Application Overview of Medium Voltage Adjustable Speed Drives (ASD)

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Safety Moment - Petextrians

After decades of decline, pedestrian fatalities are once again on the rise.
“Petextrians” — people who text while walking — may be partly to blame, according to the report.”
(ABC News Report)

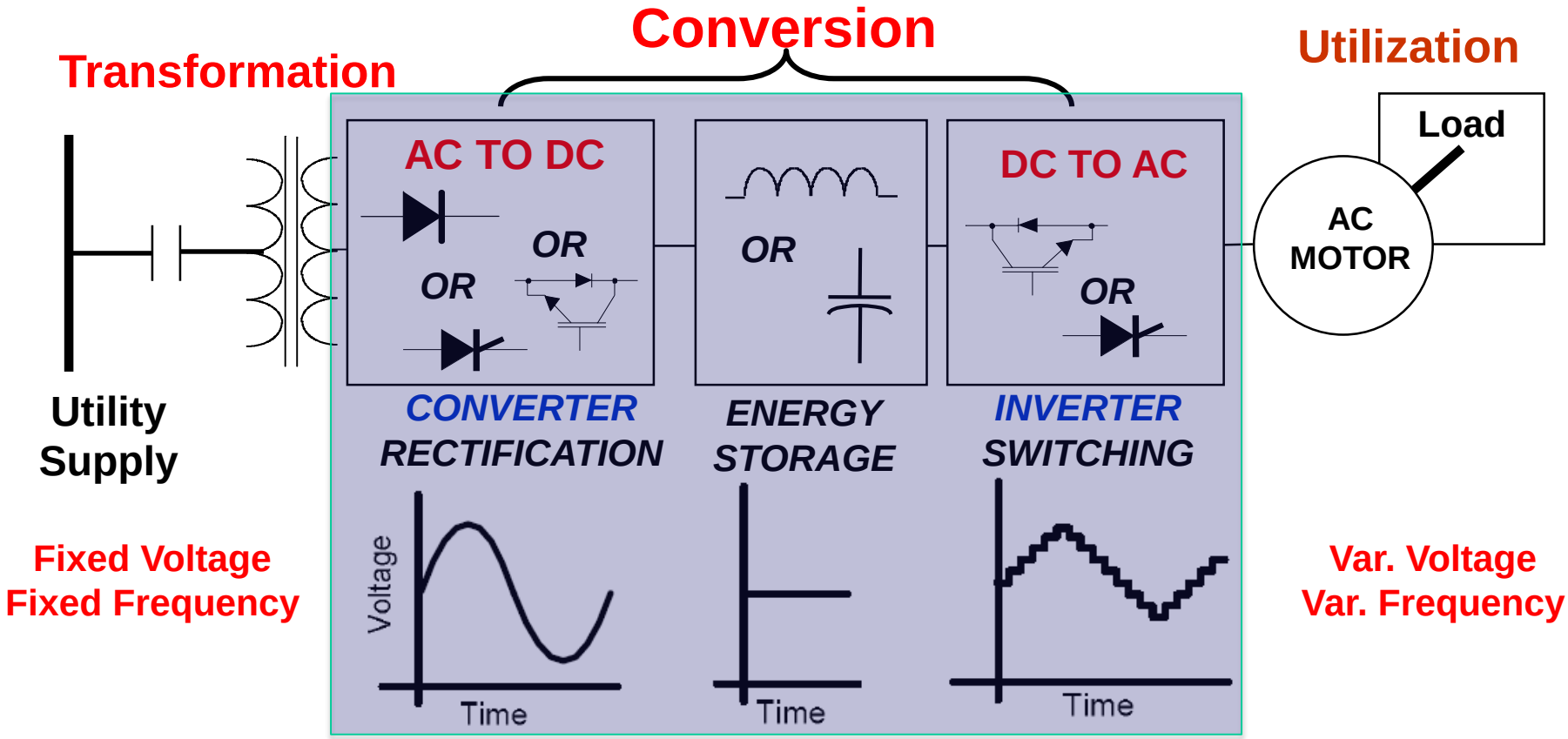
Quality Moment

Quality means doing it right when no one is looking.

- Henry Ford

Applicable dimension

Parameter	Description
Service types	Rotating machinery such as pumps, compressors, extruders, fans, blowers, etc.
Power Level (HP)	500HP – 130,000HP
Voltage range(kV)	Medium Voltage, > 1.0 kV


Conversion
Transformation
Utilization
AC TO DC
OR
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DC TO AC
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Load
AC
MOTOR
Utility
Supply
CONVERTER
RECTIFICATION
ENERGY
STORAGE
INVERTER
SWITCHING
Fixed Voltage
Fixed Frequency
Var. Voltage
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Voltage
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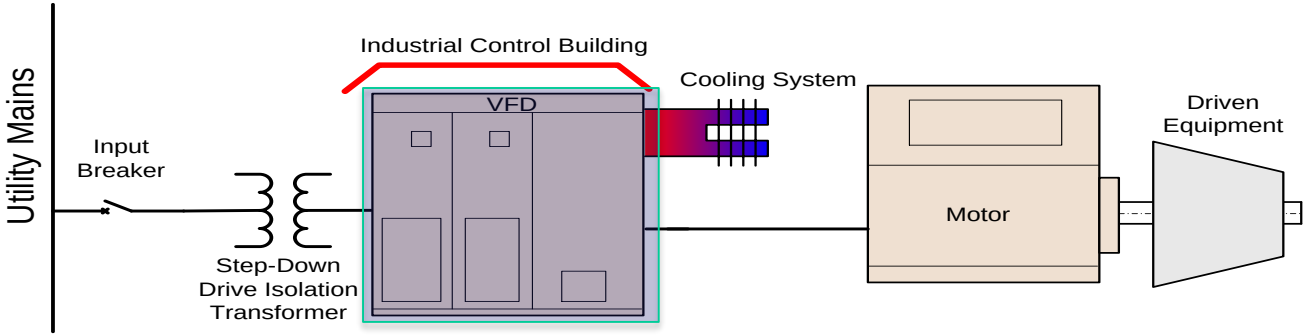
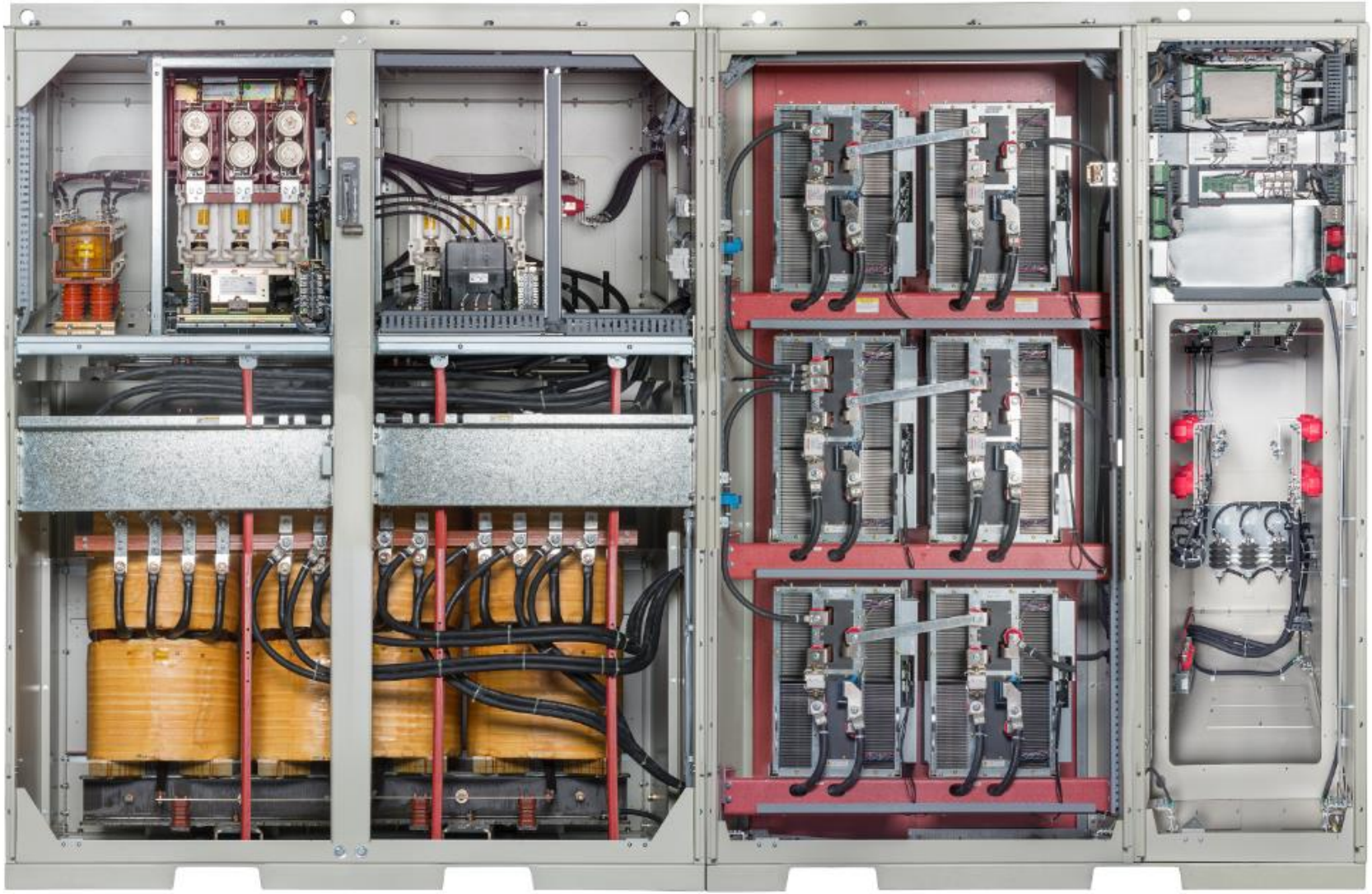
Time


Utility Mains
Industrial Control Building
Cooling System
VFD
Input
Breaker
Step-Down
Drive Isolation
Transformer
Motor
Driven
Equipment

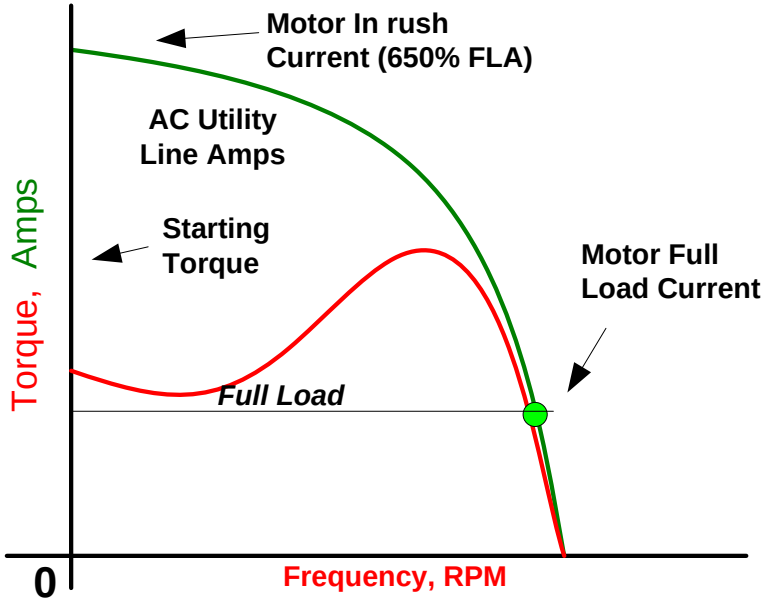
What is an ASD?

What is an ASD?

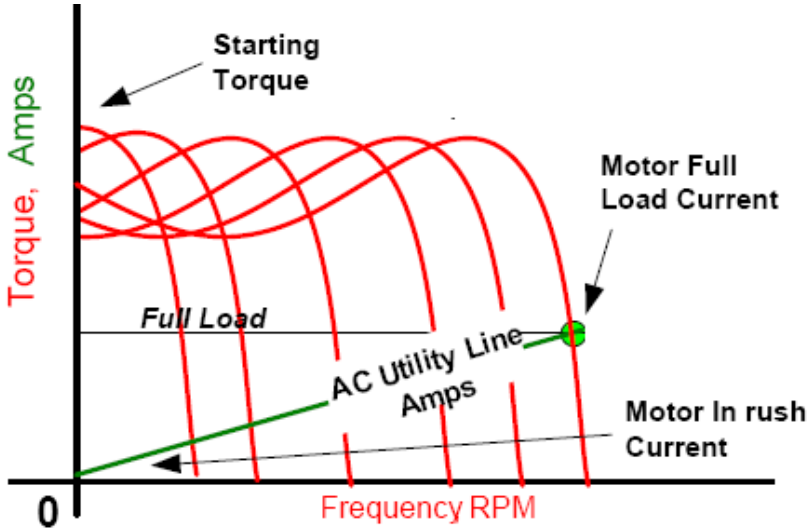


What is an ASD?

What does an ASD mean for the motor?



Direct-on-line / Fixed Frequency



Variable Frequency

What does an ASD mean for the motor?

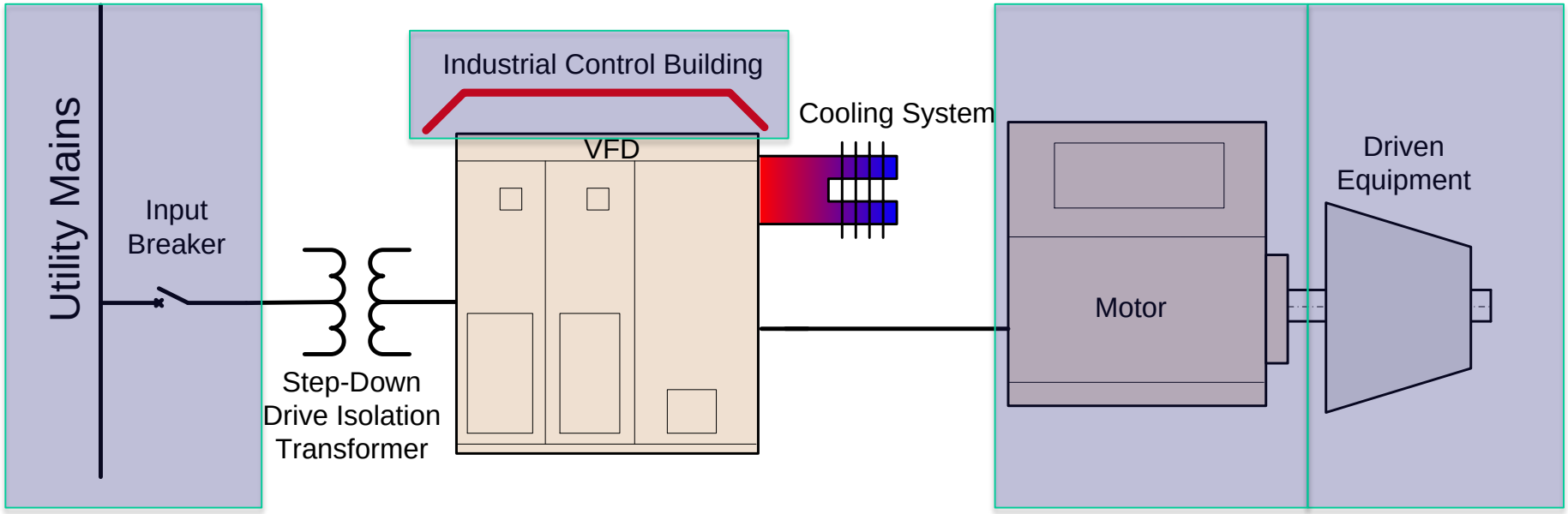
Motor Starting

- Reduced inrush current
- High Torque Loads
- Close to unity power factor

ASD System Considerations

Must consider the whole system in which the ASD will work

- From Utility to finished product or process
- Consider environment
- Consider effects on utility
- Consider the needs of the load
- Consider the effect of ASD on the motor and drive train



ASD Overall Success Factors

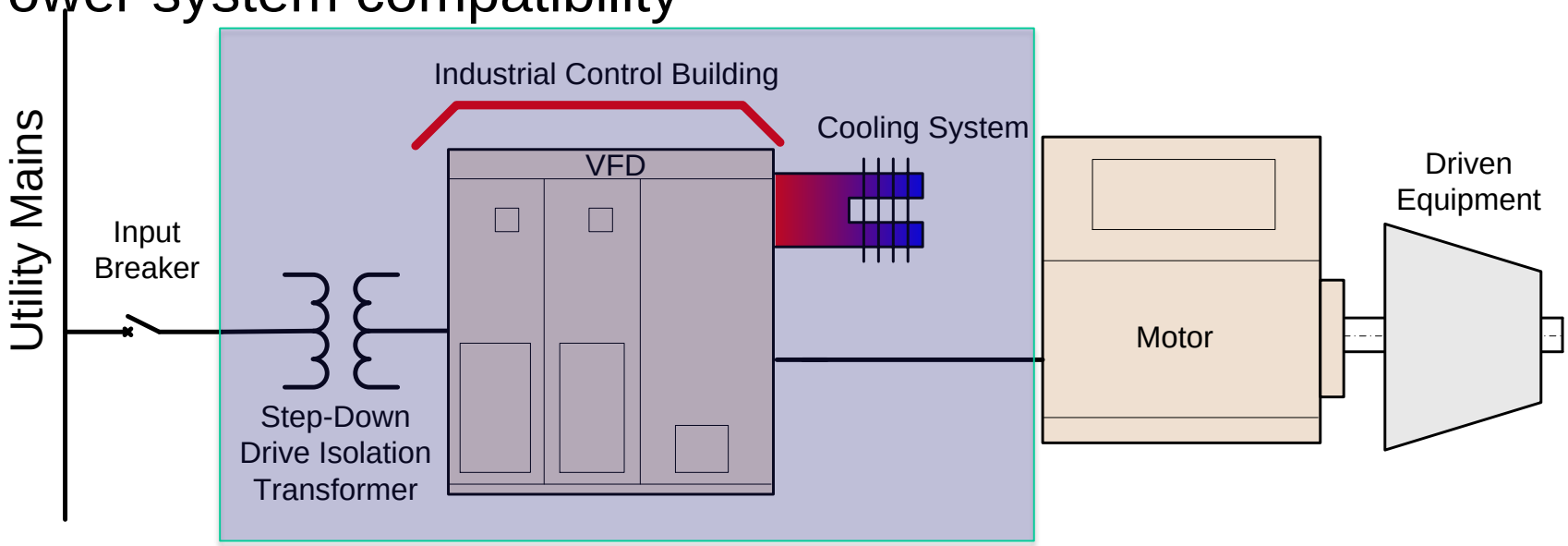
- Minimum first cost, including installation
- Maximum long-term payback.
- Good match to process & loads.
- Long equipment life.
- Ease of use for operators & technicians.
- Minimum impact on nearby equipment.
- Easy to maintain & repair.
- Smallest foot print

Application considerations can divided into the <u>following</u>:

- ❑ Electrical/Load Application Factors
- ❑ Installation Factors (E-house integration/Cabling)
- ❑ ASD Protection & Cooling methodology
- ❑ ASD standards and Factory Testing

Electrical/Power Application Factors

- Continuous kW or HP & duty cycle
- Torque & Power Overload requirements
- Load factors: CT, VT, CHP, regenerative, non-regenerative.
- Drive and Motor Voltage
- Power system compatibility



#2 - Define the power system requirements

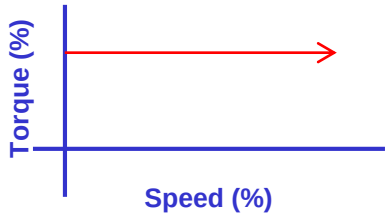
#3 – Determine best drive solution!

#1 - Define the process loads and duty cycle

Load Type Examples

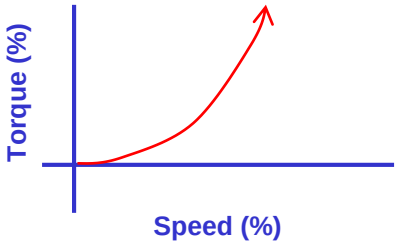
Constant Torque

- Conveyors
- Grinding Mills
- Kilns
- Reciprocating Compressors
- Positive Displacement [Screw Type] pumps, compressors



Variable Torque

- ID / FD Fans
- Centrifugal Pumps
- Centrifugal Compressors
- Pipeline booster pumps
- Axial Compressors



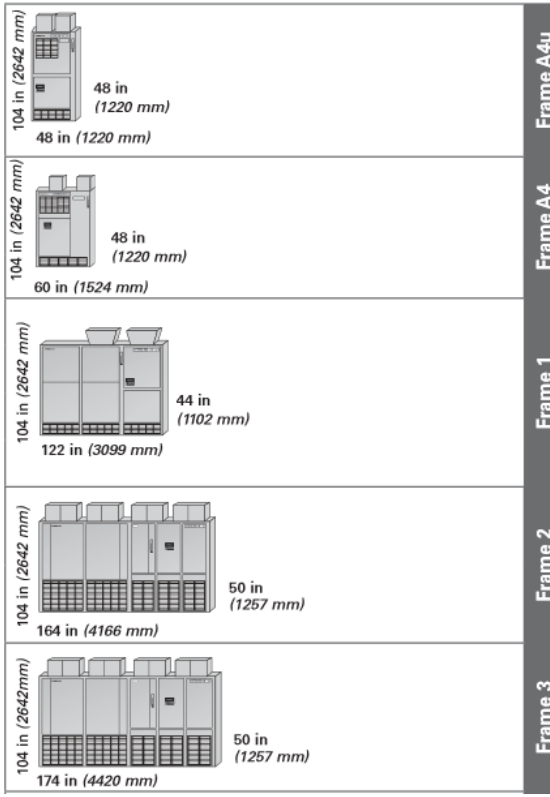
Keep In Mind

Drives are sized & priced based on Motor Full Load Current AND Operating Envelope

Example:

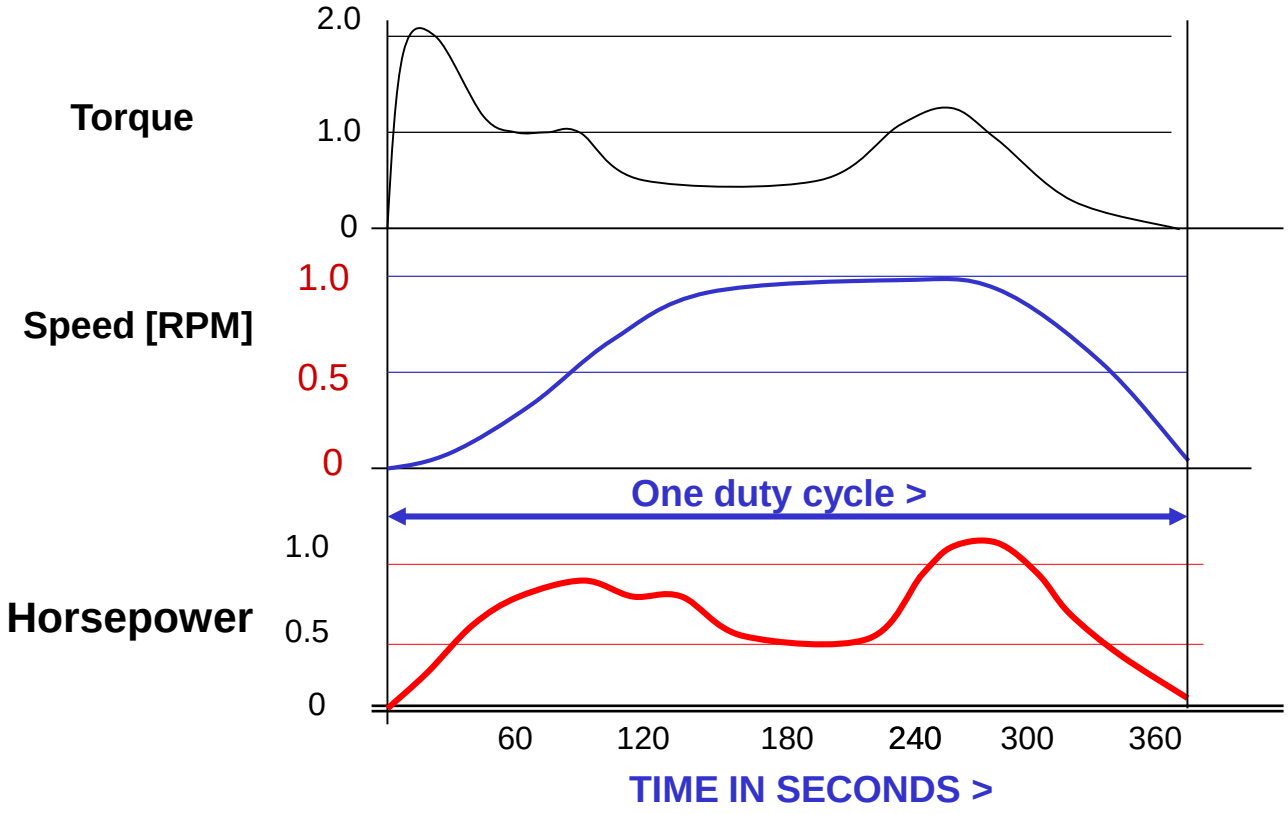
1. 7000 HP, 1800 rpm, 4000V, FLA 910A = 6300 kVA

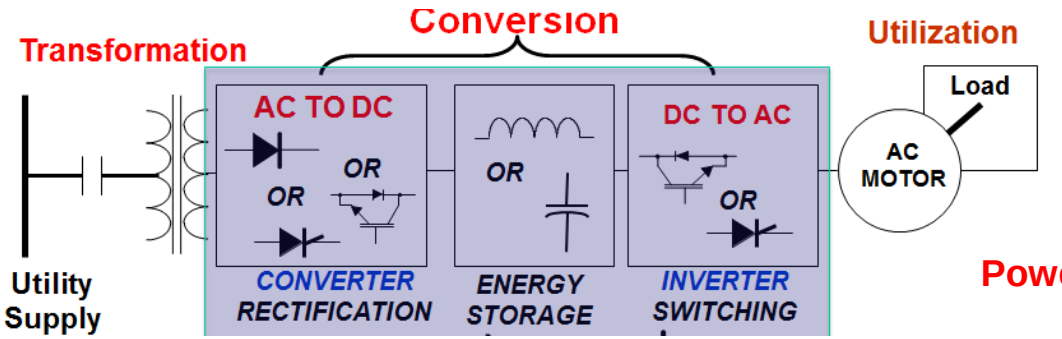
2. 7000 HP, 450 rpm, 4000V, FLA 1240A = 8600 kVA



	4000 Series 4160 Volts Out	
	Motor Shaft hp (kW)	Output Amps $I_{Phase}AC$
Frame A4μ	600 (448)	74
Frame A4	800 (599)	99
	900 (671)	112
	1000 (746)	124*
Frame 1	1000 (746)	124
	1250 (933)	155
	1750 (1306)	217
	2000 (1492)	248*
Frame 2	2250 (1679)	279
	2500 (1865)	310
Frame 3	3000 (2238)	372
	3500 (2611)	434

Lets take an example





Power = Speed x Torque

Drive Ratings and Torques

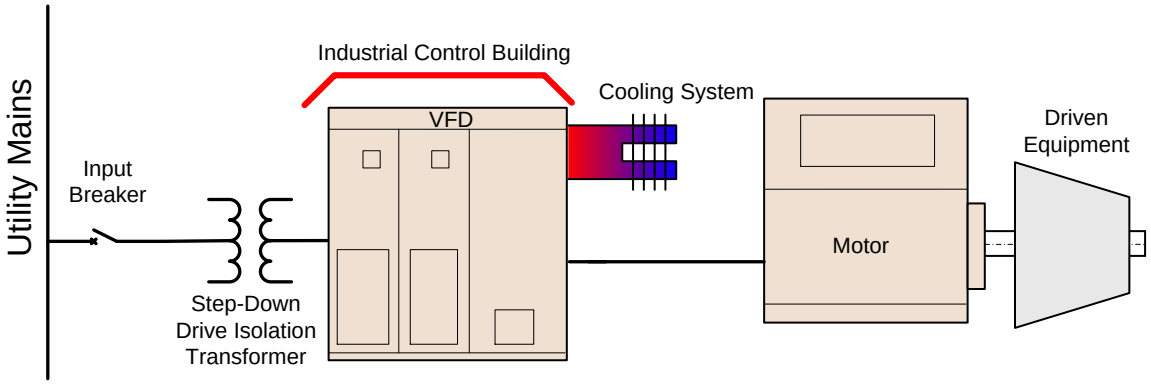
- Variable Torque (VT) ratings usually include 110 -115% OL rating for 60 seconds when starting from rated Temp

- Constant Torque (CT) rating usually includes 150% OL rating for 60 seconds when starting from rated Temp.

On Constant Torque applications, take a close look at the Speed Torque Curve for selecting the correct ASD size

Power System Compatibility

- Power distribution (available utilization voltages)
- Protection.
- Harmonics limits.
- Power factor control.
- Efficiency.



- Breakers, transformers, and cable must be rated to carry full kVA & harmonics.

- Transformers need to be “drive isolation” rated with proper considerations for the drive type.

Power system compatibility - Keep In Mind

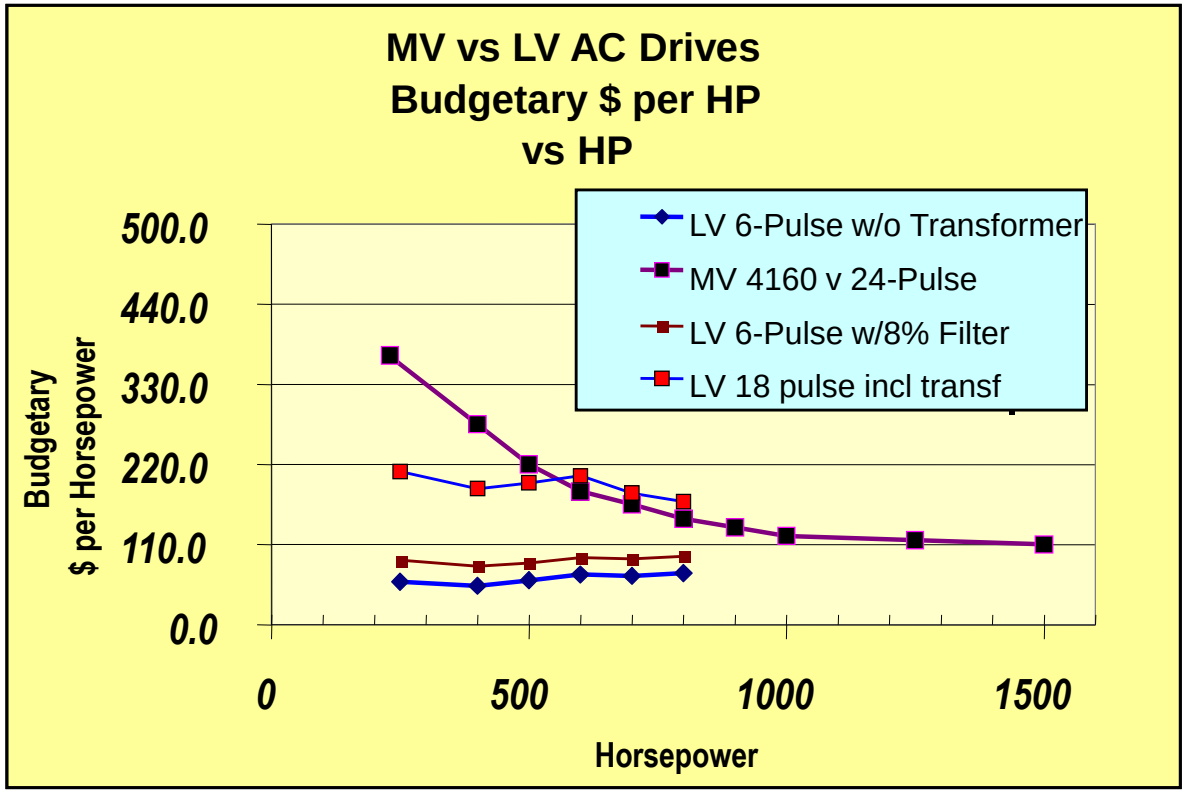
- Always provide and electrical one-line diagram
- Some tips for ASD voltage level selection

Motor Power	ASD Input Voltage	Motor Voltage
• 250HP – 5000HP	2.3, 4.16, 3.3, 6.6, 10, 11, 13.8 kV	2.3, 4.16, 3.3, 6.6, 10, 11 kV
• 5000HP – 10,000HP	4.16, 6.6, 10, 11, 13.8, 25, 34, 66 kV	Matched to ASD output voltage
• >10,000HP	10, 11, 13.8, 25, 34, 66, 110, 138 kV	Matched to ASD output voltage

Note: if ASD is used for starting ONLY, then
Motor Voltage = Utility Voltage (Max 13.8kV)

Medium voltage versus low voltage – what to use??

- MV drive $ / HP decreases with HP
- Installed cost must be considered including:-
  - Harmonic mitigation requirements
  - Cabling costs
  - Installation costs
  - Reliability



Drive Output Voltage & Motor Application

- Why Pick LV [<690v] Drive & Motor?
  - LV drives are lower cost / HP than MV
  - Reduces some safety & MV training concerns
  - HP range is small enough
  - Individual preference

- Why pick MV over LV?
  - Lower cost wiring, smaller cables
  - Lower power system harmonic impact
  - High HP LV require dual winding motors
  - Individual preference

Some MV vs. LV Conclusions

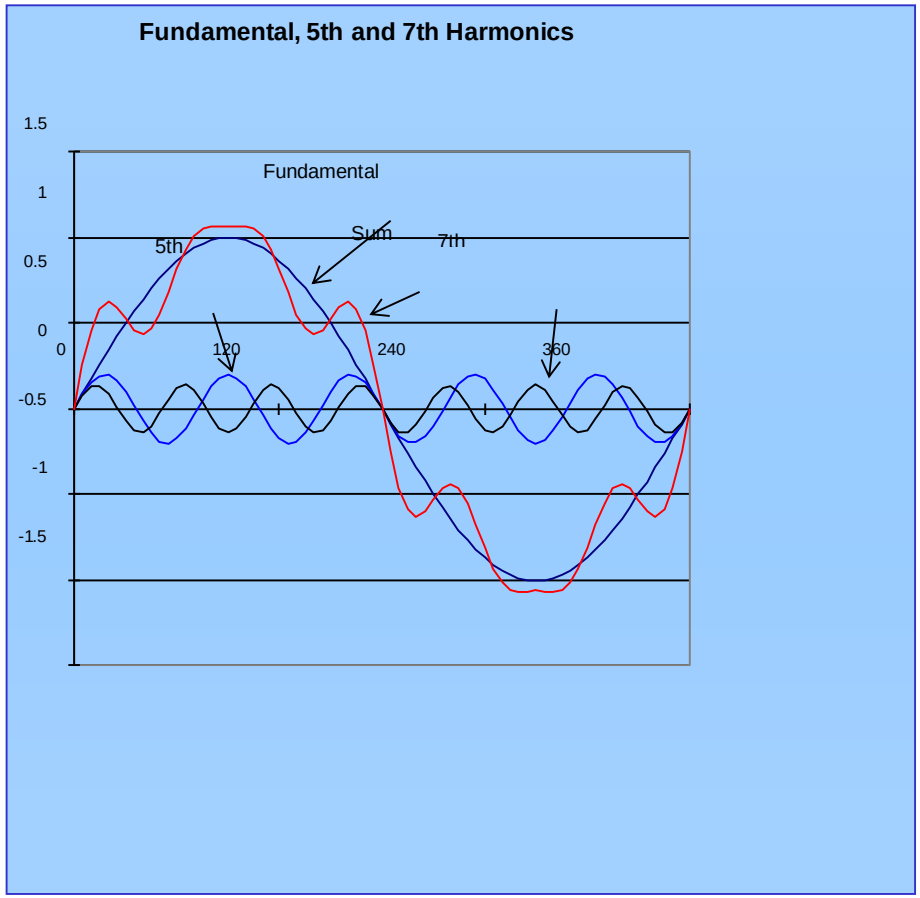
- For drives > 1000 HP, MV makes sense
- For long cable runs, MV makes sense
- For drives < 500 HP, LV makes sense.
- If low power system harmonics are required, LV filter or multi-pulse cost adders can favor MV over LV.
- In the range 500 to 1000 HP the various application & installation factors apply.

- Final choice may boil down to user preference.

Power Line Harmonics

- "Harmonics" are voltages and currents at frequencies that are multiples of utility power frequency.

- Harmonic currents are drawn by loads such as drives, computers and ballasts that take their power in non-sine-wave format. These are so-called non-linear loads.



IEEE 519-2014 Table 10.3 I_{TDD} Limits

Maximum Harmonic Curent Distortion in % of I-Load

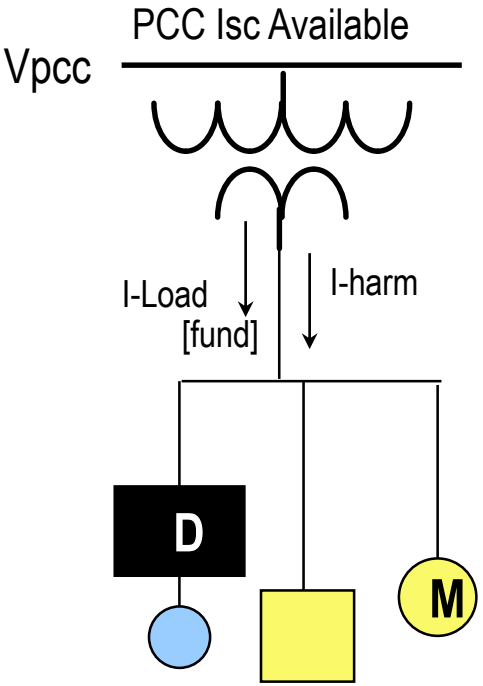
Isc to I-load Ratio	h < 11	h = 11 to <17	h = 17 to <23	h = 23 to <35	h = 35 & up	TDD %
< 20	4.0	2.0	1.5	0.6	0.3	5.0
20 < 50	7.0	3.5	2.5	1.0	0.5	8.0
50 < 100	10.0	4.5	4.0	1.5	0.7	12.0
100 < 1000	12.0	5.5	5.0	2.0	1.0	15.0
>1000	15.0	7.0	6.0	2.5	1.4	20.0

Notes: Even Harmonics limited to 25% of the harmonic level

TDD = Total Demand Disortion %, based on maximum demand current at the point of common coupling [PCC].

Isc = Maximum Short Circuit current or kVA at the PCC

I-load = Fundamental freqency load current or kVA at the PCC



Specifying a min. 24-Pulse VSI VFDs or Active Front End VFD is safest option for harmonic mitigation

Power System & Drive Efficiency

- Drive itself is typically 98% or more efficient
  - With all fans, transformers, pumps, etc, efficiencies of 96-97% are common
  - Efficiency impact of drive varies with speed

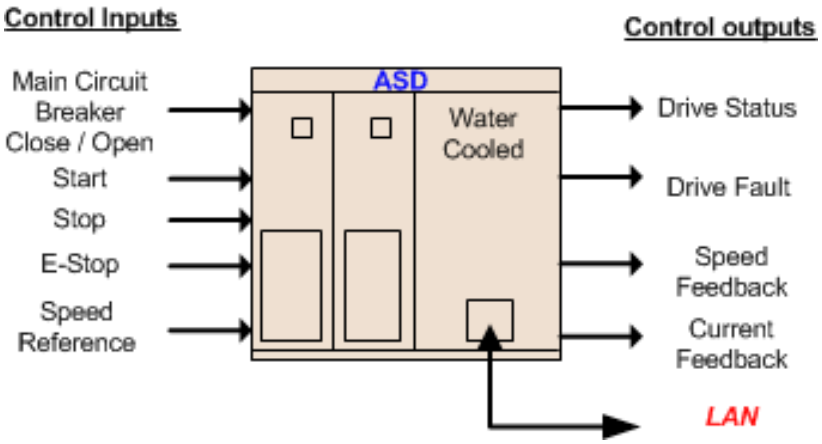
- Efficiency effect of the drive can be eliminated at full speed by synchronous bypass.

For Air-cooled Versus Water-cooled Overall system efficiency use:

92% for air-cooled (Includes VFD and E-house HVAC)
96% for water-cooled (Includes VFD and E-House HVAC)

Operator Control and Communication

- Interface with larger process
  - Controls for operator –
    - Simple start-stop contacts
    - More complex HMI
  - Process equipment controls – system PLC



- LAN communication of drive status if/as needed to plant PLC or DCS

- Plan for remote diagnostics capability

Drives function best when:

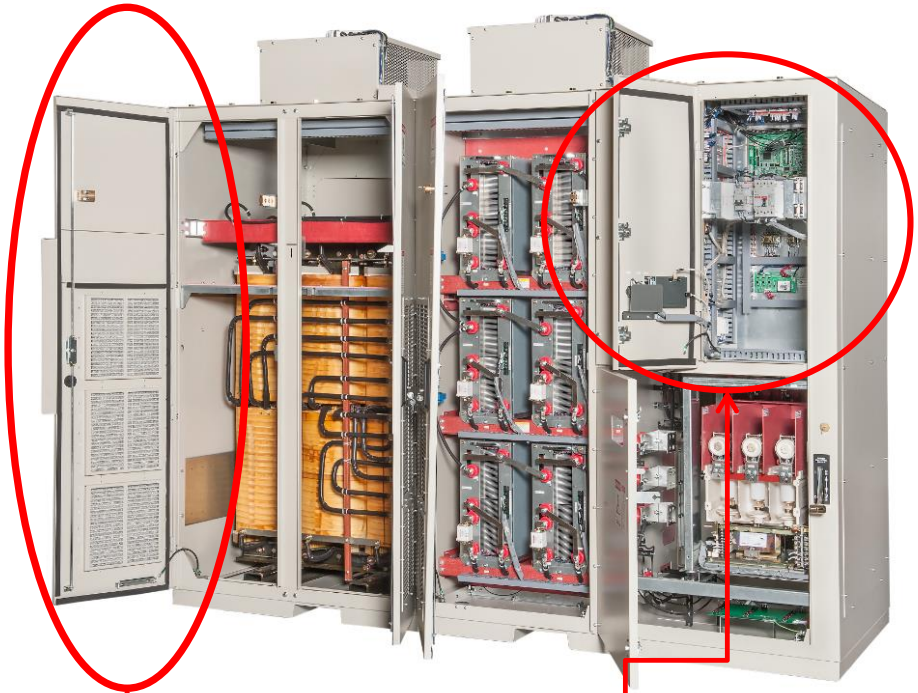
- Kept clean from dust, dirt & atmospheric contaminants
- Free from damaging moisture
- Operate within they rated ambient temperature & altitude ratings
- Properly connected & integrated into a reliable electrical system
- Integrated into the overall plant facility including proper site, equipment rooms, equipment handling
- **Properly stored BEFORE being installed**

Enclosures for VFDs

NEMA 1 (IP 20/21)	NEMA 3R (IP 23/33)	NEMA 12 (IP 51/52)
• Indoor Use • Protect from contact & falling dust • Force ventilated • Gasketed • All standard air/water cooled VFDs		

Enclosures for VFDs

NEMA 1 Gasketed enclosure



NEMA 1

Gasketed

NEMA 12

NEMA 3R Enclosure

Convection

cooling

Passive coo

Enclosure

- NEMA 1 air-cooled VFD's MUST be placed in climate controlled E-houses

- Special attention MUST be paid:
  - Air-cooled VFD's in dusty environments like rubber & cement plants.
  - Water cooled might be better option >4000HP
  - Corrosive environments where H2S might be present like water / chemical plants

- Cost basis of NEMA 1: NEMA 3R = 1 : 2.5.

- Follow manufacturer guidelines for air quality control requirements

Air Quality UL Pollution Degree 2. And Meet or Exceed: EN50178:1994 Section A.6.1.4 Table A.2 (m) IEC 529:1989-11 (IP20) (e) UL 508C	**Gas**: Maximum concentration of corrosive gases at 50% relative humidity and 40°C Sulfur Dioxide (SO_2) 30 ppb Hydrogen Sulfide (H_2S) 10 ppb Nitrous fumes (NO_x) 30 ppb Chlorine (Cl_2) 10 ppb Hydrogen Fluoride (HF) 10 ppb Ammonia (NH_3) 500 ppb Ozone (O_3) 5 ppb **Dust:** Particle sizes from 10 - 100 microns for the following materials Aluminum Oxide, Cement Ink, Sand/Dirt Lint, Steel Mill Oxides Coal/Carbon dust, Paper Soot

Enclosure

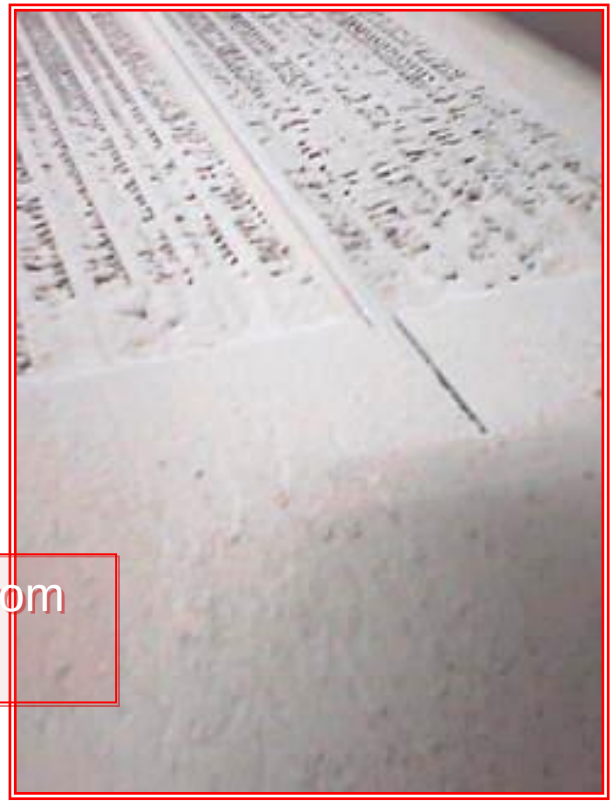
Filtered, pressurized room, caulking, extra filters…

Extra filters with Velcro…

Slide

Dust!

Some time later!



There are lots of ways to run from dust, but you can't hide!

Atmospheric & impinging moisture

- NEMA-1 or 1A indoor rated drives need to be kept dry – even during storage

- Protect from condensing moisture
  - Happens when equipment temp is below dew point
  - Prevented by space heaters and dry equipment rooms
  - Can precipitate misoperation or failures

- Prevent or protect against dripping moisture [enclosure design, drip shields].

Slide

Storage & running

Drip Shield – just in case!

Space heaters for storage

ASD Operational / Environmental limitations

- Altitude: De-rate current rating 2-3% per 1000 ft above 3000 feet. May have to de-rate voltage for very high altitudes.

- Temperature De-rate: 1.5% per degree C above base rating (usually 40C) up to max (usually 50 C).

Operation

- 0 to 40 or 50 C with a relative humidity of 95% maximum, non-condensing.
- VFDs are very sensitive to moisture due to high voltage potential

Storage

- Equipment is generally designed for a non-operating (storage) temperature range of –25 C to 70 C.

Use of cabinet space heaters is recommended and a MUST for operation at sub zero temperatures.

ASD Solutions

- Recommend to put NEMA 1 enclosure ASD's in a temperature controlled E-house or MCC building

- ASD's could also be placed in non-temperature controlled environment, but might need to de-rate the VFD → possible in water/wastewater, recreational or non-dusty applications

ASD Solutions

ICB / PCR for Starting Duty VFD

Low Capacity ACU

ICB / PCR for 5000 HP VFD

Redundant ACU

Specifying E-houses – Key to reliability

- Good standard to use is PIP ELSSG11, Electrical power center specification

If End User / EPC / OEM is supplying the ASD building

ASD Vendor to supply:-

Heat Dissipation in kW
Max. ASD Operating Temp.
ASD Humidity
Weights & Dimensions
Air-flow requirements

Outline ultimate responsibility of the entire system

If End User / EPC / OEM splits the scope of building and ASD

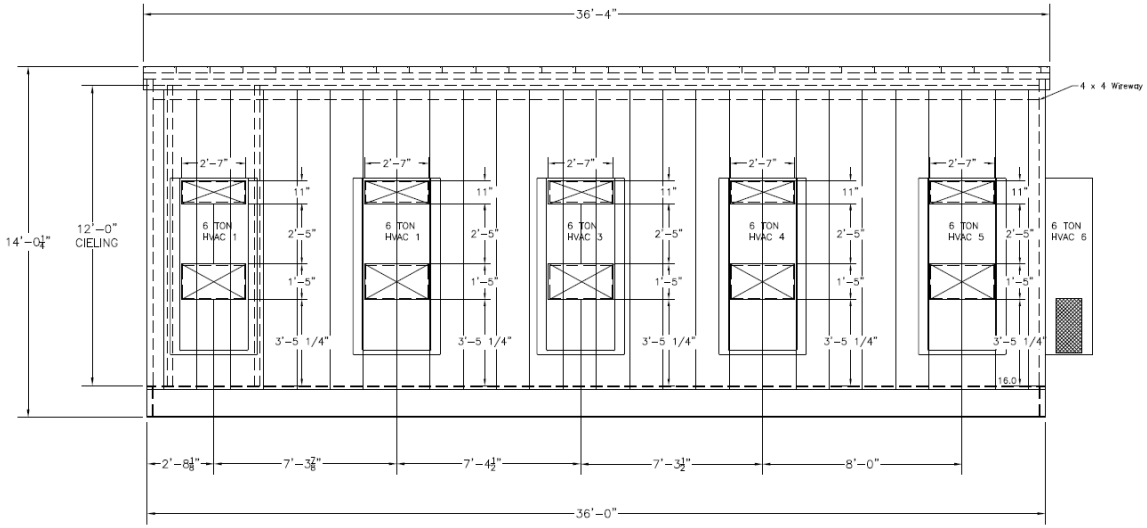
ASD Vendor ⟷ Building Vendor

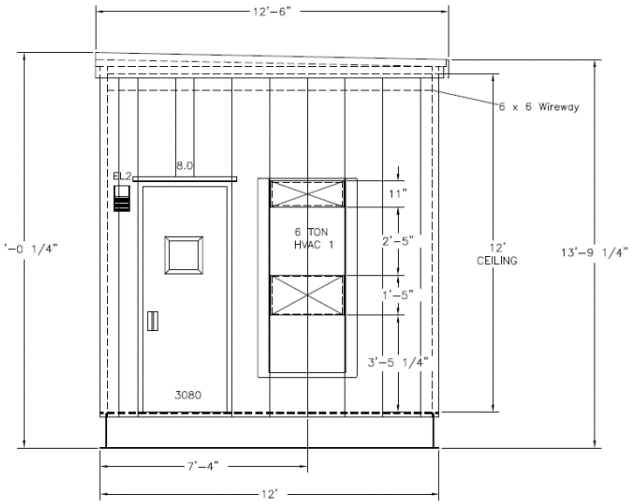
Heat Dissipation in kW
Max. ASD Operating Temp.
ASD Humidity & Air Quality Req.
Weights & Dimensions
Air-flow requirements
Clarify responsibility ASD hook-up, plumbing, wiring, check-out

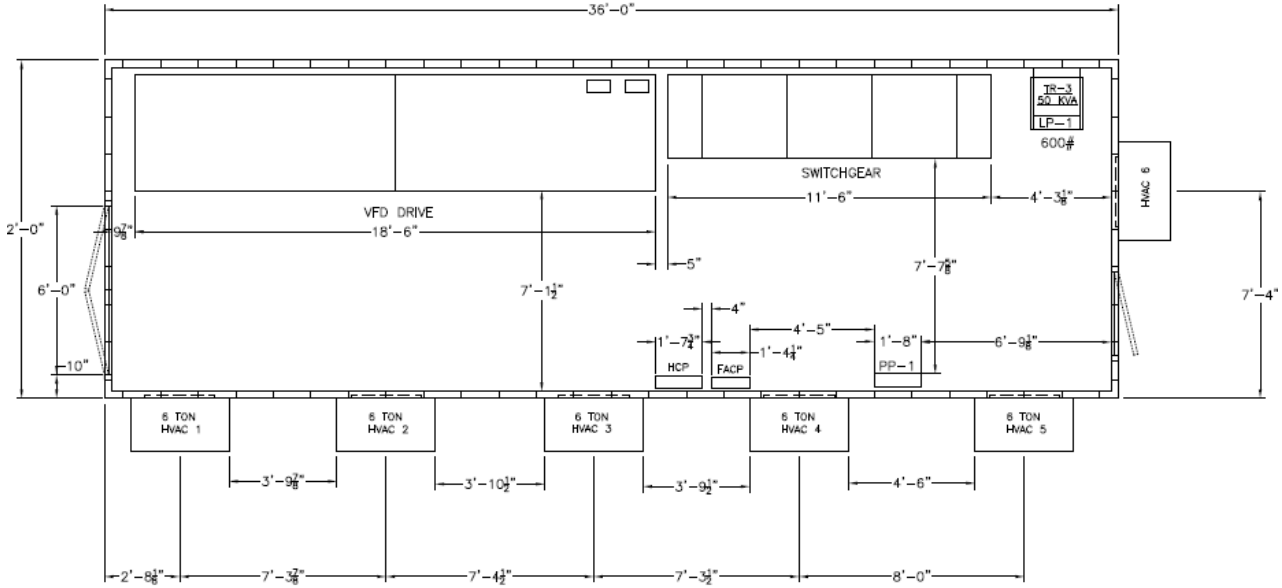
E-house requirements

- Minimum requirements for ASD E-houses are:-
  - E-House NEMA rating, Typically 3R
  - Fire/Smoke detection
    - Note: Fire suppression is usually not provided and is optional (like FM200 waterless suppression)
  - N+1 HVAC based on ASD heat loss
  - 480V, 120V Panel boards for lights, control, ASD Aux
  - Bus Ducts or cable trays
  - PE stamp, certifications (if any), access restrictions
  - Local codes. Default is NEC
  - Location of E-house final destination – For E-house estimating shipping splits

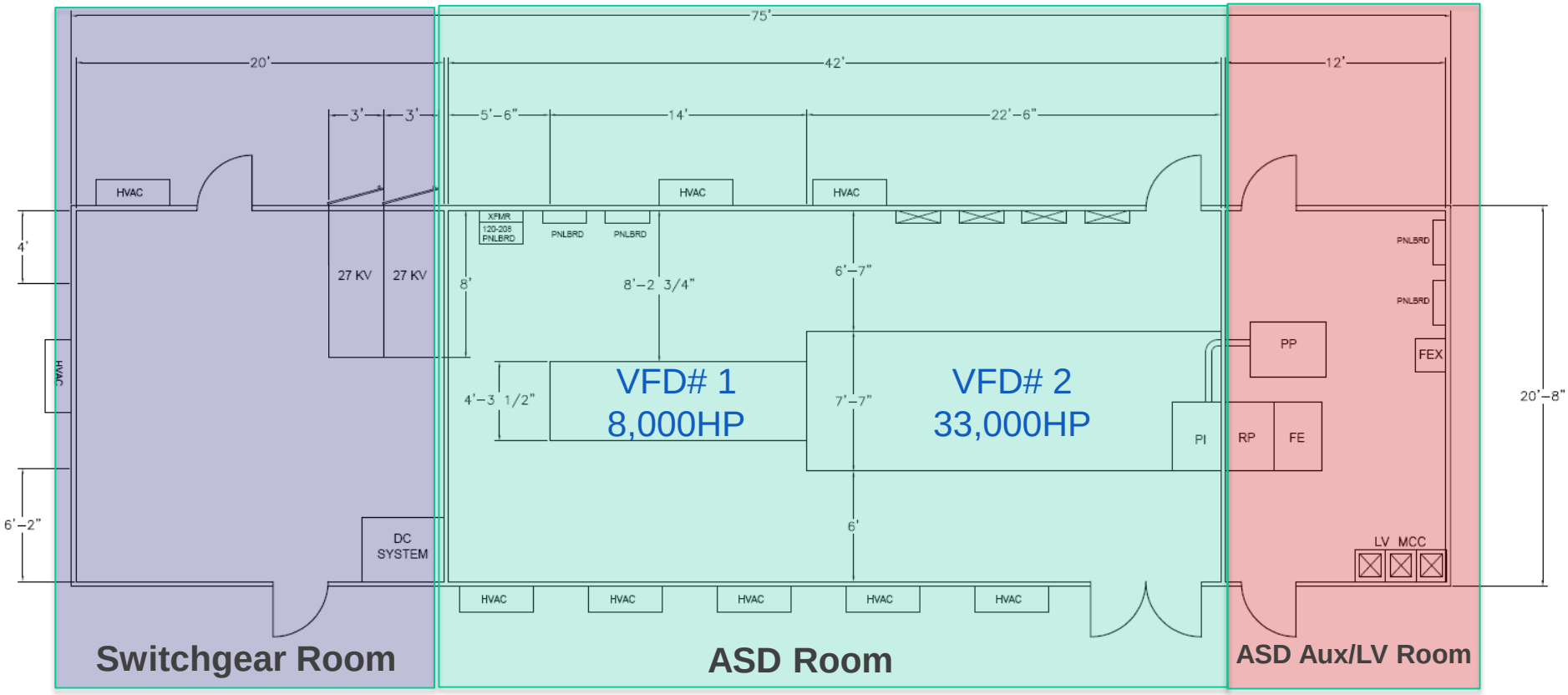
Sample E-house layouts







Sample E-house layouts



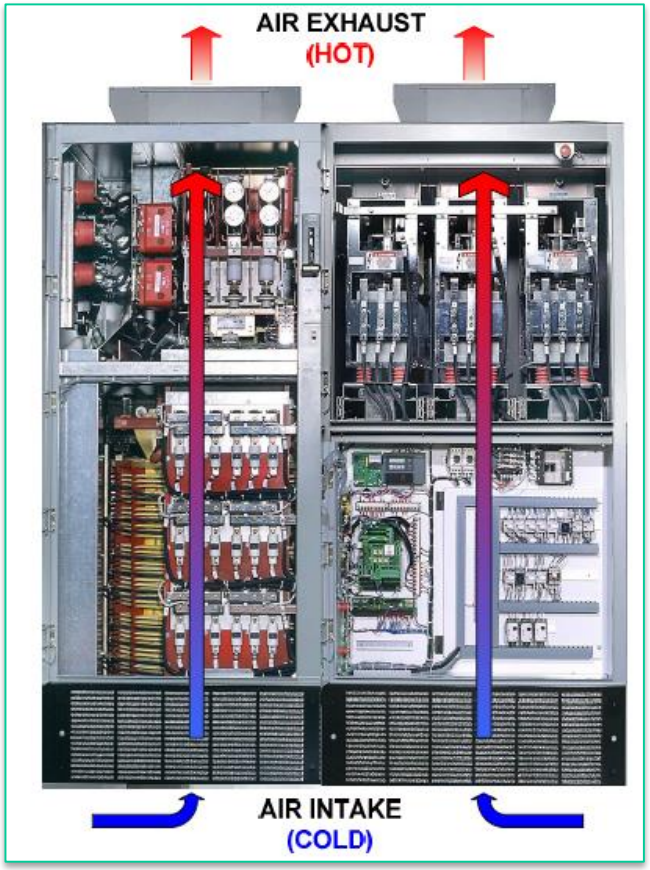
Preferable for ASD vendor to take responsibility of E-house specially for large ASDs

Temp. Controlled E-house versus ducting air out

- Many clients ask if they can duct-out hot air from the ASD to save on HVAC building
- YES, **but:-**
  - Make-up air must be provided: ~4500CFM to 17,000CFM
  - Air must be scrubbed off moisture content, fine dust, hazardous gases and other contaminants
  - Air must be heated if temperature gets to sub-zero. Big air heaters required
  - ASD might need to be de-rated for hot ambient conditions
  - Warranty might not be honored.
  - Installed / End user assumes all risk
  - Usually not suitable for very low/high ambient, high humidity, dusty or areas where gas might be present.

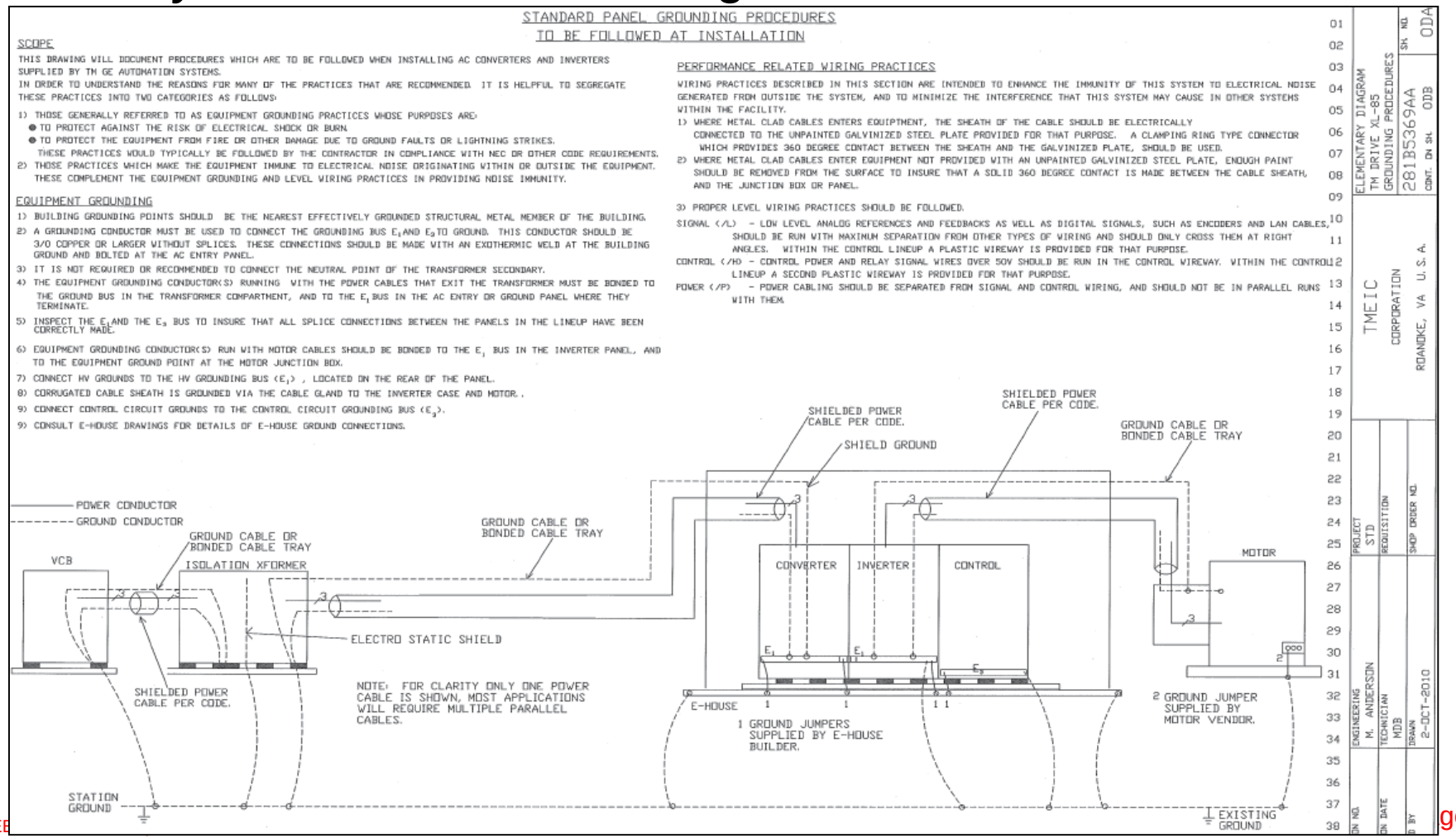
How Air Cooling Works?

- The most basic form of cooling
- Uses industrial fans
- Cool air suction from front or bottom and exhaust hot air to top or back
- ASD uses washable aluminum filters to keep dust out.



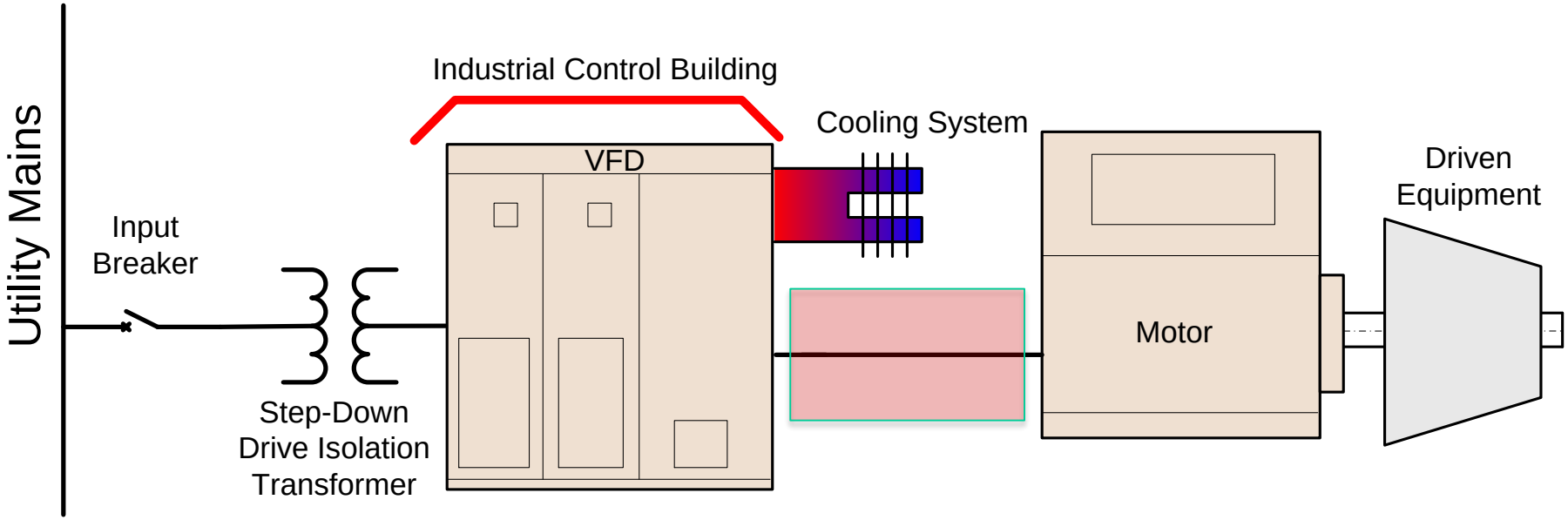
Installation area: Grounding

- ASD must be solidly grounded to facility system ground
- Looping or series installation of ground is NOT permitted
- Always follow manufacturer guidelines



Installation area: Cables From ASD to Motors

- Drives themselves are usually tolerant of most cable types & methods
- BUT, Cabling affects EMI radiation or motor.
- Cables > 500 meters need special attention [cable capacitance]

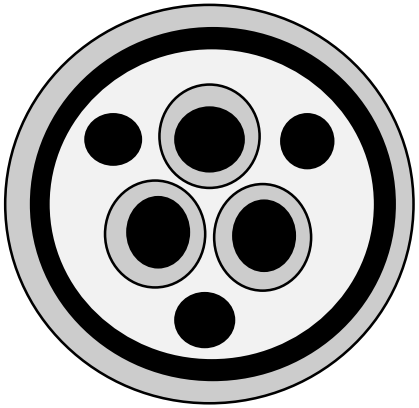


“Most Ideal” Cable for PWM Inverter Use

- **Most critical for LV drives, much less critical for MV Drives**

- **Continuous, Corrugated, welded aluminum armor, with 3 symmetrical ground conductors.**
  - **Minimizes EMI / Radiated noise**
  - **Minimizes common mode volts at bearings**

- **Example PWM cable manufacturers:**
  - LV - Annixter/BICC “Philsheath”
  - LV- Rockbestos Supernant “Gardex CC”
  - MV – Okonite C-L-X Type MV-90 or MV-105
  - MV – Amercable MM-VFD – More flexible – Bronze armor shield



First Choice

3 Phase Conductors

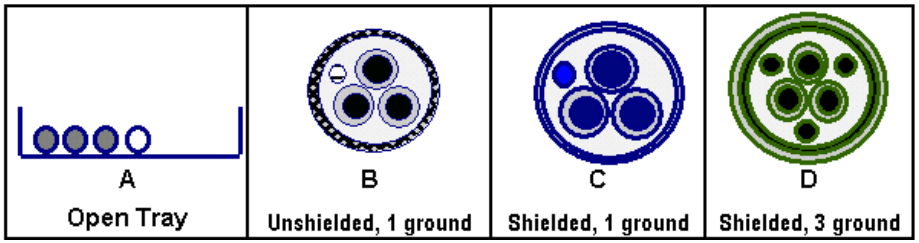
3 Symmetrical Grounds

1 Overall Shield/Armor

Motor-Drive Cable Methods And Tradeoffs

		Relative Performance Area		Usefulness by Drive Type			
Ref	Cable Type or Method	EMI Propagation & Cross-Talk from PWM	Minimizing Bearing Voltages & Currents	2-Level < 690 volts	3 Level, NPC*	5 level or More, NPC*	Comments
A	**Open Tray, individual conductors**	Poor	Poor	**Not recommended**	Marginally acceptable	Marginally acceptable	**Use caution** by separating other conductors from inverter to motor cables by 300 MM [12 inches] or more
B	**3-conductor unshielded with 1 ground**	Poor	Better	**Not recommended**	Acceptable	Acceptable	**Use caution** by separating other conductors from inverter to motor cables by 300 MM [12 inches] or more
C	**3-conductor shielded with 1 non-centered ground.**	Good	Better	Marginally acceptable	Acceptable	Good	Shield should be grounded at both drive power-common and motor frame
D	3-conductor shielded with 3 symmetrical grounds, continuous extruded aluminum armor	Good	Good	Good	Good	Good	Shield should be grounded at both drive power-common and motor frame

* NPC = Neutral Point Clamped Inverter Power Circuit



Cable Sample Recommendations

CABLE RECOMMENDATIONS FOR POWER CABLING RATED 2000VAC OR ABOVE.

SELECTION AND TERMINATION OF POWER CABLING IS CRITICAL TO THE SAFE AND RELIABLE OPERATION OF THIS SYSTEM. ISSUES WITH RADIATED ELECTRICAL NOISE, DISRUPTIVE GROUND CURRENTS AND SAFETY ALL HAVE ROOTS IN POWER CABLING SELECTION AND TERMINATION. THESE RECOMMENDATIONS COMPLY WITH THE REQUIREMENTS OF THE NATIONAL ELECTRIC CODE OF THE USA. IT IS THE RESPONSIBILITY OF THE INSTALLER TO INSURE THAT LOCAL CODES ARE FOLLOWED WHERE THEY CONFLICT WITH THESE RECOMMENDATIONS.

SELECTION:

RECOMMENDED FOR INVERTER OUTPUT IS OKONITE OKOGUARD OKOSEAL TYPE MV-105 P/N 115-23-3816.

CONVERTER INPUT DOES NOT REQUIRE MC TYPE CABLE OR SYMMETRICAL GROUNDS. HOWEVER, SHIELDED POWER CABLE SHOULD BE USED PER NEC GUIDELINES. SEE FIGURE 2. CONVERTER CABLE INSULATION LEVEL SPECIFIED SHOULD BE EQUAL TO OR HIGHER THAN 8.2KV.

TERMINATION AT THE MOTOR OR TRANSFORMER:

WHERE MC CABLES ARE USED, FITTINGS SHOULD BE USED TO INSURE THAT THERE IS A 360 DEGREE ELECTRICAL CONNECTION BETWEEN THE ALUMINUM SHIELD AND THE JUNCTION BOX. ANY GROUND CONDUCTORS SHOULD BE TERMINATED TO THE EQUIPMENT GROUNDING LUG PROVIDED FOR THAT PURPOSE. INDIVIDUAL CONDUCTORS SHOULD BE CONNECTED USING COMPRESSION LUGS.

TERMINATION AT THE INVERTER OR CONVERTER:

IT IS NECESSARY TO REMOVE ENOUGH CABLE SHIELD AND PHASE CONDUCTOR SHIELD SO THAT INDIVIDUAL PHASE CONDUCTORS CAN REACH FROM THE POINT THE CABLE ENTERS THE EQUIPMENT CABINET, TO THE AC CONNECTION POINTS OF THE INVERTER OR CONVERTER. ONCE THE SHIELD HAS BEEN REMOVED, FITTINGS SHOULD BE USED, TO INSURE THAT THERE IS A 360 DEGREE ELECTRICAL CONNECTION BETWEEN THE ALUMINUM SHIELD AND THE CABINET GROUND (MC TYPE CABLE). GROUND CONDUCTORS SHOULD BE CONNECTED TO THE E1 GROUND BUS PROVIDED FOR THAT PURPOSE. PHASE CONDUCTORS SHOULD BE CONNECTED ACCORDING TO THE EQUIPMENT DRAWINGS. ALL CONDUCTORS SHOULD BE TERMINATED WITH COMPRESSION LUGS.

SHIELDED CABLES MAY BE RUN IN CLOSE PROXIMITY TO OTHER SHIELDED POWER CABLES, SO FAR AS ELECTRICAL COUPLING IS CONCERNED. RULES REGARDING SPACING FOR THERMAL REASONS MUST BE RESPECTED.

NOTE: CUSTOMER REQUIREMENT

ALL CABLES RATED AT OR ABOVE 2000V SHALL USE STRESS RELIEF CONES.

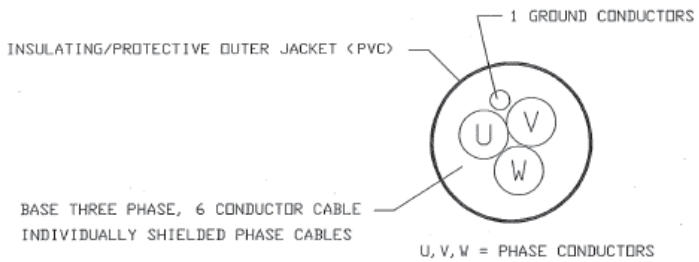


FIGURE 1: OKONITE OKOGUARD OKOSEAL TYPE MV-105 RECOMMENDED FOR INVERTER OUTPUT

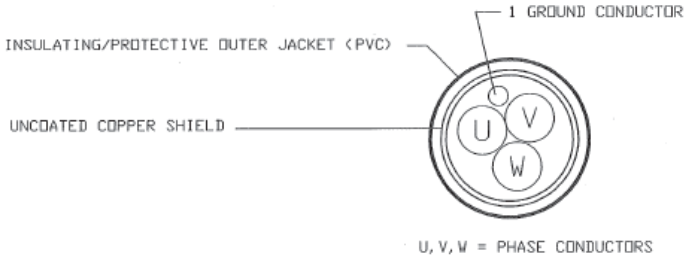


FIGURE 2: THREE PHASE SHIELDED CABLE WITH GROUND. RECOMMENDED FOR CONVERTER INPUT

ELEMENTARY DIAGRAM
TM DRIVE XL-85
CABLING RECOMMEND
281B5369AA
CONT. ON SH. OF A
TMEIC
CORPORATION
ROANOKE, VA U.S.A.
PROJECT STD
REQUISITION
SHOP ORDER NO.
ENGINEERING M. ANDERSON
TECHNICIAN
DRAWN 2-OCT-2010

Cable Sample Recommendations

Power Cable with armor and fittings

Control Connections [bottom picture]

Segregated by voltage level

Segregated by signal type

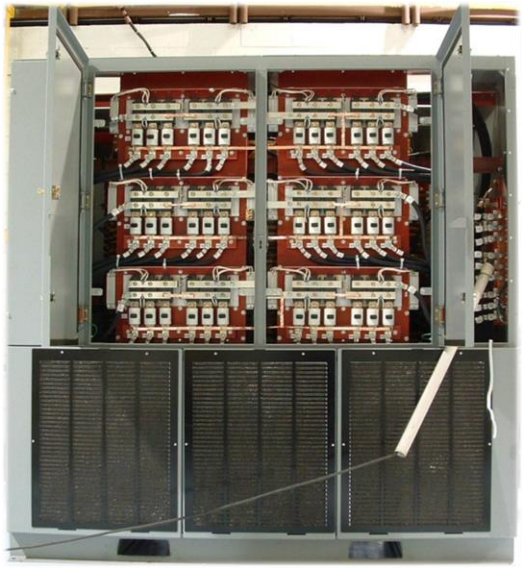
Other installation considerations

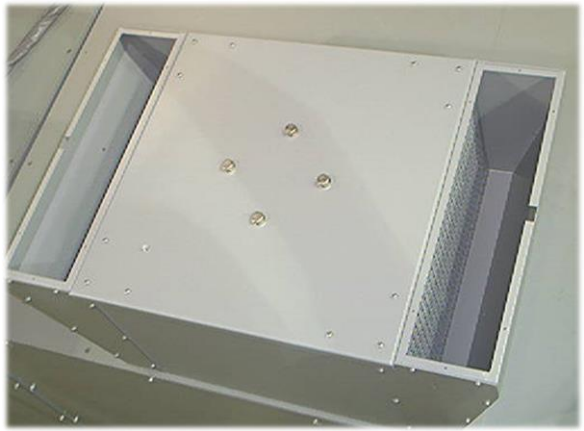
- Foundation Plans
  - Pads for transformers and switchgear
  - Pads or columns for Equipment houses
  - Transformer represents 75% of the weight
- Off loading equipment
  - Cranes, fork-trucks
- Personnel protection
  - Fences, signs, railings
  - Training

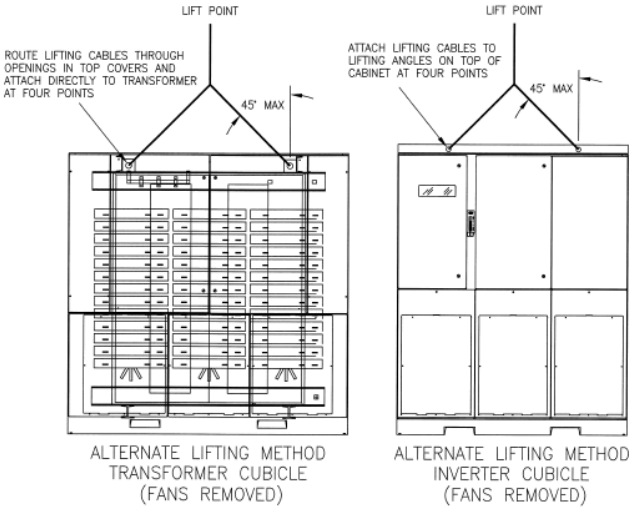
Max HP	Drive Weight in Pounds
1000	7500
2000	11500
It is 2500	18000
3500	22500
6000	35000

Equipment handling

- ASDs are shipped in splits & pieces
- Major shipping items include:
  - Transformer section
  - Power conversion/control section
  - Fan assemblies
  - Filter panel (if provided)
  - Power inverter modules (for larger drives)

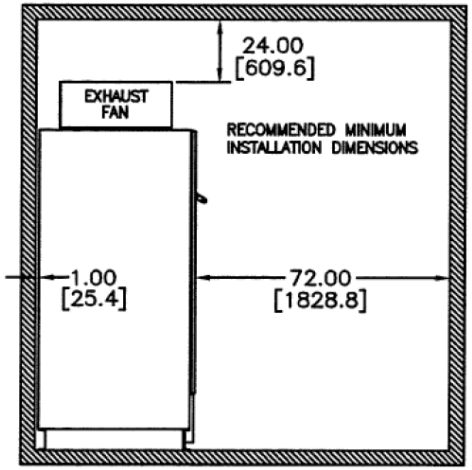






Final ASD location

- Location must allow for ASD maintenance access
- Must also meet required NEC code & other electrical codes
- Also account for:
  - Enclosure for door swing and clearance
  - Clearance allowance for power modules & component removal
  - Clearance for lifting equipment, ramps, etc
  - Cable bending radius
  - Top or bottom entry



INSTALLATION DETAIL

Where can I find ASD installation details

Finding installation details

- High level in Commercial Quotations
- ASD brochure
- Representative Elementary drawings
- Final ASD drawings

Please ask any and every installation question that your might have

Questions?

The Curse of Knowledge