Lunch & Learn Meeting

Fundamentals & Application of Medium Voltage Adjustable Speed Drives (ASD)

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TMEIC

IEEE IAS Atlanta Chapter
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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
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Service types</td>
<td>Rotating machinery such as pumps, compressors, extruders, fans, blowers, etc.</td>
</tr>
<tr>
<td>Power Level (HP)</td>
<td>500HP – 130,000HP</td>
</tr>
<tr>
<td>Voltage range (kV)</td>
<td>Medium Voltage, &gt; 1.0 kV</td>
</tr>
</tbody>
</table>
Typical Motor Starting Characteristics

![Graph showing motor speed, current, and torque characteristics](image-url)
Why is starting large motors stressful?

- Highest current is seen when shaft is still
- Starting currents create stresses and torques that can damage motor and attached load
- The motor and the load must breakaway and accelerate
- Remember current equals heat!

**Power System Challenge**

- Balance allowed inrush amps with Voltage drop
- Balance power system effects with torque demand of load
Motor Speed Control Strategies

Available Motor Speed Control Methods

Direct-On-Line (DOL)  Other Mech. Methods  Adjustable Speed Drives (ASD)

Constant Utility Frequency (50 or 60Hz)

Adjust Frequency


What is an ASD?

Transformer

Utility Supply

Fixed Voltage

Fixed Frequency

Conversion

Energy Storage

AC TO DC

Converter Rectification

DC TO AC

Inverter Switching

Load

AC Motor

Utilization

Var. Voltage

Var. Frequency

Industrial Control Building

Cooling System

VFD

Drive Isolation Transformer

Step-Down

Input Breaker

Utility Mains
What is an ASD? – Other common terminology

**Transformation**

Utility Supply

**Conversion**

AC TO DC

**Converter Rectification**

DC TO AC

**Inverter Switching**

Energy Storage

**Output Voltage Levels / Steps**

(higher the better, min 5-level from 0-Peak)

**Utilization**

Load

**Pulses (DFE)**

Harmonic performance equivalent (AFE)

Voltage

Time
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
What do we mean by “Medium Voltage ASD”

- Medium Voltage drives range from 2300V – 13800V.
- Voltage defined at output.
- Input voltage to the VFD between 2.3kV – 138kV

**ASD = VFD = EVFD = VVVF** (can be used interchangeably)
Typical Range of ASDs

Motor Horsepower (HP)

ASD Output Voltage (V)

Air Cooled

Water Cooled
Single VFD / single motor

<table>
<thead>
<tr>
<th>Simple Electrical One-line</th>
<th>Voltage Level Scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>Utility -&gt; Bypass -&gt; VFD</td>
<td>Utility = VFD</td>
</tr>
<tr>
<td></td>
<td>VFD = Motor</td>
</tr>
<tr>
<td>Utility -&gt; Bypass -&gt; VFD</td>
<td>Utility &gt; VFD</td>
</tr>
<tr>
<td></td>
<td>VFD = Motor</td>
</tr>
<tr>
<td>Utility -&gt; Bypass -&gt; XFMR</td>
<td>Utility = VFD</td>
</tr>
<tr>
<td></td>
<td>VFD ≠ Motor</td>
</tr>
</tbody>
</table>
Multi drive – Multi Motor

Utility Voltage bus 4.16kV

- DB-5i
- PLC Coordination & Interface
- VFD Bus

7500HP

Incoming Switch

Synchronized Bypass

MPR

Aux ct

DB-5i

7500HP

7500HP

7500HP

7500HP

Synchronized Bypass

Bypass Bus

7500HP

7500HP

7500HP

7500HP
Historical Overview

Transistor Family

- Bipolar Power Transistor (BPT)

Thyristor Family

- Silicon Controlled Rectifier (SCR)
- Gate Turnoff Thyristor (GTO)
- Integrated Gate Commutated Thyristor (IGCT)
- Symmetric Gate Commutated Thyristor (SGCT)

Low Voltage Insulated Gate Bipolar Transistor (LV IGBT)
Medium Voltage Insulated Gate Bipolar Transistor (MV IGBT)
Injection Enhanced Gate Transistor (IEGT)

Time Line of Adjustable Speed Drives

- DC Motor Drives
- Synchronous Motor Drives
- Induction Motor Drives
- Ind/Synch Motor Drives
ASD Topologies

• AC Drive Topology:
  
  *A map-like diagram showing the elements of an AC drive and the relationships between them.*

• The Common Threads:
  
  - All AC Drives *rectify AC to DC.*
  - All AC Drives *use switches to create AC from DC.*

• Drive *topologies* were created as power rectifiers and switches grew in ratings and capabilities.

• Each new or uprated device opens up new applications
Major ASD Topologies

**Voltage Source Inverters (VSI)**

- Energy storage/DC Link is **Capacitor**
- Maintains constant Voltage at DC Link
- Converter (AC/DC) is either Passive (using diodes) or Active (using PWM)

**Current Source Inverters (CSI)**

- Energy storage/DC Link is **Inductor**
- Maintains constant current at DC Link
- Converter (AC/DC) is Active (using phase control or PWM)
Comparing Drives of All Topologies

• Current Source Drives
  • LCI – Load Commutated Inverter
  • GTO/SGCT Current Source Induction Motor Drive

• Voltage Source Drives
  • LV IGBT “Paice” Multilevel PWM
  • MV IGCT PWM – Diode or Active Source/Converter
  • MV IGBT PWM – Integrated package
  • MV IEGT PWM – Active or Diode Source/Converter

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 following:

- 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

1. Define the process loads and duty cycle
2. Define the power system requirements
3. Determine best drive solution!
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
Let's take an example

<table>
<thead>
<tr>
<th>Torque</th>
<th>Speed [RPM]</th>
<th>Horsepower</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.0</td>
<td>1.0</td>
<td>0.5</td>
</tr>
<tr>
<td>1.0</td>
<td>0.5</td>
<td>0.0</td>
</tr>
<tr>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

TIME IN SECONDS >

ONE DUTY CYCLE:

\[ \text{Power} = \text{Speed} \times \text{Torque} \]

Transformation

Conversion

Utilization

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

<table>
<thead>
<tr>
<th>Motor Power</th>
<th>ASD Input Voltage</th>
<th>Motor Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>250HP – 5000HP</td>
<td>2.3, 4.16, 3.3, 6.6, 10, 11, 13.8 kV</td>
<td>2.3, 4.16, 3.3, 6.6, 10, 11 kV</td>
</tr>
<tr>
<td>5000HP – 10,000HP</td>
<td>4.16, 6.6, 10, 11, 13.8, 25, 34, 66 kV</td>
<td>Matched to ASD output voltage</td>
</tr>
<tr>
<td>&gt;10,000HP</td>
<td>10, 11, 13.8, 25, 34, 66, 110, 138 kV</td>
<td>Matched to ASD output voltage</td>
</tr>
</tbody>
</table>

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

Recent Trend: Some users select MV >250 HP
Many users select MV > 500 HP.
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.
### Maximum Harmonic Current Distortion in % of I-Load

<table>
<thead>
<tr>
<th>Isc to I-load Ratio</th>
<th>h &lt; 11</th>
<th>h = 11 to &lt;17</th>
<th>h = 17 to &lt;23</th>
<th>h = 23 to &lt;35</th>
<th>h = 35 &amp; up</th>
<th>TDD %</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 20</td>
<td>4.0</td>
<td>2.0</td>
<td>1.5</td>
<td>0.6</td>
<td>0.3</td>
<td>5.0</td>
</tr>
<tr>
<td>20 &lt; 50</td>
<td>7.0</td>
<td>3.5</td>
<td>2.5</td>
<td>1.0</td>
<td>0.5</td>
<td>8.0</td>
</tr>
<tr>
<td>50 &lt; 100</td>
<td>10.0</td>
<td>4.5</td>
<td>4.0</td>
<td>1.5</td>
<td>0.7</td>
<td>12.0</td>
</tr>
<tr>
<td>100 &lt; 1000</td>
<td>12.0</td>
<td>5.5</td>
<td>5.0</td>
<td>2.0</td>
<td>1.0</td>
<td>15.0</td>
</tr>
<tr>
<td>&gt;1000</td>
<td>15.0</td>
<td>7.0</td>
<td>6.0</td>
<td>2.5</td>
<td>1.4</td>
<td>20.0</td>
</tr>
</tbody>
</table>

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

**TDD** = Total Demand Distortion %, 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 frequency load current or kVA at the PCC

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**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)
Speed & Torque Control Requirements

• Each application is unique
  - Simple, free-standing pumps
  - Complex – e.g. sync to utility, multiple motors per drive, multiple drives on same load

• Process control – usually 4-20 mA for speed

• Go Tachless if possible
  - Precise speed control rare with MV drives and high kW level drives
  - High load torques (>150% OL) may require tachometer
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
Drive Design For Reliability

- Minimum parts – fewest power components, and simplest firing circuits
- No “Weak links” like marginally rated capacitors, switching devices, etc
- Conservatively rated, fully qualified components
  - Quality built in not “burn-in tested”
  - Quality tracked
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).

- Drives put out heat – must be removed or vented to outside

- ASDs are designed to be installed in a relatively clean, dry environment

Operation
  - 0 to 40 or 50 C with a relative humidity of 95% maximum, non-condensing.

Storage
  - Equipment is generally designed for a non-operating (storage) temperature range of –25 C to 70 C.
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 & Air Quality Req.
  - Weights & Dimensions
  - Air flow requirement

Outline ultimate responsibility of the entire system

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

- ASD 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

- Building Vendor
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
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]
## Motor-Drive Cable Methods And Tradeoffs

<table>
<thead>
<tr>
<th>Ref</th>
<th>Cable Type or Method</th>
<th>Relative Performance Area</th>
<th>Usefulness by Drive Type</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>EMI Propagation &amp; Cross-Talk from PWM</td>
<td>Minimizing Bearing Voltages &amp; Currents</td>
<td>2-Level &lt; 690 volts</td>
</tr>
<tr>
<td>A</td>
<td>Open Tray, individual conductors</td>
<td>Poor</td>
<td>Poor</td>
<td>Not recommended</td>
</tr>
<tr>
<td>B</td>
<td>3-conductor unshielded with 1 ground</td>
<td>Poor</td>
<td>Better</td>
<td>Not recommended</td>
</tr>
<tr>
<td>C</td>
<td>3-conductor shielded with 1 non-centered ground</td>
<td>Good</td>
<td>Better</td>
<td>Marginally acceptable</td>
</tr>
<tr>
<td>D</td>
<td>3-conductor shielded with 3 symmetrical grounds, continuous extruded aluminum armor</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
</tr>
</tbody>
</table>

* NPC = Neutral Point Clamped Inverter Power Circuit

![Diagram of cable types]

- Open Tray
- Unshielded, 1 ground
- Shielded, 1 ground
- Shielded, 3 ground
The Curse of Knowledge