2018 Clean and Safe Drinking Water Workshop
Hotel Gander

Variable Speed Drives
Controlling Centrifugal Pumps
Energy Savings

Presenter: Dave Galbraith
What is a Variable Speed (Frequency) Drive?

AKA… VFD, VSD, ASD, Drive, Inverter, Converter, etc.

A **VFD** converts the 50-60Hz fixed-frequency and fixed-voltage AC power supply into a DC supply, using an integrated rectifier.

Integrated power electronics then inverts the DC supply into a simulated PWM sinusoidal output with continuously variable frequency and voltage, which is used to drive the motor.

Converters = change AC to DC
Inverters = change DC to AC
Speed Formula

\[ \text{RPM} = \frac{120 \times F}{P} \]

- \( F \) = Frequency in Hz
- \( P \) = Poles in the Motor

Examples of Synchronous Speed:

\[ 120 \times \text{Hz} / \text{Poles} = \text{RPM} \]

- \( 120 \times 60 / 2 = 3600 \)
- \( 120 \times 60 / 4 = 1800 \)
- \( 120 \times 60 / 6 = 1200 \)
- \( 120 \times 60 / 8 = 900 \)

Examples:

- 30Hz = 50% speed
- 45Hz = 75% speed
- 90Hz = 150% speed
Basic Construction of VFD

- **Rectifier Converter Section**: AC to DC conversion.
- **DC link Filter Section**: Capacitor (C) for smoothing.
- **Inverter DC to AC**: Control, monitoring, and communication.
- **Motor**: M 3~

Key Components:
- **L1**, **L2**, **L3**: Supply Voltage
- **U_line**, **U_DC**, **U_out**: Voltage Levels
- **V1**, **V2**, **V3**, **V4**, **V5**, **V6**: Diodes for inverter

Control Electronics:
- Control, monitoring, and communication.
Pumping example:

- Throttling
- Bypass control
- On-Off control

- Simple construction
- Optimal capacity is difficult to achieve
- An increase in capacity means reconstruction of the system
- Control by throttling, recirculation or start and stop
- Risk of damage at start-up
- Operating costs are high
In this situation, what would you do?

1. Keep your foot on the gas and control your speed with the brakes.

2. Change to a lower gear and slow down.
Constant Torque Loads
Centrifugal Fans, Blowers & Pumps

Variable Torque Loads

\[ T = \text{speed}^2 \]

\[ \text{Hp} = \text{speed}^3 \]
Full Speed & Throttled versus Variable Speed

Energy Used

No throttle

Energy Used Throttle

Energy Used VFD
AC & DC VFDs are to be rated by
Supply Voltage & Current
(208V, 240V, 380V, 460V, 575V, 600V, 690V, etc)

Horsepower & kW are only used as a guide

The type of Load and the application will determine the proper size of the VFD

VFD Enclosures are typically NEMA 1 (IP21)
NEMA 12, 3R, 4X etc are options
VFDs are most often used with **Centrifugal Pumps** ...which are typically **Variable Torque Loads**

VFDs are also being used with **Blowers for Aeration in Lagoons and other Wastewater tanks** ....which are mainly **Constant Torque Loads**

VFDs on **Progressive Cavity & Positive Displacement Pumps; Mixers or Screws, Conveyors, Hoists, Drills**, are **Constant Torque Loads**
Variable Torque

In these applications:

- Torque varies directly with speed squared
- Power varies directly with speed cubed

This means that at half speed, the horsepower required is approximately one eighth of rated maximum.

Throttling a system by using a valve or damper is an inefficient method of control because the throttling device dissipates energy which has been imparted to the fluid. A variable frequency drive simply reduces the total energy into the system when it is not needed.

- In addition to the major energy saving potential, a drive also offers the benefits of increased process
<table>
<thead>
<tr>
<th>Speed of Fan/Pump</th>
<th>Mechanical Power Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>90%</td>
<td>73%</td>
</tr>
<tr>
<td>75%</td>
<td>42%</td>
</tr>
<tr>
<td>50%</td>
<td>13%</td>
</tr>
</tbody>
</table>

Power Required by Fan/pump as a Function of Speed
Common Stresses on Pump Systems

Hydraulic Stress (AKA Water Hammer) is caused by abrupt change in flow; usually from quick starting or stop of the pump without a “Soft Start or Soft Stop”. The shock wave can travel at the speed of sound and could create up to 600PSI depending on the size of pipe and length.

Electrical Stress can affect the Motor and the power supply. A typical motor can use at least five times the inrush current when started across-the-line at 60Hz. Frequent starts can cause damage to the motor, pump and possibly overload the electrical system. This causes overheating in the motor windings, the wires and the breakers. Using a VFD on a Centrifugal Pump eliminates the inrush current completely by controlling the Ramp up and Ramp down (with Soft Starting & Soft Stopping).

Mechanical Stress in a typical small 1750RPM motor (unloaded) will accelerate from zero to synchronous speed in less than one second without any ill effects. By adding a Centrifugal Pump Load, the motor will accelerate up to full speed in less than two seconds depending on the application, pump design, impeller diameter, mass, type of fluid flowing, etc. The inertia can be quite significant and additional stresses and radial forces are put on the shaft, bearings, keyway, etc. If the shaft coupling is misaligned, then additional stresses can also affect the motor/pump. With the use of a VFD, the abrupt mechanical stresses can be reduced.
Constant Speed Pump Curve

Throttling power & efficiency @ ½ flow

- 5.6 HP 69%
- 6.3 HP 77%
- 7.1 HP 78%
- 7.5 HP 75%

Gallons Per Minute

Head in ft.
Variable Speed Pump Curves

power & efficiency @ ½ flow using a VFD
## System Data

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liquid density</td>
<td>62 lb/ft³</td>
</tr>
<tr>
<td>Static head</td>
<td>20 ft</td>
</tr>
</tbody>
</table>

## Pump Data

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal volume flow</td>
<td>480 gpm</td>
</tr>
<tr>
<td>Efficiency</td>
<td>77%</td>
</tr>
<tr>
<td>Nominal head</td>
<td>43 ft</td>
</tr>
<tr>
<td>Max head</td>
<td>55 ft</td>
</tr>
</tbody>
</table>

## Existing Flow Control

- Throttling control

## Motor and Supply Data

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply voltage</td>
<td>690 V</td>
</tr>
<tr>
<td>Motor power</td>
<td>7.5 Hp</td>
</tr>
<tr>
<td>Motor efficiency</td>
<td>96.0%</td>
</tr>
</tbody>
</table>

- Required motor power: 7.5 Hp including 10% safety margin

## Operating Profile

<table>
<thead>
<tr>
<th>Flow</th>
<th>Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 %</td>
<td>0 h</td>
</tr>
<tr>
<td>0 %</td>
<td>0 h</td>
</tr>
<tr>
<td>0 %</td>
<td>0 h</td>
</tr>
<tr>
<td>0 %</td>
<td>0 h</td>
</tr>
<tr>
<td>100 %</td>
<td>8760 h</td>
</tr>
<tr>
<td>0 %</td>
<td>0 h</td>
</tr>
<tr>
<td>0 %</td>
<td>0 h</td>
</tr>
<tr>
<td>0 %</td>
<td>0 h</td>
</tr>
</tbody>
</table>

- Annual running time: 8,760 h
### Measurement Units

| Calculated by: |  |
| Calculated for: |  |
| Pump ID: |  |

**Improved Flow Control by ABB Drive series:**

- ACS550
- ACS550-U1-011A-6

### Results

- **Saving percentage:** 53.6%
- **Annual energy consumption:**
  - with existing control method: 33 MWh
  - with improved control method: 15 MWh
- **Annual energy saving:** 18 MWh
- **Annual CO2 reduction:** 9 t
- **CO2 emission/unit:** 0.5 lb/kWh

### Economic Data

| Currency unit | $ |
| Energy price | 0.14 $/kWh |
| Investment cost | 2,000 $ |
| Interest rate | 4% |
| Service life | 10 years |

### Economic Results

- **Annual saving:** 2,469 $
- **Payback period:** 0.8 years
- **Net present value:** 18,192 $
### Common problems when starting and stopping motors with different starting methods

<table>
<thead>
<tr>
<th>Type of problem</th>
<th>Direct-on-line</th>
<th>Star-delta start</th>
<th>Drives</th>
<th>Softstarter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slipping belts and heavy wear on bearings</td>
<td>Yes</td>
<td>Medium</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>High inrush current</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Heavy wear and tear on gear boxes</td>
<td>Yes</td>
<td>Yes (loaded start)</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Damaged goods / products during stop</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Water hammering in pipe system when stopping</td>
<td>Yes</td>
<td>Yes</td>
<td>Best solution</td>
<td>Reduced</td>
</tr>
<tr>
<td>Transmission peaks</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>
VFD
Draw Backs & Solutions
• Harmonics generated from Input Diode Bridge
  • Solution is to provide Line Choke/Reactor to reduce
    • Recommend Line Choke/Reactor to be included with VFD as part of the manufacture's design

• Voltage Spikes and non-sinusoidal wave forms
  – Solution is to use motor with MG1-Part 31 Ratings
  – Solution is to use DV/DT Filter – reduces the effects
    • MG1-Part 31 is a spec that describes that the motor can be used with a VFD because the insulation rating on the windings.

• Common Mode Voltages – in motor cable
  – Solution is to use Common Mode Filters
    • In addition; VFD rated cable also helps mitigate the effects
Adverse effects on sensitive Instrumentation

- Ultrasonic Level, Magnetic Flow Meters, Generator Controllers, Solid State Circuit Breakers tripping, etc.
  - Partial list of Solutions
    - Provide proper grounding for all equipment (high and low voltage)
    - Locate VFD cables away from sensitive equipment and cables
    - Use shielded cables for Instrumentation
    - Adhere to Mfg.'s installation Instructions i.e. special Grounding

- Ultimate solution – use and Ultra-Low Harmonic VFD
  - Provides less than 4% Current Total Harmonic Distortion
  - Produces better Current Sine Wave for Motor
VFD

Major Benefits
• Reduction in speed reduces wear of pump parts
  • bearings, seals, other moving parts – life is extended
    • Bearing wear reduces by the seventh power of speed
      • Slowing the pump speed reduces the requirement of maintenance

• MTBF (mean time between failure) = 20 years
  – Provided regular maintenance is performed
    • Cleaning out dust, cooling fan replacement, etc.

• Excellent Displacement Power Factor ~ 97%
  – No requirement for PF Correction Capacitors
    • No inrush currents – as with Direct Online Starting
• Open Loop VFD/Motor speed control
  • No requirement for Motor Shaft Encoder Feedback Sensor
    • Process control can be optimized via 4 - 20 mA Transducer/Signals
      • Flow, Level, Temperature & Pressure are measurements used for inputs

• Integral Diagnostics and Fault Protections
  – Micro-processors – monitors and protects VFD and Motor
    • Protections - Short Circuit, Ground Fault, Overload, Motor Stall, Underload,
      Over Voltage, Under Voltage, Phase Loss, Over Temperature, etc.

• Serial Communications & PLC Functions Available
  – EtherNet, Modbus, DeviceNet, Profibus, etc.
    • Multiple I/O – Analogue and Digital – fully programmable
• **Variable Speed – Over & Under Base Speed**
  • If Motor is lightly loaded, the VFD can output above 60Hz (within reason)
    • Over Speeding Pump - Provides additional flows (if motor is under-loaded & can handle higher speed) to help occasional peak conditions without requiring a different pump.
      • Pressures and Motor Current draw to be monitored for protection.

– **VFD can output below 60Hz (system curve dependant)**
  • Reducing Speed of Pump - Provides additional process, pressure and flow controls.
  • Considerable energy savings with operating Rotodynamic (AKA) Centrifugal Pumps at reduced speeds... Affinity Laws.
Various Versions...

Wall Mounted Modules
Cabinet-Built
Analog I/O

Digital Inputs

Relay Outputs

Expansion Slots – I/O & Fieldbus

Built-in Modbus using EIA-485

Mains Input & Motor Terminals

Removable Conduit Box
Thank you

Questions?