VFD Training
Training Agenda

1. Why use a VFD / Proper control of systems for efficiency
2. Using all VFD efficiency features
3. VFD theory of operation
4. Basic power structure
5. Installation requirements
6. Motor compatibility
7. VFD options
8. Enclosure types
9. BAS interface
10. Spare VFD’s?
<table>
<thead>
<tr>
<th>Centrifugal Fan &amp; Pump</th>
<th>Affinity Laws</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CFM</strong> $\propto$ <strong>Speed</strong></td>
<td>(1)</td>
</tr>
<tr>
<td><strong>Static Pressure</strong> $\propto$ <strong>Speed</strong>&lt;sup&gt;2&lt;/sup&gt;</td>
<td>(2)</td>
</tr>
<tr>
<td><strong>Torque</strong> $\propto$ <strong>Speed</strong>&lt;sup&gt;2&lt;/sup&gt;</td>
<td>(3)</td>
</tr>
<tr>
<td><strong>Horsepower</strong> $\propto$ <strong>Speed</strong>&lt;sup&gt;3&lt;/sup&gt;</td>
<td>(4)</td>
</tr>
</tbody>
</table>
Energy Requirements of Centrifugal Loads

% Speed of motor

% Rated HP

Cube Root Relationship

0% 20% 40% 60% 80% 100%

120%

100%

80%

60%

40%

20%

0%

0% 20% 40% 60% 80% 100%
Fan Power Consumption

ABB Drives
Example assumptions:

It is assumed that the drive is to operate 24 hours / day, 7 days / week and 52 weeks / year.

It will be assumed that the system requires a 100 Hp prime mover.
## Energy Analysis

Efficiency = power out / power in

<table>
<thead>
<tr>
<th>% Speed</th>
<th>% Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>93</td>
</tr>
<tr>
<td>90</td>
<td>92</td>
</tr>
<tr>
<td>80</td>
<td>89</td>
</tr>
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<td>70</td>
<td>87</td>
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<tr>
<td>60</td>
<td>81</td>
</tr>
<tr>
<td>50</td>
<td>70</td>
</tr>
<tr>
<td>40</td>
<td>50</td>
</tr>
<tr>
<td>30</td>
<td>32</td>
</tr>
</tbody>
</table>
The following duty cycle will be assumed:

<table>
<thead>
<tr>
<th>% Speed</th>
<th>% Time</th>
</tr>
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<tbody>
<tr>
<td>100</td>
<td>2.5</td>
</tr>
<tr>
<td>90</td>
<td>7.5</td>
</tr>
<tr>
<td>80</td>
<td>10</td>
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<tr>
<td>70</td>
<td>15</td>
</tr>
<tr>
<td>60</td>
<td>22</td>
</tr>
<tr>
<td>50</td>
<td>22</td>
</tr>
<tr>
<td>40</td>
<td>21</td>
</tr>
</tbody>
</table>

ABB Drives
Typical VAV System Duty Cycle
<table>
<thead>
<tr>
<th>% Speed</th>
<th>% Flow</th>
<th>% HP</th>
<th>Required Output (KW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>100</td>
<td>100</td>
<td>74.6</td>
</tr>
<tr>
<td>90</td>
<td>90</td>
<td>72.9</td>
<td>54.4</td>
</tr>
<tr>
<td>80</td>
<td>80</td>
<td>51.2</td>
<td>38.2</td>
</tr>
<tr>
<td>70</td>
<td>70</td>
<td>34.3</td>
<td>25.6</td>
</tr>
<tr>
<td>60</td>
<td>60</td>
<td>21.6</td>
<td>16.1</td>
</tr>
<tr>
<td>50</td>
<td>50</td>
<td>12.5</td>
<td>9.3</td>
</tr>
<tr>
<td>40</td>
<td>40</td>
<td>6.4</td>
<td>4.8</td>
</tr>
</tbody>
</table>

ABB Drives
<table>
<thead>
<tr>
<th>Input Value</th>
<th>Duty Cycle</th>
<th>Calculated Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>74.6</td>
<td>.93</td>
<td>80.2</td>
</tr>
<tr>
<td>54.4</td>
<td>.92</td>
<td>59.1</td>
</tr>
<tr>
<td>38.2</td>
<td>.89</td>
<td>42.9</td>
</tr>
<tr>
<td>25.2</td>
<td>.87</td>
<td>29.0</td>
</tr>
<tr>
<td>16.1</td>
<td>.81</td>
<td>19.9</td>
</tr>
<tr>
<td>9.3</td>
<td>.70</td>
<td>13.3</td>
</tr>
<tr>
<td>4.8</td>
<td>.50</td>
<td>9.6</td>
</tr>
<tr>
<td>% Speed</td>
<td>% Time</td>
<td>Total Hrs/Yr</td>
</tr>
<tr>
<td>---------</td>
<td>--------</td>
<td>--------------</td>
</tr>
<tr>
<td>100</td>
<td>2.5</td>
<td>8760</td>
</tr>
<tr>
<td>90</td>
<td>7.5</td>
<td>8760</td>
</tr>
<tr>
<td>80</td>
<td>10</td>
<td>8760</td>
</tr>
<tr>
<td>70</td>
<td>15</td>
<td>8760</td>
</tr>
<tr>
<td>60</td>
<td>22</td>
<td>8760</td>
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<tr>
<td>50</td>
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<td>8760</td>
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<tr>
<td>40</td>
<td>21</td>
<td>8760</td>
</tr>
<tr>
<td>Calculation</td>
<td>Result</td>
<td></td>
</tr>
<tr>
<td>---------------------</td>
<td>----------</td>
<td></td>
</tr>
<tr>
<td>80.2 X 219</td>
<td>17,564</td>
<td></td>
</tr>
<tr>
<td>59.1 X 657</td>
<td>38,829</td>
<td></td>
</tr>
<tr>
<td>42.9 X 876</td>
<td>37,580</td>
<td></td>
</tr>
<tr>
<td>29.0 X 1314</td>
<td>38,106</td>
<td></td>
</tr>
<tr>
<td>19.9 X 1927</td>
<td>38,347</td>
<td></td>
</tr>
<tr>
<td>13.3 X 1927</td>
<td>25,629</td>
<td></td>
</tr>
<tr>
<td>9.6 X 1840</td>
<td>17,664</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>213,719</td>
<td></td>
</tr>
</tbody>
</table>
Energy Savings

Constant Speed System
687,900 KWH/YR X $.10/KWH = $68,790 / YR

VFD System
213,719 KWH/YR X $.10/KWH = $21,372 / YR

Constant Speed Vs AF System
$68,790 - $21,372 = $47,418 in savings per year
Golden Nuggets for a successful installation

- Large amount of operating hours
- Large amount of partially loaded operating hours
- A variable volume system or retrofit to VAV plans*
- Verify motor full load amp draw, not just listed HP
- Ensure controls in place for maximum savings but ensures comfort (very important)
  - For parallel motor applications run both motors at half speed, not only one motor at full speed
- Install VFD per manufactures guidelines!
Other reasons to use a VFD?

• More energy savings
  – Running a centrifugal load at 50% speed on a **100HP** motor only uses **15HP** but delivers 50% flow!
  – Improves power factor to .98

• Soft start feature increases lifespan of mechanical loads and helps reduce demand charges, and water hammer, etc
  – Much better than reduced voltage start

• Inherent protection for single phase, overload, short circuit and ground fault
Using the VFD energy saving features

- [https://www.youtube.com/watch?v=lEX_EO2vsB8](https://www.youtube.com/watch?v=lEX_EO2vsB8)
What is a Drive / VFD/ AFD/ASD?

If 230 VAC Power Line:

\[
\frac{230 \text{ V}}{60 \text{ Hz}} = 3.83 \frac{\text{V}}{\text{Hz}}
\]

\[
\frac{460 \text{ V}}{60 \text{ Hz}} = 7.67 \frac{\text{V}}{\text{Hz}}
\]
VFDs Control Frequency and Voltage

Linear V/Hz
Squared V/Hz

ABB—Flux Optimization
Better motor efficiency for all speeds and loads

Linear vs squared V/Hz
Flux Optimization is auto!
VFD Basics

Fixed Input Voltage & Frequency AC

Fixed Voltage DC

Controlled Voltage & Frequency AC
How VFD’s Operate

Input Converter (Diode Bridge)  DC Bus (Filter)  Output Inverter (IGBT’s)

Motor
Positive DC Bus +
Negative DC Bus -

RECTIFIER

INVERTER
RECTIFIER

Positive DC Bus

Negative DC Bus

INVERTER
Area Under The Square-Wave Pulses Approximates The Area Under A Sine Wave
Fundamentals of Variable Frequency Drives

Pulse Width Modulation (PWM)

High Frequency, Motor Noise and Stress (2-20Khz)
VFD Types

**Micro Drives** – Small, cost reduced, **no harmonic filters**, no on-site warranty, short lifespan

**Standard Drives** – Robust, high volume, standard harmonic filters, on-site warranty, long life

**Performance Drives** – Capable, tight motor control, PLC type functions, robust, harmonic filters, long life
Avoid Problems with Good Wiring Practices

- **Motor wires**
  - Separate metal conduit
  - High strand count wire
  - Dedicated ground from motor to VFD chassis

- **Line wires**
  - Separate metal conduit
  - Ground from VFD chassis to main ground bus

- **Control wires**
  - Separate metal conduit
VFD Installation

- Motor – VFD compatibility (long cable runs). **NEMA MG1, Part 31** compliance & shaft grounding
- Size the VFD by the motor(s) FLA, not HP
- Size feeders per the input current of the VFD, not the motor FLA
VFD Installation

• Motor – VFD cable
  – Liability reducer for the Mfg
  – Use is non-conduit installations

• Shaft grounding
  – Conductive ring
  – Carbon brush
VFD Fuses?

- New UL 61800-5-1 Standard changes test requirements (SCCR ratings also)
- Circuit breakers are too slow
- Bigger problem the larger the VFD
- Fast acting (class T)
I need spare fuses

• If a power fuses clears, the power structure likely failed

• The most common mode is a phase to phase short

• Do NOT replace and re-power!
Avoid Problems with Proper Grounding

Solid wire

High strand count wire

Power source to VFD, VFD to motor
Surge / Transient Protection

- Protection from AC line transients is important
- Generator testing
- Switching power factor caps
- Indirect lightning
- Some VFD’s include a standard TVSS system, some do not. Protection should be phase to phase and phase to ground. Extra attention to corner grounded systems (corner grounded delta, floating or resistant grounded systems)
VFD Installations - Ambient

- Most drives are rated 0-40C (104F)
  - Derating required for higher temps (for 50C). Large impact on drive lifespan.
  - Heaters required for cold temperatures
- Corrosive environments
  - Conformal coating for PCB’s
A 3” conduit from supply air provided “cooling air”

VFD’s are “stacked”. Heat from bottom VFD’s blow into the top row.

Maybe 20 CFM of airflow when 750 CFM min. is required. Very expensive to fix

No harmonic considerations
VFD Options
ABB ACH550: VFD Electrical One-Line
Disconnect device

- Door interlocked, padlockable
- Disconnect/fuses
- Circuit breaker
- Act as code required motor disconnect
  - Direct line of sight
  - 50’ from the motor
Bypass

- Constant speed system if VFD fails
  - Across the line
  - Soft starter
- Redundant VFD
Redundant VFD’s

• Lead / Lag system
  • Lag VFD starts automatically if lead fails
  • Lead can be manually or remotely selected
  • Allow variable speed back-up
Enclosures Types

- Ambient Temperature
- UL rated
  - UL Type 1 dry, clean indoor
  - UL Type 12 dirty, dripping water
  - UL Type 3R outdoor
  - UL Type 4 hose down
- NEMA ratings are self certifying
  - UL has very specific requirements
Proper enclosure selection can save money!
Enclosure need to be engineered!
UL Type-1 Rated VFD

• Indoor use
• Clean dry environment
• Good locations:
  – Dry and clean mechanical rooms
  – Some place you would keep your computer and have lunch
  – Humidity controlled
• Vast majority of drives installed in HVAC applications are Type-1
UL Type-12 Rated VFD

- Indoor use
- Moderately dirty and wet environment
- Good for:
  - RTUs
  - Damp areas / light water
  - Exposed to outside air (not weather)
  - Dirt / dust
UL Type-3R Rated VFD

- For outdoor use
- Provides a degree of protection from:
  - Falling dirt
  - Rain, sleet & snow
  - Sun exposure
- Good for mounting on Roof tops
- Includes heaters for Wisconsin winters!
Interfacing with BAS

- Monitoring / Monitoring & Control
  - Don’t waste your connection!
    - S/S, Speed, Run & Fault
    - VFD temperature, trip ID, trip reset (remote), load “health” (plugged pump, stuck valve, etc), man-auto control, KWH and much more!
Should I stock spare VFD’s?

- The capacitors in VFD’s have a shelf life of about 3 years
- The VFD should be powered for 24 hours (no motor connected)
- Does not have to be connected to a motor