AC Adjustable Speed Drives (ASD's)

Variable Speed Control

The simplest and least expensive way to control the speed of a process or piece of equipment is to operate all the equipment at full speed.

C Many applications require the speed of a process or piece of equipment to be varied.

C Prior to the advent of the AC Adjustable Speed Drive, many technologies have been used, although each has its inherent advantages and disadvantages.

Types of Variable Speed Control:

Control Valves, Dampers and Vanes
Fossil Fuel Engines
Eddy Current Clutches
Hydraulic Couplings
Variable Pitch Sheaves
DC Solid State Controllers
AD Adjustable Speed Drives (ASD's)

AC Adjustable Speed Drives (ASD's)

AC Adjustable Speed Drives (ASD's) have become very popular variable speed control devices used in industrial, commercial and some residential applications.

C These devices have been available for about 20 years and have a wide range of applications ranging from single motor driven pumps, fans and compressors, to highly sophisticated multi-drive machines.

C They operate by varying the frequency of the AC voltage supplied to the motor using solid state electronic devices.

C These systems are fairly expensive but provide a higher degree of control over the operation and in many cases, reduce the energy use enough to a least offset if not more than pay for the increased cost.

C ASD's allow precise speed control of a standard induction motor and can result in significant energy savings and improved process control in many applications.

C Can control the speed of a standard squirrel cage NEMA type B induction motor.

C Suitable not only for new applications, but also for retrofit on existing motors.

Adjustable Speed Drive (ASD) Function

AC Adjustable Speed Drives can be thought of as electrical control devices that change the operating speed of a motor.

ASD's are able to vary the operating speed of the motor by changing the electrical frequency input to the motor.

C The speed an AC induction motor operates is given by the following equation:

$$\text{Synchronous Speed} = \frac{120 \text{ X Frequency}}{\text{Number of Poles}}$$

Where: Frequency = Electrical frequency of the power supply in Hz.
Number of poles = Number of electrical poles in the motor stator.

C Motors speed can be changed by altering the electrical frequency, the # of poles, or both.

C Motor speed can be changed by altering the # of poles in a motor from 4 to 2:

4 pole motor operating on 60 hertz = 1800 rpm.
2 pole motor operating on 60 hertz = 3600 rpm.

C We really **CHANGED** speed rather than varied speed!

C Motor speed can be changed by altering the frequency of the electrical supply:

4 pole motor operating on 50 hertz = 1500 rpm.
4 pole motor operating on 40 hertz = 1200 rpm.

C By varying frequency, we can adjust the speed over a wide range or vary the speed precisely using precise changes in the electrical frequency input to the motor.

Power and Torque

ASD's actually control both frequency and voltage simultaneously to maintain a constant volts/hertz ratio which keeps current flow similar to full speed conditions.

- This allows the motor to draw full current at any speed and produce full torque as motor speed changes.

- What happens to the Horsepower when we lower the speed and torque using frequency?

$$\text{Horsepower} = \frac{\text{Speed (in RPM) x Torque (in pound-feet)}}{5{,}252}$$

- Reduced Horsepower = Reduced Energy Use = Energy Savings!!!!!!!!!!!

What About INCREASING Speed?

Some specially designed motors meant for use with ASD’s are designed to operate at higher than normal speeds at frequencies above 60 hertz.

- Increasing frequency above 60 hertz makes the motor run faster than normal and creates two primary concerns:

  1. Was the motor or the load it drives designed to operate at these increased speeds?

     – Many motors and devices were not mechanically balanced to operate at increased speeds and will create vibration, mechanical and safety problems.

  2. ASD's are not capable of increasing voltage so as frequency increases above 60 hertz, the torque produced starts to decrease.

     – In order to maintain a constant horsepower output to drive our load, if speed is increased, torque must decrease!

At some point of increased speed we may not be able to produce enough torque to drive the load and at this point, the motor will slow even with increasing frequency.

- This point is different for each manufacturer's motor and dependant on the torque required by the load. Only the manufacturer can help determine when this occurs.

ASD Advantages & Disadvantages

Adjustable Speed Drives have a number of advantages and disadvantages compared to other types of variable speed controls including:

Advantages	Disadvantages
C Energy Savings	1. Initial Cost
C Improved Process Control	2. Motor Heating at low Speeds
C Reduced Voltage Starting	3. Maintenance
C Lower System Maintenance	4. Output Harmonics
C Bypass Capability	5. Induced Power Line Harmonics
C Multi-motor Control	

Advantages - Energy Savings

Adjustable Speed Drives can be used to save significant amounts of energy in process operations compared to traditional control methods where the load or speed of the operation varies.

C AC Adjustable Speed Drives are among the most efficient types of speed control when used on axial (variable torque) loads like centrifugal fans, pumps and compressors.

– As the motor reduces the operating speed of the fan, pump or compressor the horsepower required to operate the system is greatly reduced.

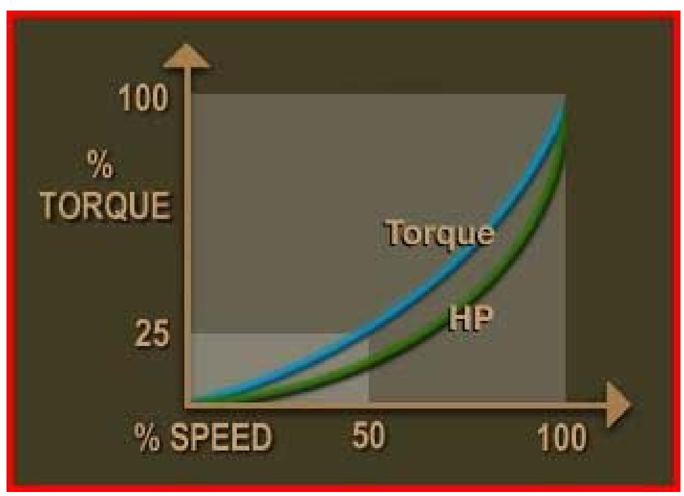
– This is a major advantage of the ASD and one of the primary reasons ASD's have become so popular in many process operations.

Variable Torque Loads

Variable torque loads require much lower torque at low speeds than at high speeds.

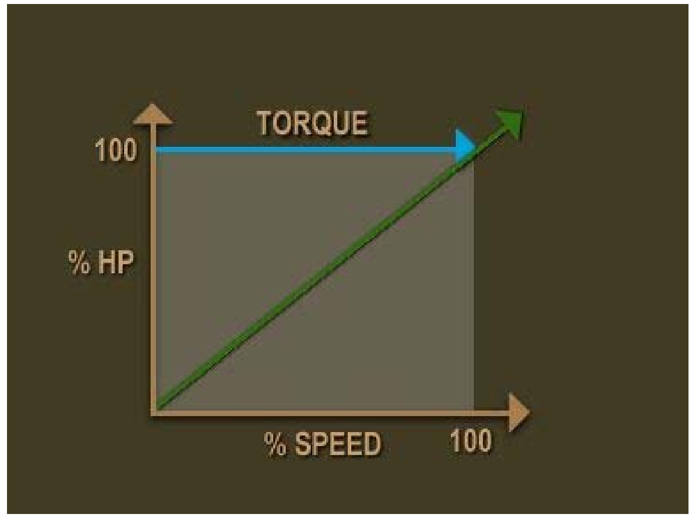
C The torque required varies as the square of the speed and the horsepower required varies as the cube of the speed.

C When the speed of a variable torque load is reduced to 50%, the torque required to drive the load is reduced to 25% and the horsepower is reduced to 12.5% of the amount required to drive the load at full load speed.



C Variable torque loads include most centrifugal and axial pumps, fans and blowers and many mixers and agitators.

Constant Torque Loads



Constant torque loads require the same amount of torque at low speeds as at high speeds.

- Torque remains constant throughout the speed range, and the horsepower increases and decreases in direct proportion to the change in speed.
- If the speed drops to 50 percent, then the power required to drive the operation will drop to 50 percent while the torque remains constant.

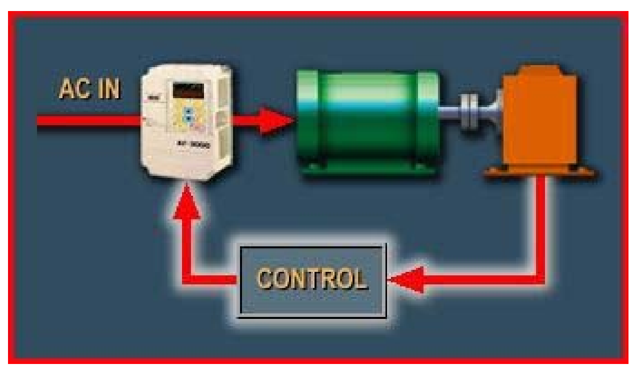
Constant torque loads include most conveyors, positive displacement and reciprocating pumps, and compressors.

Advantages - Reduced Voltage Starting

An ASD acts like a reduced voltage starter to limit the amount of in-rush current when the motor starts.

- The ASD can generally limit the in-rush current to a maximum of 150%.

Advantages - Improved Process Control



The ASD is a solid state electronic device which lends itself well to automated process control networks.

- It can take process control signal inputs for start/stop and speed control and output signals to DCS and PLC systems, or provide information other computers.
- Other types of variable speed control can be very limited as to their interfacing to a process control system or have no capability whatsoever.

Advantages - Lower System Maintenance

An ASD can reduce system maintenance requirements for both the control and drive train equipment compared to other types of variable speed control.

C The ASD can reduce the wear on belts, sheaves, gearboxes, and couplings in a system.

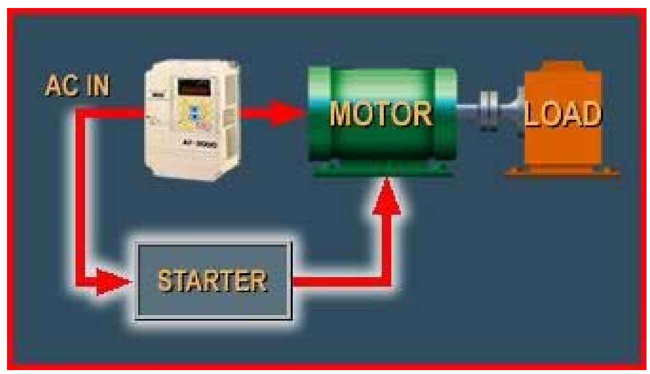
C Control valves can sometimes be a maintenance problem due to lining wear when throttling a material which is very caustic or extremely rough in nature.

C All of these are wear items and can add to the overall maintenance of the process control plant.

C The ASD does not cycle motors on and off, as commonly seen with certain processes. By eliminating the cycling of these motors, the variable frequency drive eliminates the amount of in-rush and the torque pulsations felt throughout the system.

Advantages - Bypass Capability

Many ASD systems make use of a bypass starter in parallel with the drive which allows the drive to be easily bypassed when critical applications require a back-up control means.



C Other types of variable speed control are usually physically coupled between the motor and the load and must be uncoupled, repaired, and then re-coupled into the line-up when there is a failure.

C The ASD can be bypassed in a matter of seconds where other types of speed control may be down for hours or even weeks, while it is being repaired if there is not a spare control.

Advantages - Multi-Motor Control

Some ASD's can control multiple motors from the same drive which can be an advantage over other types of variable speed control devices.

C The advantage of this is the smaller physical size of the control being used, as well as the reduced initial cost of the ASD system.

ASD Disadvantages

ASD's are not the best choice for all variable speed applications. Some of the drawbacks to using an ASD (which are generally the advantages to using other types of speed controls) are as follows:

Disadvantage - Initial Cost

The initial cost of an ASD is generally greater than other types of variable speed controls mentioned and is a common obstacle for a process plant to install the ASD.

- Pay-back from energy savings has traditionally been used to justify installation of ASD's however improvements in process control are increasingly being considered.
- The energy savings payback is generally low for applications where the average speed requirement is near the motors rated speed level.
- As a general rule, a payback of 2 to 3 years typically justifies the use of an ASD.

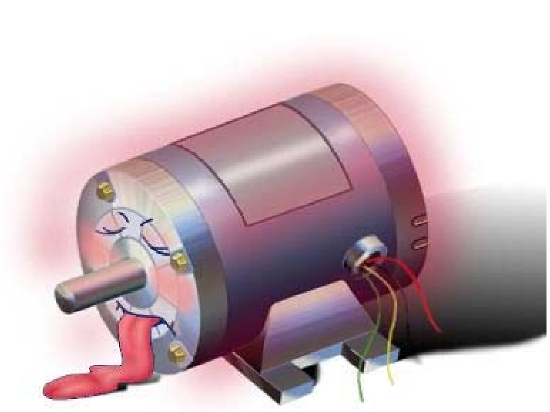
Disadvantage - Maintenance

ASD's, like many other solid state electronic devices, require special troubleshooting knowledge for operations and maintenance personnel.

- Maintenance personnel can obviously look at mechanical type devices to see if the devices have failed or easily diagnose the cause of the failure.
- ASD's have made significant advances in their diagnostic capability, but still may require additional training for maintenance personnel not familiar with solid state design technology.

Disadvantage - Motor Heating at Low Speed Operation

ASD's used to run constant torque loads at slow speeds, have a high potential for motor heating.



- No matter what speed the motor runs, the current draw to the motor will be the same with a constant torque load.
- At low speeds, the cooling fan on the motor produces less cooling air.
- If the motor produces the same amount of heat at low speed due to the constant torque load and there is less cooling air, the motor will overheat.

As a rule of thumb, you can generally take a fully loaded Class B insulation motor down to 50 percent speed on constant torque loads without overheating.

C You can generally take a fully loaded Class F insulation motor down to approximately 20 percent speed without overheating the motor.

C When a Class F insulation motor needs to be run below 20 percent speed on a constant torque application, the motor needs to be derated.

Disadvantage - Output Harmonic Distortion

The output electrical waveform generated by the ASD is not a pure sinewave and includes harmonic distortion which is supplied to the motor.

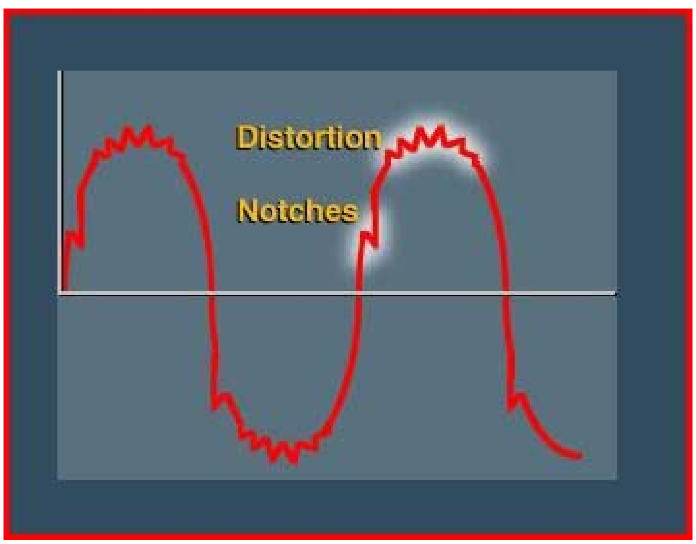
C The harmonics are multiples of a fundamental frequency with a current component and the current component will create heat in the motor.

C As a rule of thumb, ASD's will create between 5 to 8 percent extra heating in a motor as compared to that same motor running on a sinusoidal waveform from the power line.

C One way to overcome this problem is to use a motor with at least Class F insulation or an inverter rated motor with Class M insulation.

Disadvantage - Induced Power Line Waveform Distortion

The ASD is a solid state electronic load and will cause waveform distortion to be induced on the input electrical power supply.



C The waveform distortion created by ASD’s consists of both harmonic distortion and line notching.

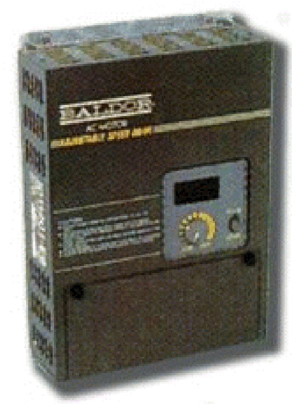
C Harmonic distortion and line notching are a result of the non-sinusoidal waveform the drive generates, which pulls the current off of the power line in non-sinusoidal pulses.

C This can severely distort the electrical power supply within the facility and if not properly protected, can hinder the operation of other devices.

C Operations using ASD’s in the vacinity of sensitive electronic equipment should consider including either an isolation transformer, or line reactors on the input of the drive to protect the other equipment from this potential problem.

Types of AC ASD's

There are three different types of ASD's on the market that primarily differ in the type of rectification they use to convert AC to DC and back to AC.



- VVI - Variable Voltage Input
- CSI - Current Source Input
- PWM - Pulse Width Modulated

These drives take the AC input voltage and frequency, covert it to DC using rectifiers, then convert it back to AC in an invertor which changes the voltage and frequency.

<u>Variable Voltage Input (VVI)</u>

The VVI is the oldest AC drive technology and was the first AC drive to gain acceptance in the industrial market.

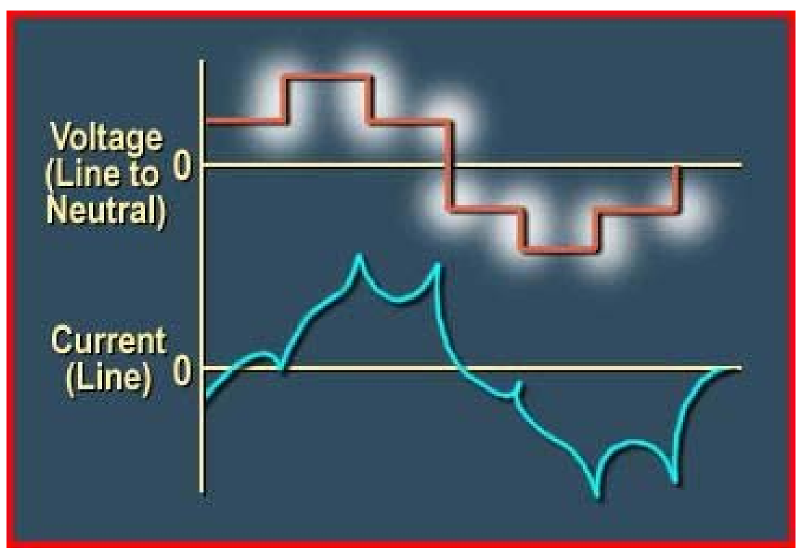
- The VVI is sometimes called a “six-step drive” due to the shape of the voltage waveform it sends to the motor.

- VVI drives are fairly economical between 25 and 150 horsepower for ranges of speed reduction from 15 to 100% (about 10 to 60 Hertz).

- These drives are also used widely on specialty high speed applications (400 to 3000 Hertz).

<u>Advantages:</u>

good speed range
multiple motor control from one unit
simple control regulator



<u>Disadvantages:</u>

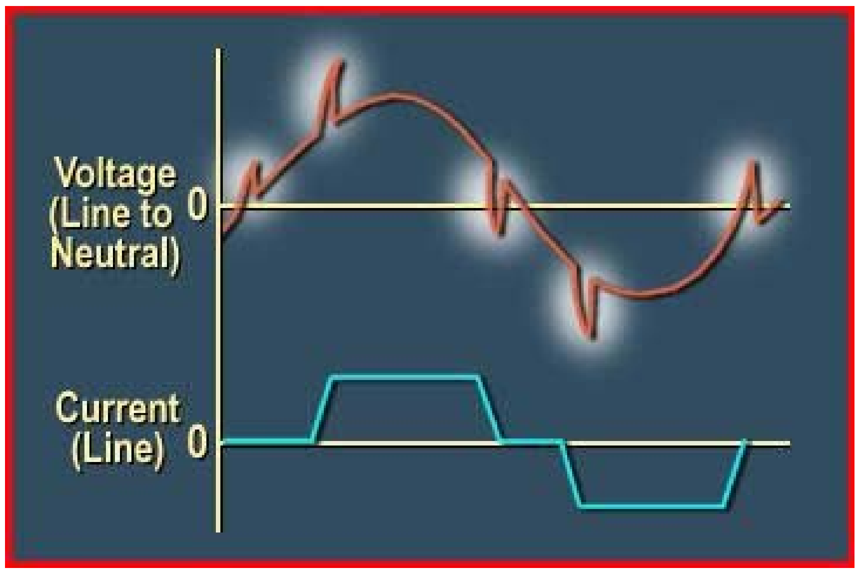
Power Factor decreases with decreasing speed
Poor ride through ability for low input voltage
Generates significant output harmonics
Low Speed Motor Cogging (shaft pulsing/jerky motion)
Requires Isolation Transformer on Input Side

During low speed operation (below 15-20 Hz) cogging can be a problem where the jerky motion of the motor shaft can create problems for bearings, gears, or gear reducers.

Current Source Input (CSI)

The CSI is very similar to the VVI except that it is more sensitive to current as opposed to a VVI drive which is more sensitive to voltage.

- CSI drives are usually lower cost above 50 horsepower than VVI drives for pumps and fan applications.
- The efficiency of a CSI drive may not be as high as a VVI drive and may not provide a total energy saving package compared to other drives.
- Due to the current characteristics produced by the CSI, cogging can be a problem at low speeds similar to the VVI.
- The voltage output is somewhat closer to the regular sine wave expected by the motor except for the sharp spikes and sags.



Advantages:

High Efficiency
Optional Regeneration Capability
Inherent Short Circuit Protection
Capable of bringing other motors on Line at full voltage

Disadvantages:

Power Factor decreases with decreasing speed.
Low Speed Motor Cogging (shaft pulsing/jerky motion)
Inability to operate more than one motor on the drive at a time
Poor ride through ability for low input voltage
Generally sold as Motor/Drive package.
Motor requires a feedback device (tachometer, etc.) to work with the drive
Cannot test drive without motor connected
Requires Isolation Transformer on Input Side
Large physical size of Drive due to internal power components.

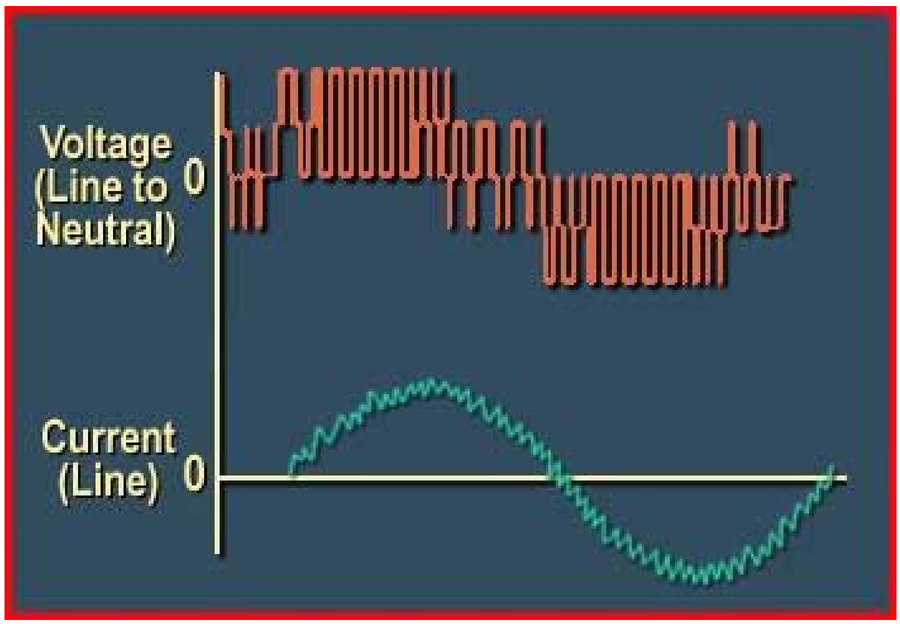
Pulse Width Modulated (PWM)

These drives are the newest technology and use sophisticated power electronics to accomplish the same frequency and voltage control.

C They provide good efficiency with very little motor heating associated with the other types of drives.

C Pulse Width Modulated or PWM drives provide the best output current to operate the motor and are becoming very popular for adjustable speed applications.

C The current supplied to the motor has no notching to any great degree and is representative of what the motor expects.



Advantages:
- High Efficiency
- Wide controllable speed range
-Ride through capability
-Open Circuit Protection for ride through capability
-Constant Power Factor regardless of speed
-Multi motor operation from one drive
-No cogging problems.
-Competitive Price.

Disadvantages:
Extra Hardware required for line regenerative capability.
Complexity of equipment is high compared to VVI and CSI.
Some PWM drives produce significant audible noise.

ASD Example Problem (Variable Torque Load)

An existing 3 phase, fully loaded 100 horsepower motor with 92% efficiency drives a water pump that has a variable load.

The motor operates 20 hours per day and water requirements for the operation vary during the day as follows:

Operation and Flow Rates:

6 a.m. to 12 noon:	50 percent of maximum flow.
12 noon to 12 midnight:	75 percent of maximum flow.
12 midnight to 2 a.m.:	100 percent of maximum flow

- A flow control valve is used to reduce the water flow rate to the plant for normal operations.

Electric Rate:	Energy:	$0.04/kilowatt-hour
	Demand:	$5/kW per month measured from 8 a.m. to 10 p.m.

- Is installation of the adjustable speed drive economical?

The present system uses:

$$\frac{100\text{ hp}}{0.92} \times 0.746 = 81 \text{ kilowatts INPUT to motor}$$

81 kW X 20 hours/day X 7 days/week X 52 weeks/year = 589,680 kWh/year

Yearly Electric Bill Equals:

81 kW X $5/month X 12 months =	$4860.00
589,680 kWh/year X 0.04/kWh =	$23,587.20
Total:	$28,477.20

Evaluate benefits of installing an adjustable speed drive:

Need the maximum load on the motor at any time and estimated duty cycle outlining expected percentage rating of the load and operation hours at that level.

Result of plant monitoring:

2 hours/day at 100 percent flow
12 hours/day at 75 percent flow
6 hours/day at 50 percent flow.

Estimate actual motor loads at each operation point.

Do not assume 75 percent flow equals 75 percent load. For fans and pumps, the load varies as the cube of the fan or pump speed.

100 percent flow: 100 horsepower X 1.00^3 = 100 horsepower.
75 percent flow: 100 horsepower X 0.75^3 = 42.2 horsepower
50 percent flow: 100 horsepower X 0.50^3 = 12.5 horsepower

Calculate new Energy Consumption at each flow level with ASD:

$$\frac{100 \text{ hp}}{0.92} \times 0.746 = 81 \text{ kW} \times 2 \text{ hours/day} \times 7 \text{ days/week} \times 52 \text{ weeks/yr} = 58{,}968 \text{ kWh}$$

$$\frac{42.2 \text{ hp}}{0.92} \times 0.746 = 34.2 \text{ kW} \times 12 \text{ hrs/day} \times 7 \text{ days/week} \times 52 \text{ weeks/yr} = 149{,}386 \text{ kWh}$$

$$\frac{12.5 \text{ hp}}{0.92} \times 0.746 = 10.1 \text{ kW} \times 6 \text{ hrs/day} \times 7 \text{ days/week} \times 52 \text{ weeks/yr} = 22{,}058 \text{ kWh}$$

Total Energy Use: 58,968 + 149,386 + 22,058 = 230,412 kWh

Yearly electric cost with the ASD:

34.2 kW X $5/month X 12 months =	$2052.00
230,412 kWh/year X 0.04/kWh =	$9,216.48
Total:	$11,268.48

Yearly Electric Cost Savings: $28,477.20 - $11,268.48 = $17,178.72

Simple payback: ASD Cost: $15,000 installed

$$\frac{\$15{,}000}{\$17{,}178.72} = \text{approximately 0.87 years or 10.5 months}$$

Installation of the ASD makes sense as long as it will last at least 0.87 years. This ASD was rated with a service life of 50,000 hours.

20 hours/day X 7 days/week X 52 weeks/year = 7280 hours/year operation.

$$\frac{50{,}000 \text{ hours}}{7{,}280 \text{ hours}} = 6.9 \text{ years average life in this operation}$$