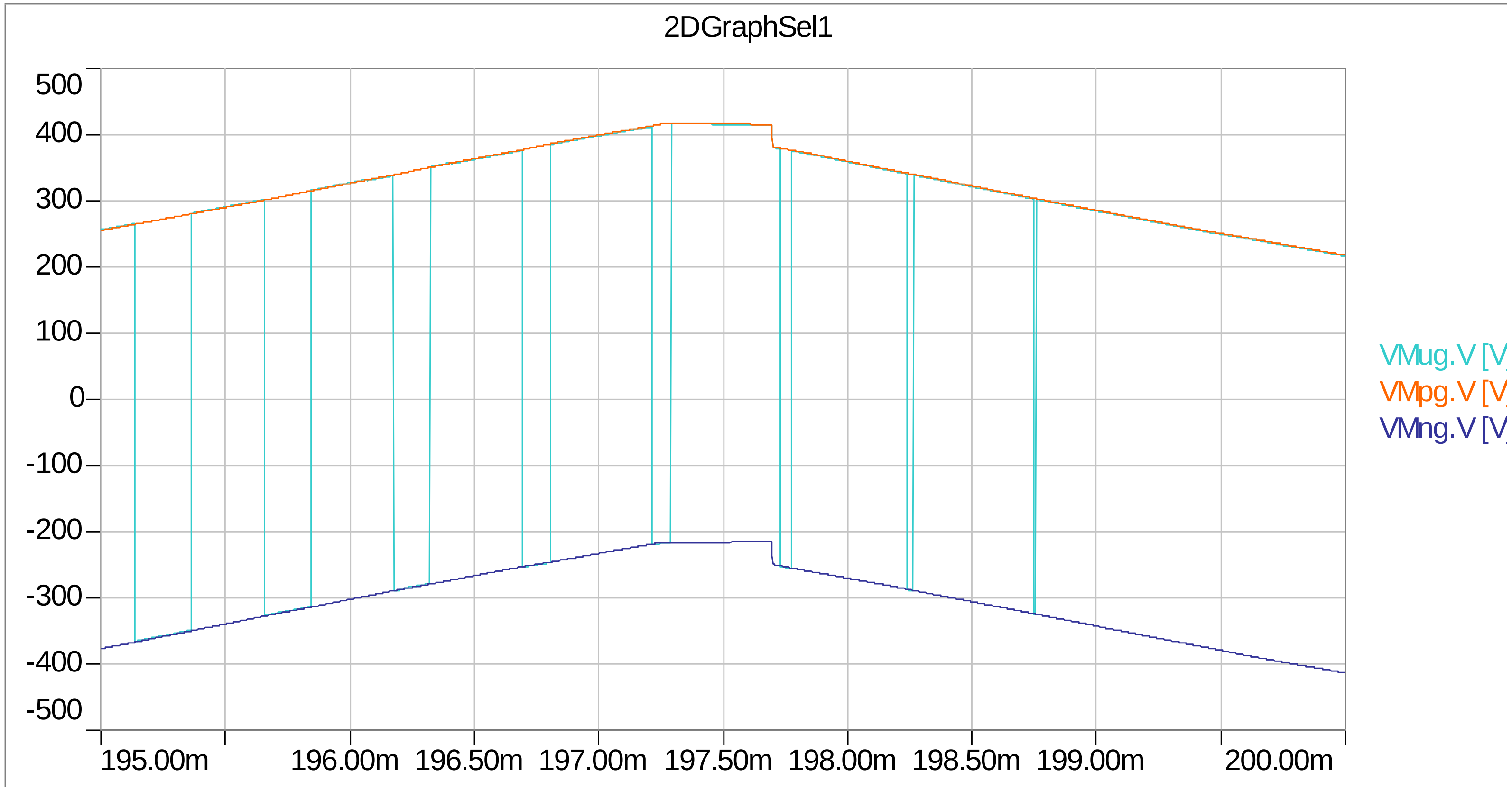
Probes 5,6,7 to gnd



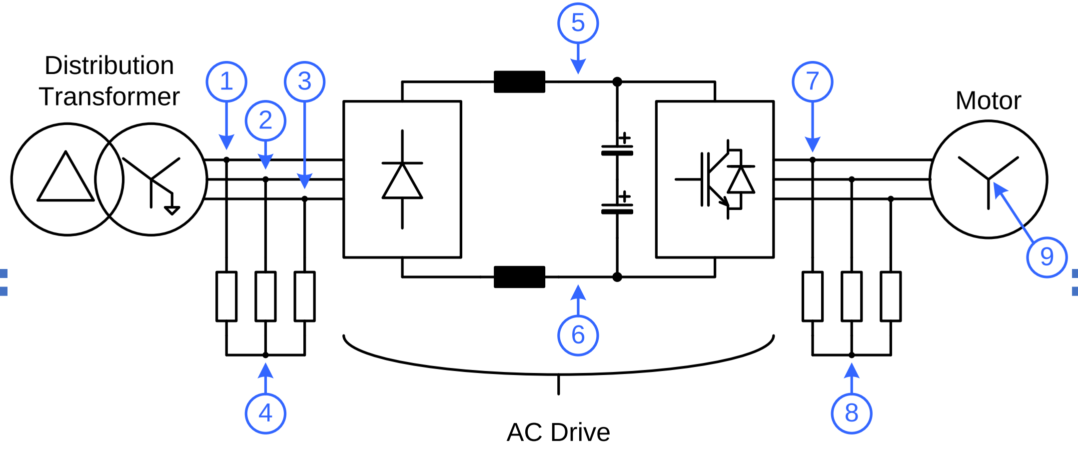


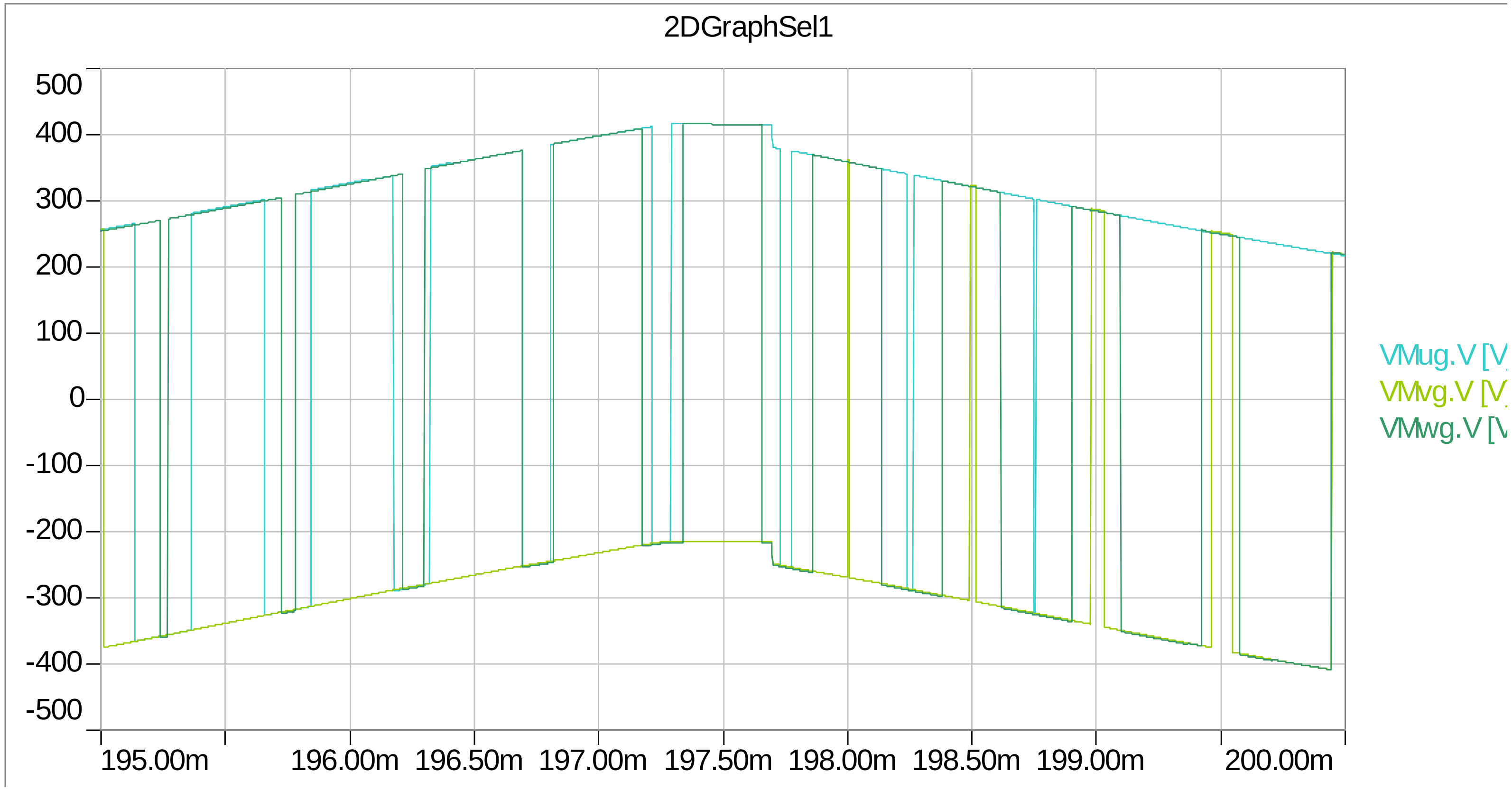
Probes 5,6,7 to gnd



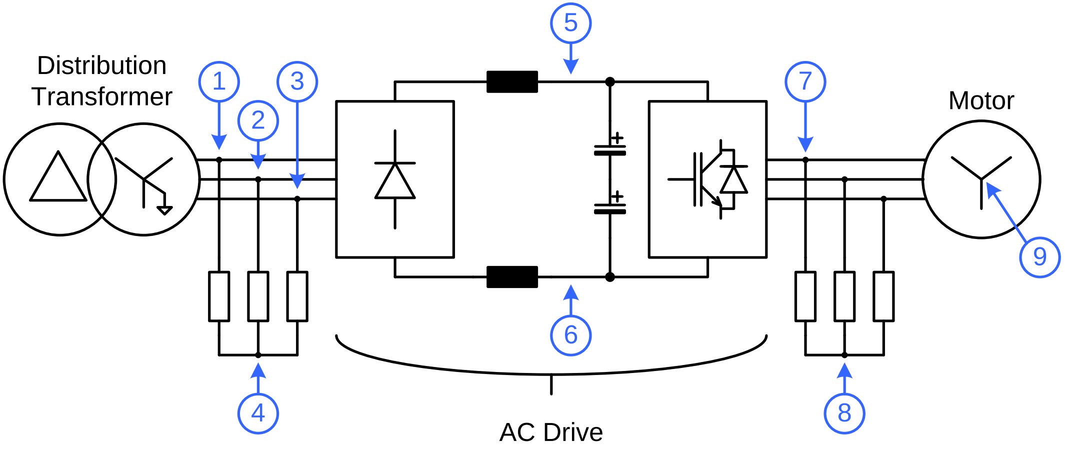


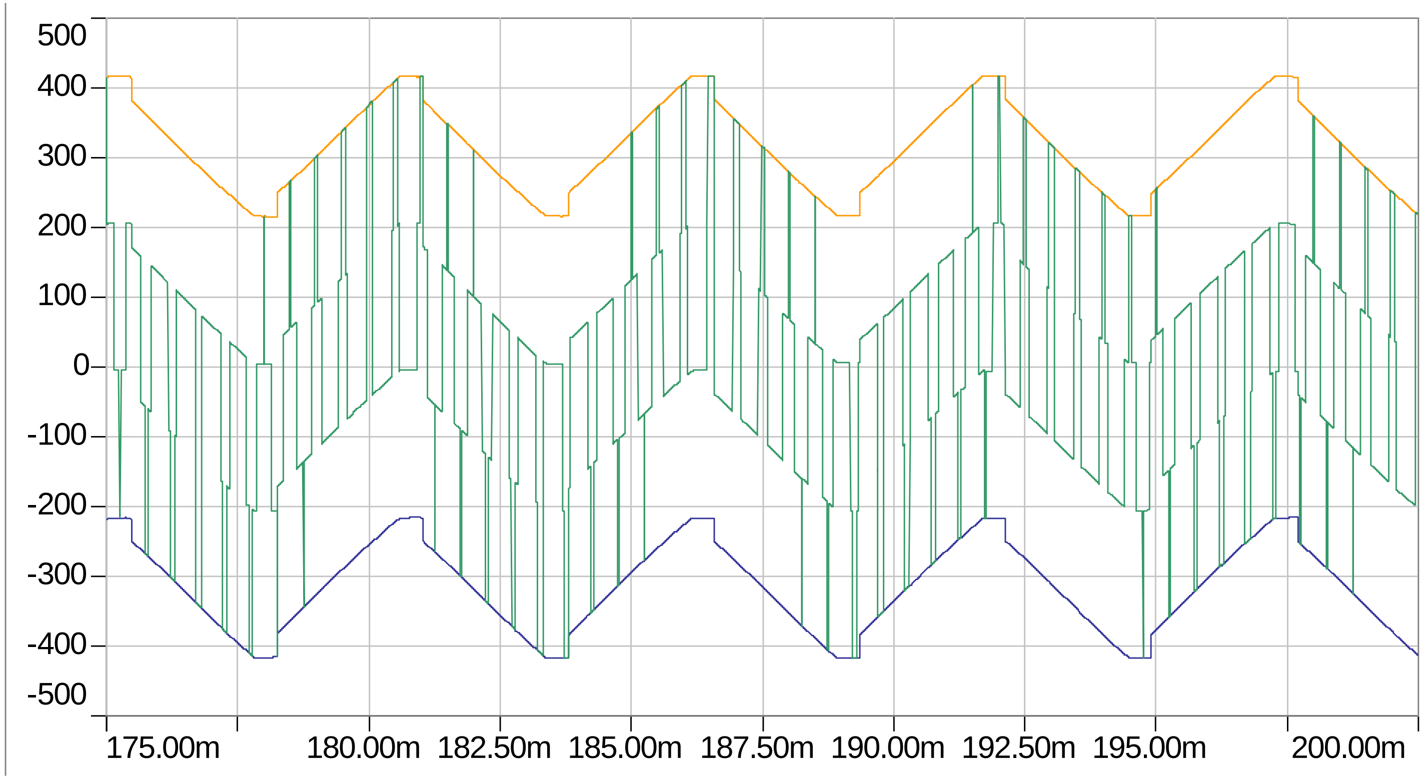
Probes 7u,v,w to gnd



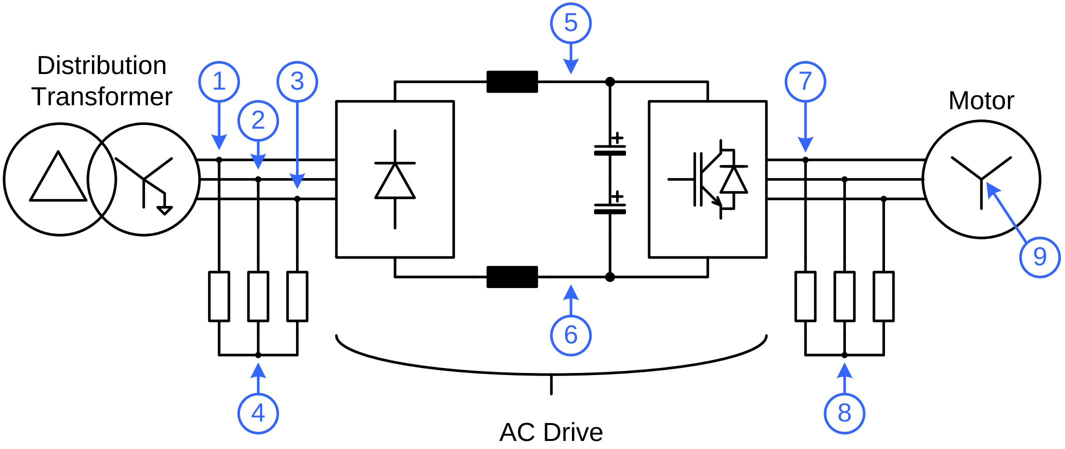


Probes 5,6,8 and 9 to gnd

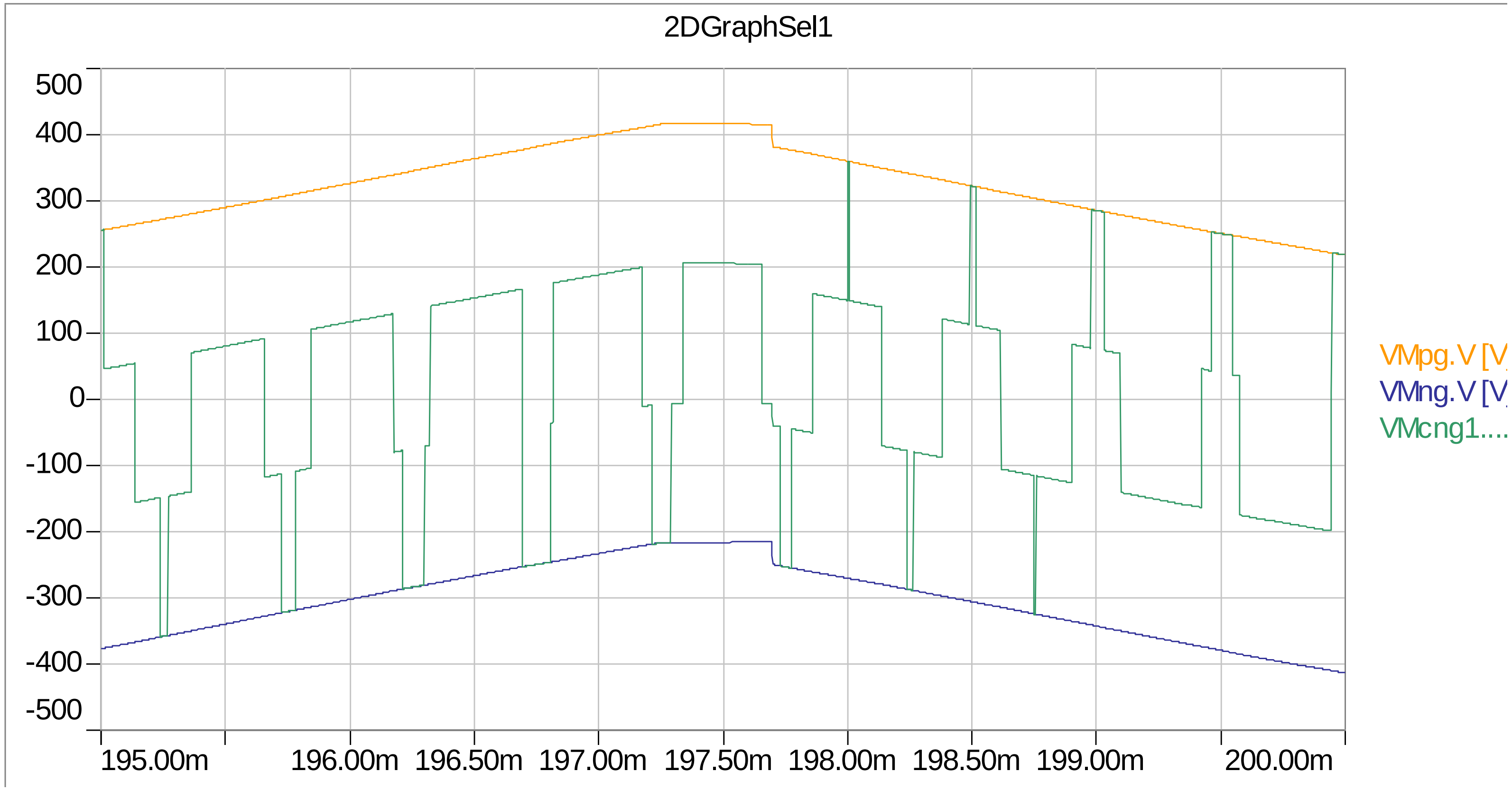




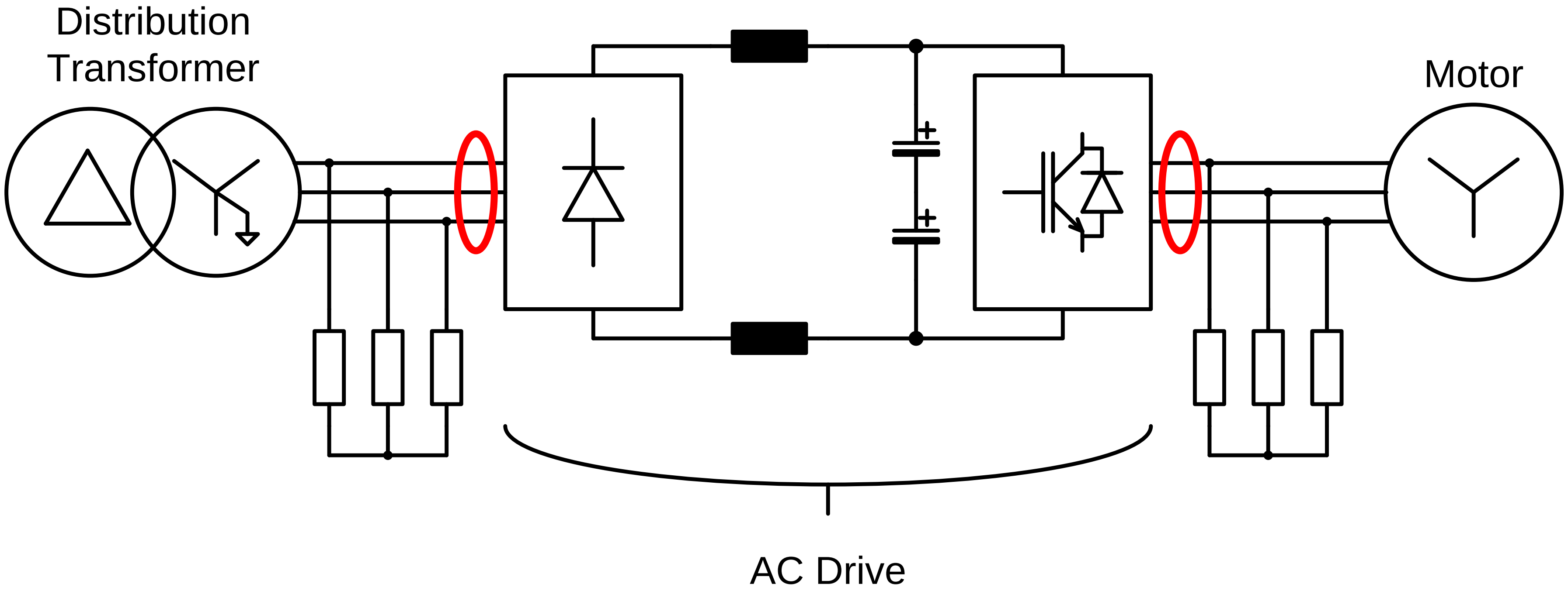
Probes 5,6,8 and 9 to gnd



8 and 9 are the CMV

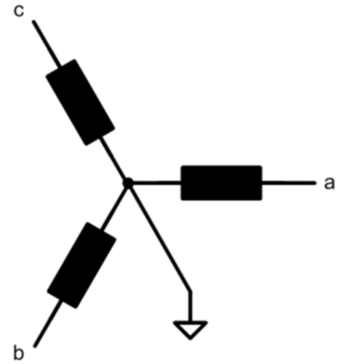


Common Mode Currents Measurement Locations



Drive Installation – Power Input

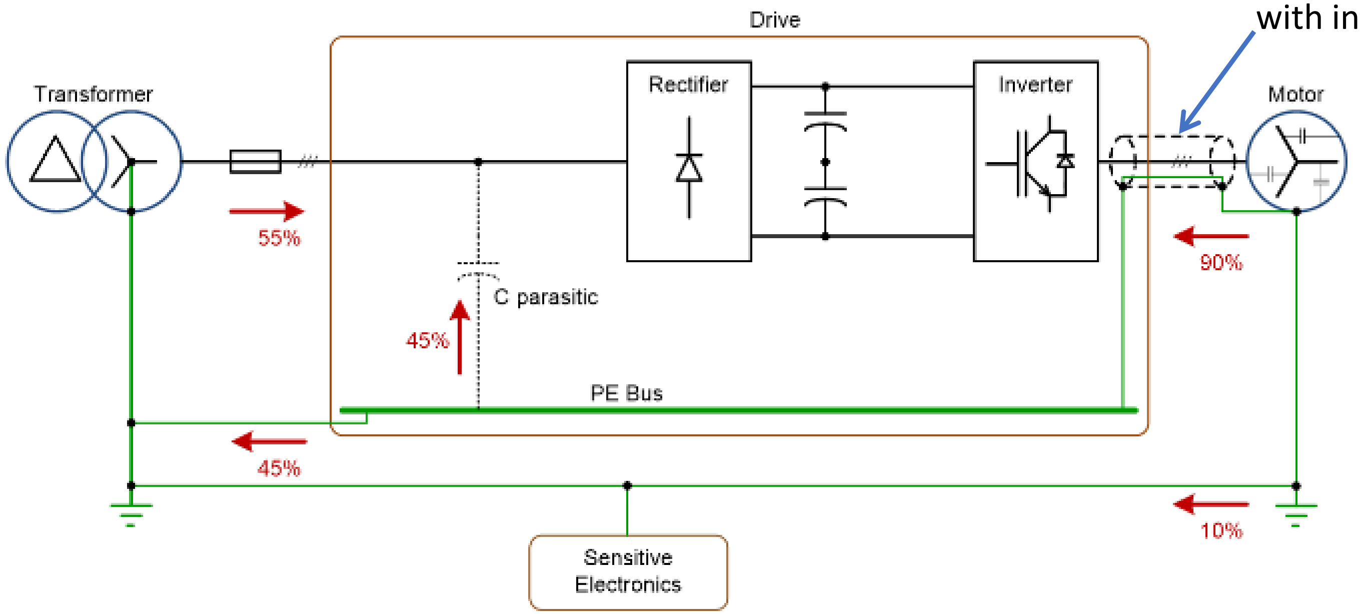
- Conventional cable type
  - Note: EMC (Electro Magnetic Compatibility) requires power input cable similar to output motor cable
- Cables sized in accordance with NEC (sections 430.6, 430.21, 430.25)
- Ampacity = 125% of drive input current normal duty rating
- If long distances, size should be increased to reduce voltage drop (Avoid voltage drop of >3% at rated load)
- Increased cable size may be needed due to quantity of cables in conduit (NEC Table 310.15(B)(2)(a))
- Increased cable size may also be needed due to ambient temperature or parallel conductor de-rates (NEC Table 310.16)
- 3-phase, grounded power network, with ground conductor



Drive Installation – Power Output

Motor cable must handle current & voltage output

- Provide low impedance, high frequency return path to drive
  - Employ Single Point Grounding
- Provide high frequency shielding qualities
- Each drive output run in separate conduit
- If output and input cable are in a common raceway, separate the cables by 12”

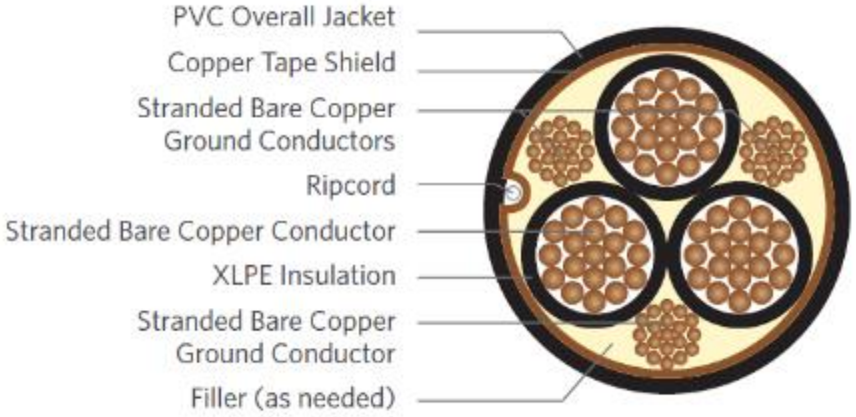


Armor or shielded cable with internal ground

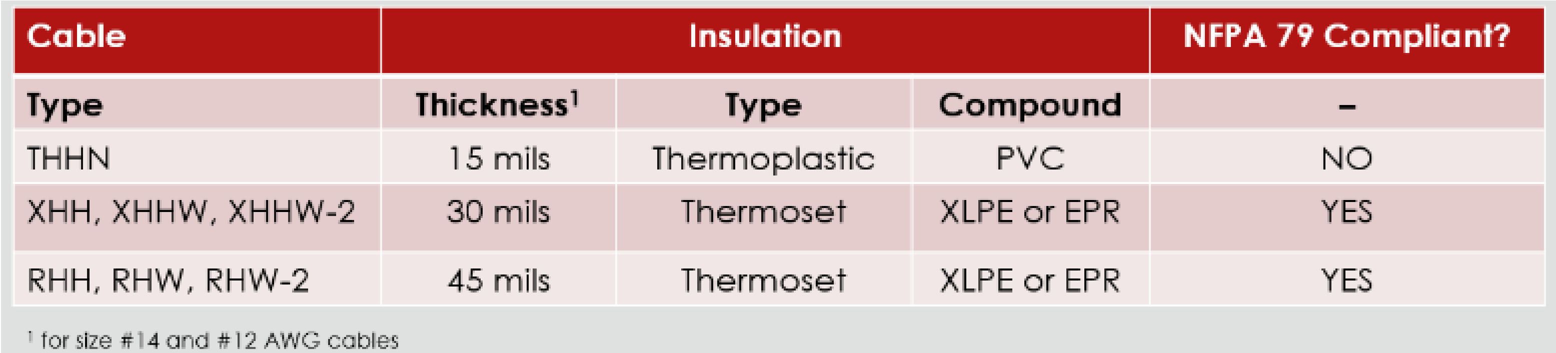
Drive Installation – Power Output

Achieve a solid return path via cable:

- Use continuous corrugated aluminum armored MC cable (symmetrical grounds recommended) OR
- Shielded power cable OR
- Fully bonded steel or metallic conduit (360^0 electrical contact joints)
  - Cables must be symmetrical and concentric
  - Use stranded cable instead of solid core cable



Drive Installation – Power Output



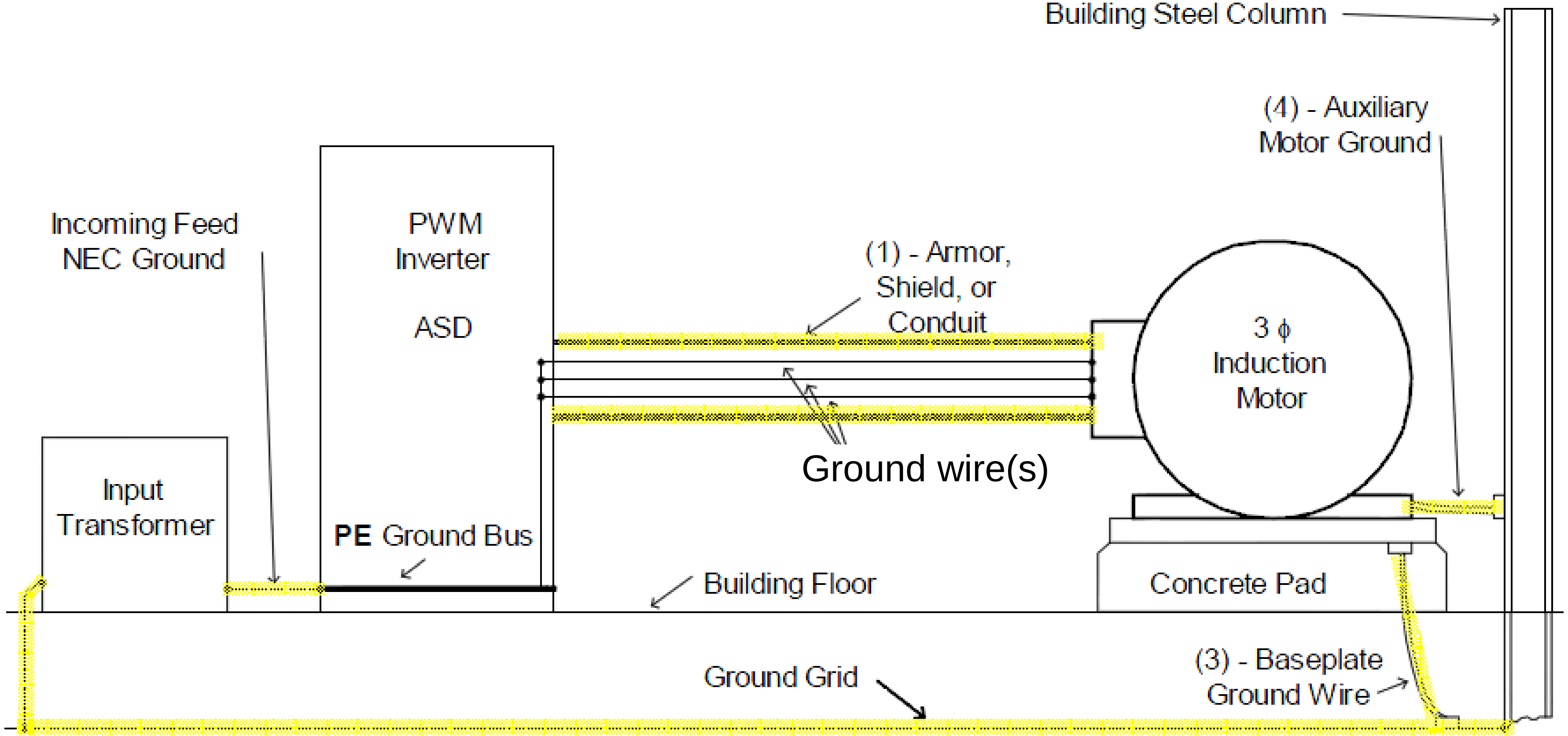
Cable	Insulation			NFPA 79 Compliant?
Type	**Thickness[1]**	**Type**	**Compound**	**–**
THHN	15 mils	Thermoplastic	PVC	NO
XHH, XHHW, XHHW-2	30 mils	Thermoset	XLPE or EPR	YES
RHH, RHW, RHW-2	45 mils	Thermoset	XLPE or EPR	YES

[1] for size #14 and #12 AWG cables

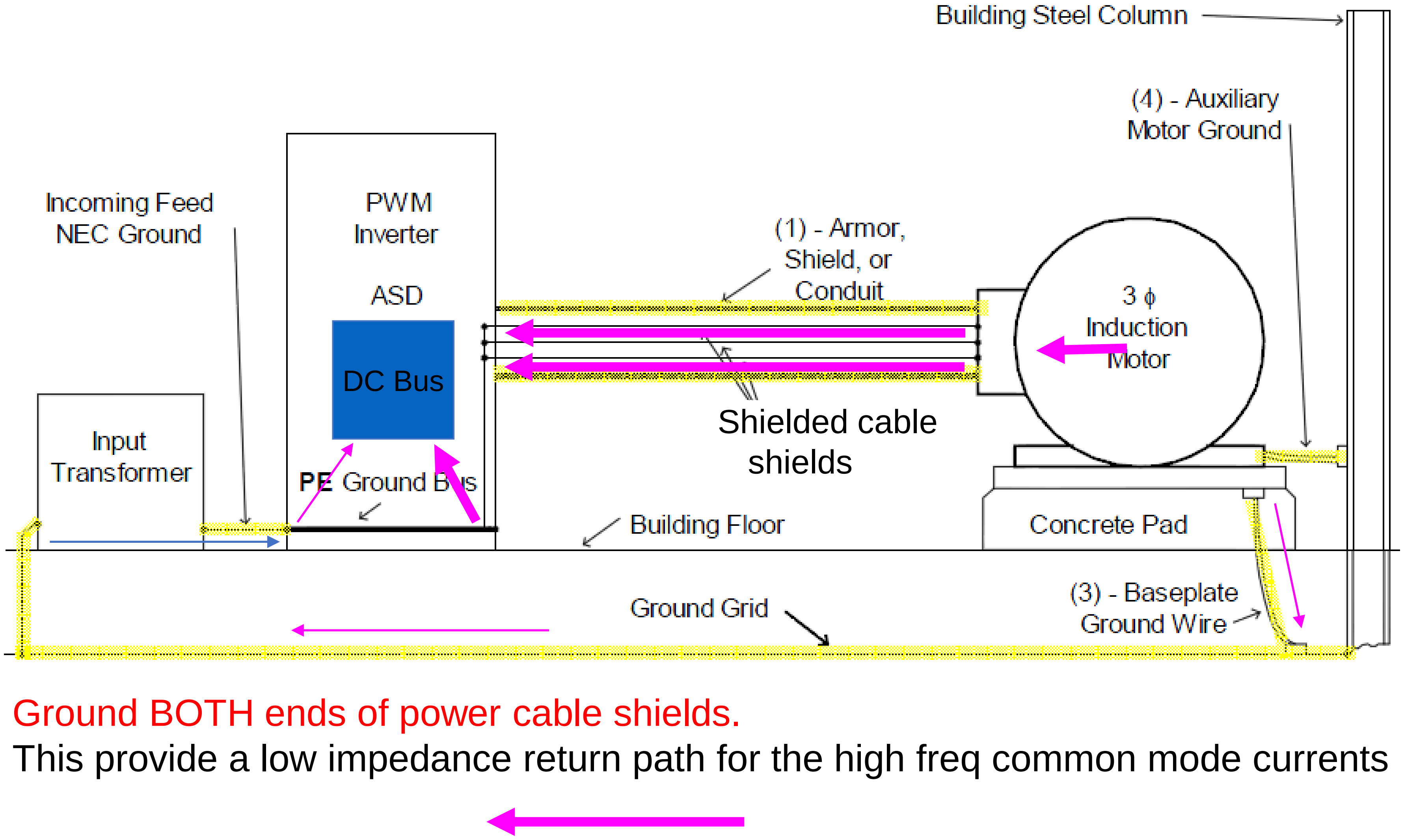
- THHN is not recommended for VFDs (OK for building wire and jackets)
  1. It will cold flow when subject to heat and pressure
  2. Corona Inception Voltage (CIV) is low
  3. Its voltage withstand is significantly lower when wet (high humidity)
  4. Its capacitance is higher which leads to more common mode current in the shield and ground
  5. NFPA 79 does not allow the use of that for drives
- Shielded Cable is needed
  1. Provides low impedance path for high frequency common mode currents back to the drive
  2. Reduces crosstalk (coupling) between adjacent wires in a common raceway, tray, conduit, etc

S Wetzel, VFD Cable: Essential or Overkill?, Southwire presentation

Safety Grounding



Common Mode Grounding

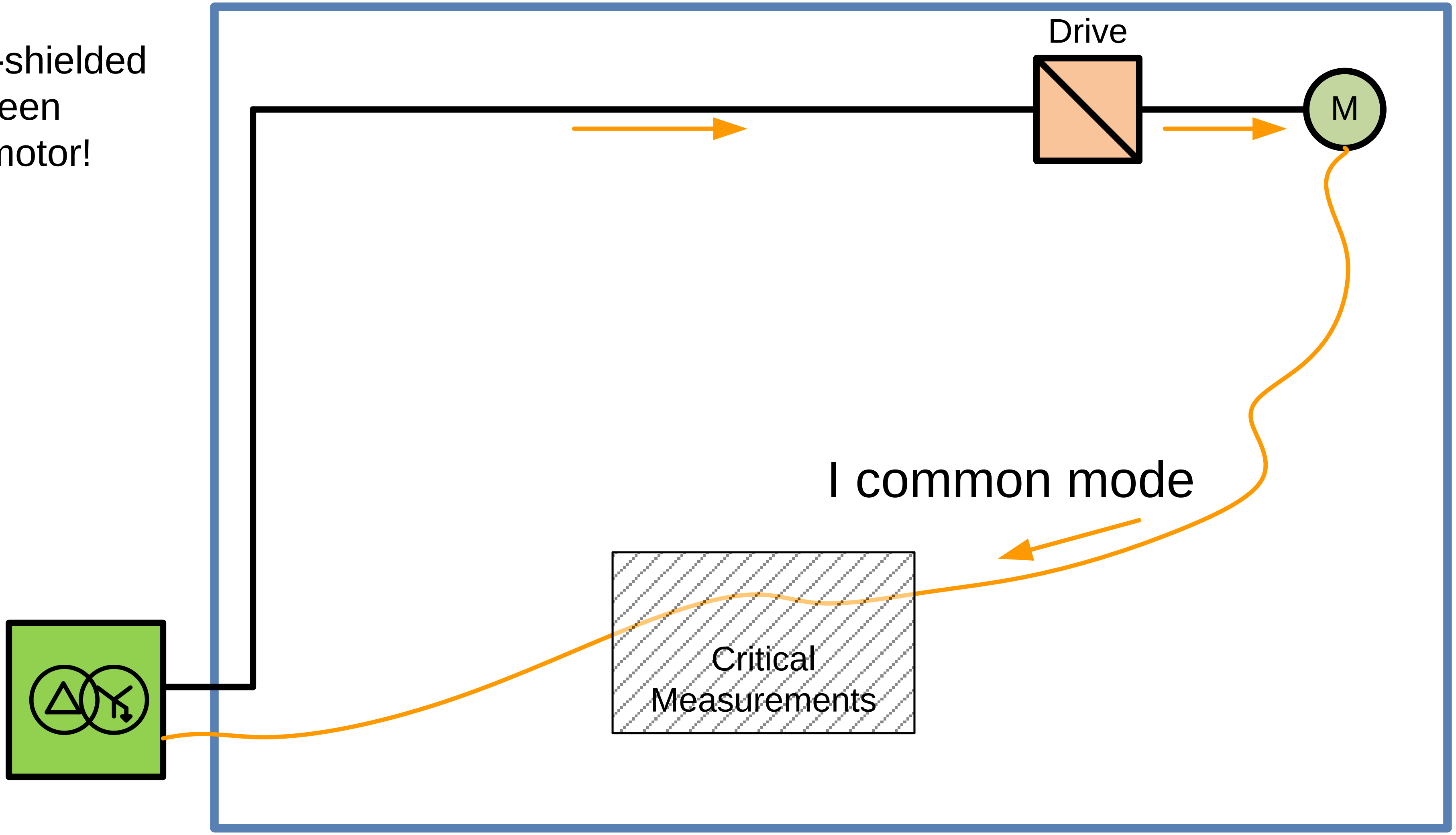


Ground BOTH ends of power cable shields.

This provide a low impedance return path for the high freq common mode currents

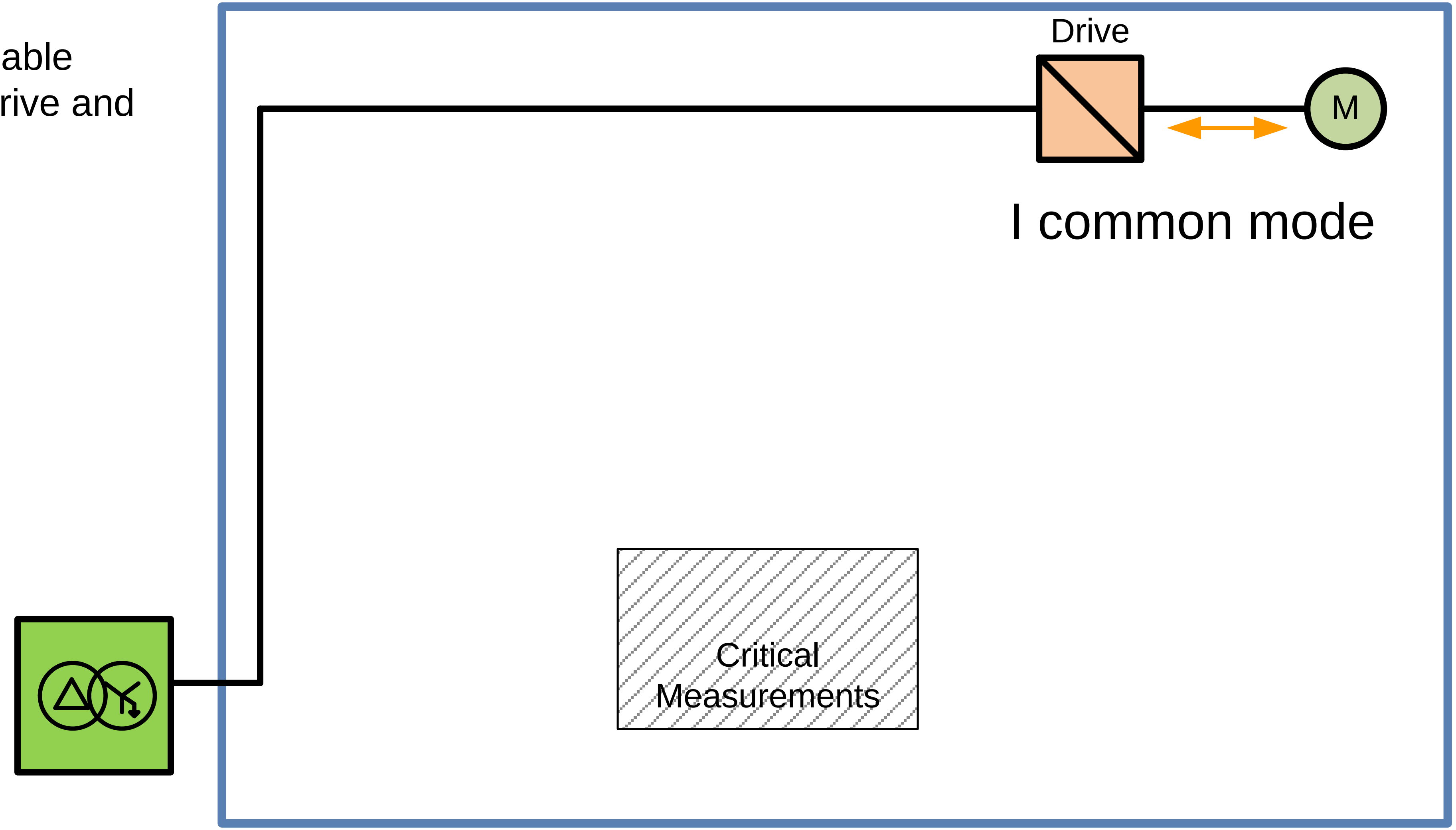
Possible Path for Common Mode Currents

Cheap, un-shielded
cable between
drive and motor!



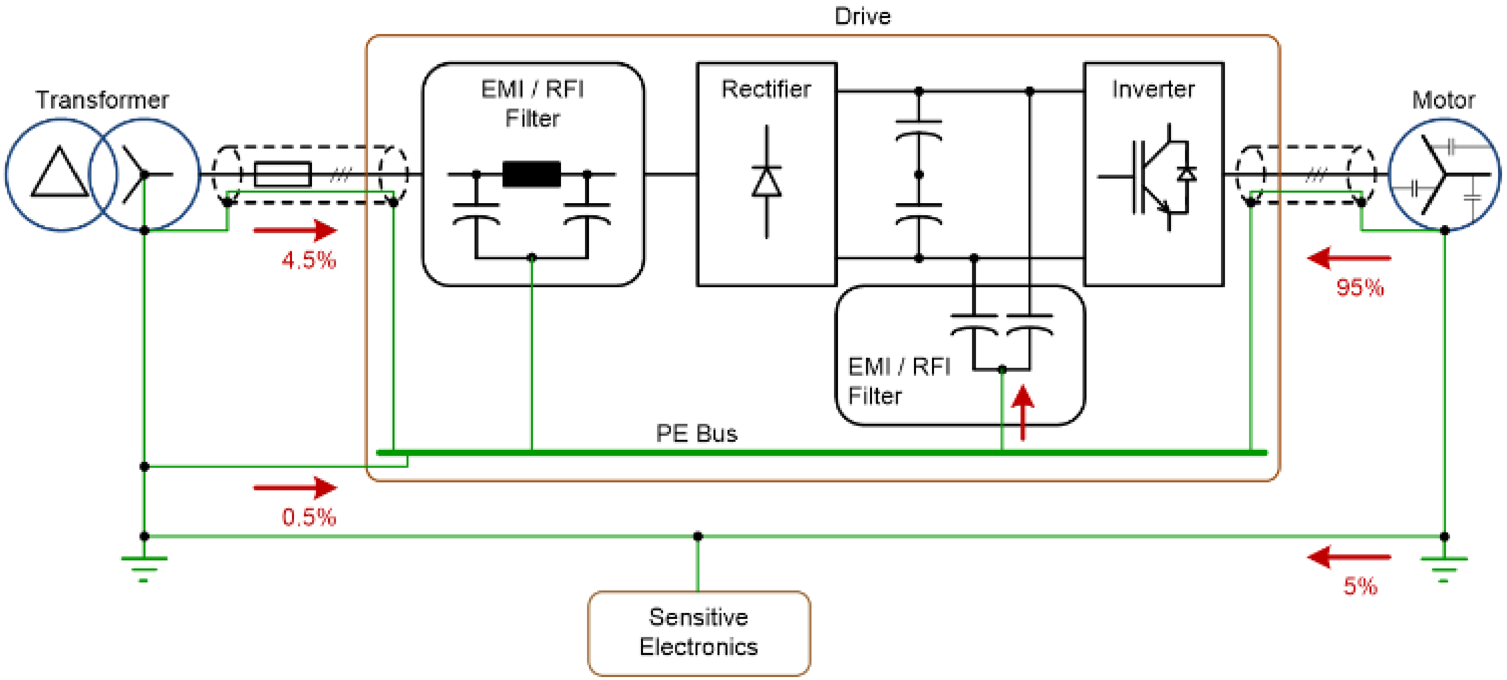
Preferred Path / Containment

Shielded cable between drive and motor!



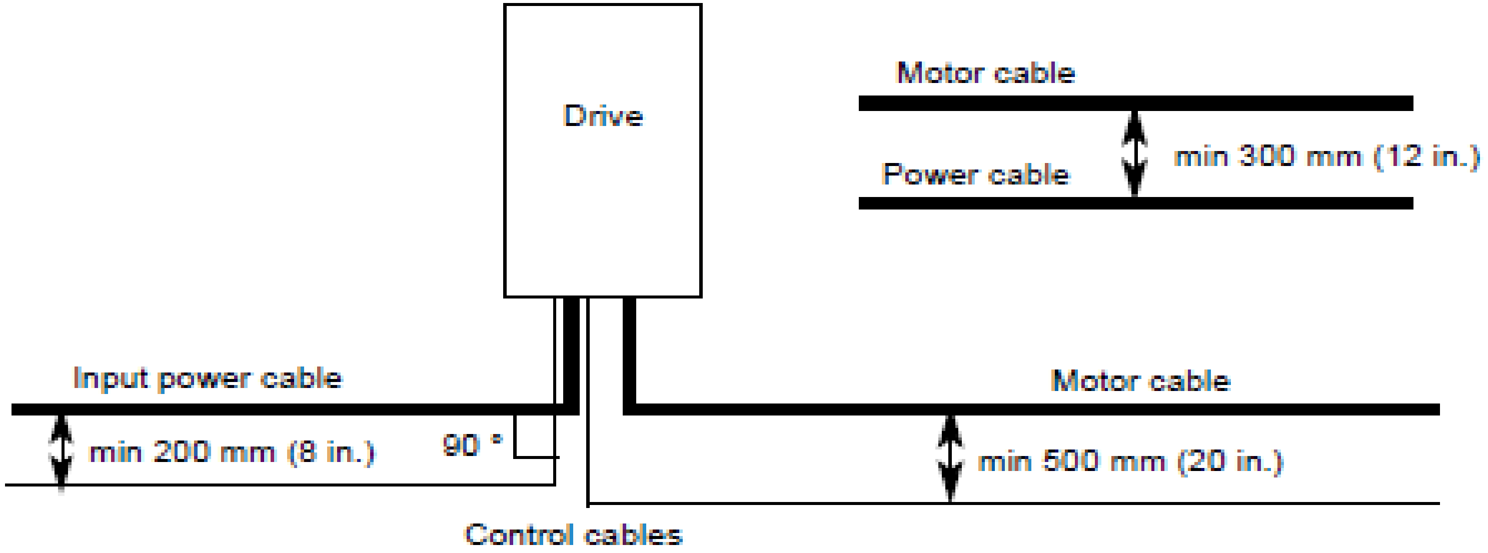
Drive Installation – Power & EMC Requirements

- Operation of a drive in a "CE" compliant country requires EMC compatibility
- To be compliant, both power input & output cables need to be shielded
  - 1st Environment Filter (may require an external filter)
  - 2nd Environment Filter (included in ABB Drives)
  - EMI / RFI filters minimize conducted & radiated noise



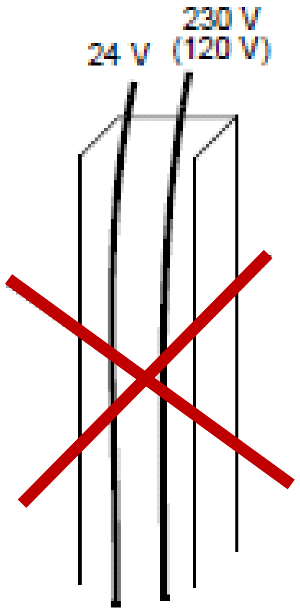
Drive Installation – Power & Control

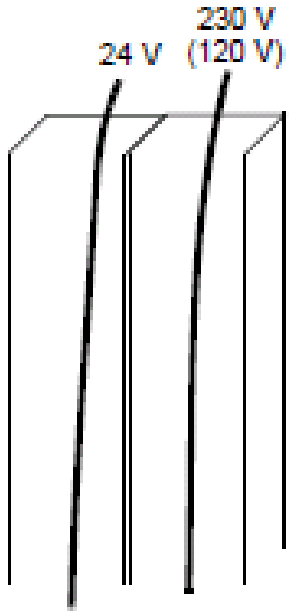
- Separate power and control wiring – use separate grounded metallic conduits for input, power & control
- If common raceways are used, separate drive input power and Control by 8” or output power and control by 20”
- Inside the drive enclosure, control wires must be permanently affixed to maintain a minimum of 2” spacing from power wiring



Drive Installation – Control Wire Routing

- Routing and Separation
  - **<u>Never</u>** run control in a conduit or raceway with power wiring
  - 120VAC control should be run in a separate conduit from power or other control (24VDC, analog, encoder or fieldbus)
  - Recommendation is one conduit each for:
    - Power Input
    - Power Output
    - 120VAC Control (if applicable)
    - All other control (24VDC, Communications, Encoder, etc)



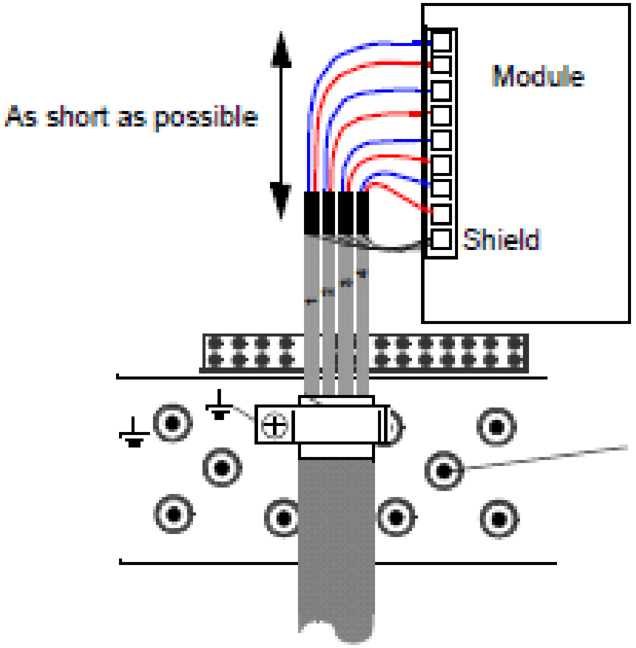


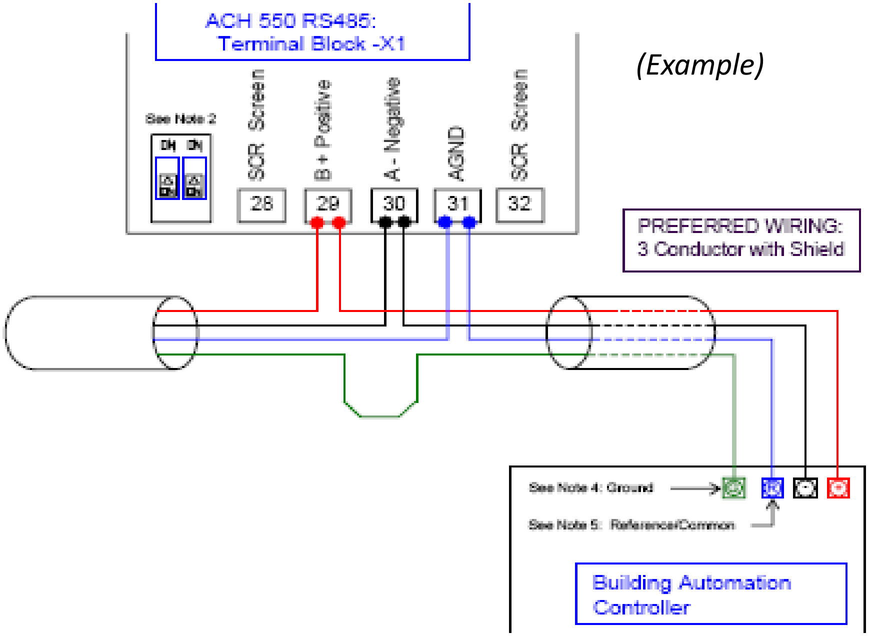
Drive Installation – Control Cables

- 120VAC control should use 600VAC rated, single conductor (e.g. THHN/THWN) or multi-conductor tray cable
- 24VDC (or 12VDC) control should be multi-conductor twisted cable (300 or 600V rating)
- Overall shield is recommended
  Belden type 9318, 9552, 9553, etc. with twisted pair, or equivalent)
- Analog Signals (0-10VDC or 0-20ma)
  - Use individually shielded multi-conductor twisted pair cable (Belden type 9318, 9369, 9369, etc. or equivalent)
  - Shield cut back and taped at the signal source – grounded at the drive end only
  - If signal device manufacturer requires grounding shield at the device, do not ground also at the drive

Drive Installation – Fieldbus Control

- Fieldbus signals should use the cable as recommended in the fieldbus manual for the specific protocol
  - Follow manufacturer's recommendation for cable type
  - Terminate shield at the location recommended by the manufacturer
  - Embedded fieldbus connections (A, B, Signal Gnd, Shield)





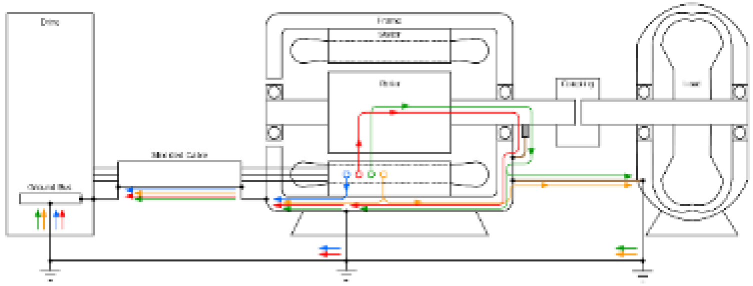
(Example)

Motor Installation

- Distance between drive and motor depends on:
  - Cable capacitance (cable acts like a capacitor)
    - Small drives – limited to about 100ft.
    - Large drives – may support up to 1000ft
  - Switch Frequency
    - Lower switch frequency - longer cable length
    - Output reactor or dv/dt filter allows longer cable distance

      and will help protect windings at short/long distances
  - EMC standards
    - Cable lengths are limited
    - Cable acts like an antenna to propagate EMC noise
  - Motor Winding & dv/dt (V reflection) – below 5ft, above 30ft
    - Inverter Duty Motors handle this issue
      (NEMA MG1, Part 31, sec. 31.4.4.2)
    - Dv/dt filter will help protect windings at short/long distances

End of Part 2


Drive
Ground Bus
Shielded Cable
Frame
Stator
Rotor
Coupling
Load