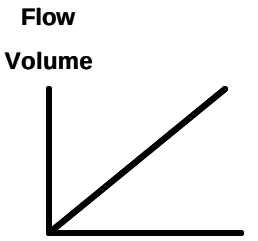
APPLICATION GUIDELINE #41

(VFD's & Energy Saving Variable Torque Applications)

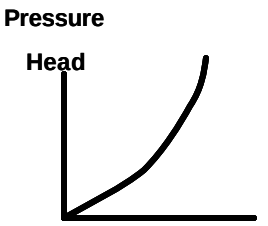
Variable Torque Applications

Variable Frequency Drive (VFD) applications can generally be broken down into constant torque or variable torque. A variable torque application is one which is usually easy to start and requires more torque as the speed of the motor is increased. Examples include Centrifugal Pump, Centrifugal Fan, and Low Viscosity Mixer. Constant torque loads require the same pushing or turning force (torque) at all speeds in the operation range of the machine. Typical examples are conveyers, hoists and positive displacement pumps.

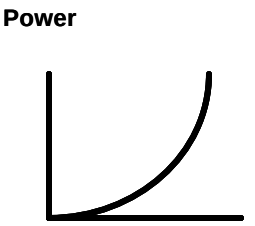
In a centrifugal pump or fan, affinity laws help us to understand that pressure is a result of the square of the speed, and power is a function of the cube of the speed. Using a VFD on variable torque loads allows you to take advantage of these affinity laws which state: As the speed of a centrifugal load decreases, the horsepower requirement will decrease with the cube of the speed, Head Pressure will decrease with the square of the speed, while flow is proportional to speed.



$$\frac{\text{Flow}_1}{\text{Flow}_2} = \frac{\text{RPM}_1}{\text{RPM}_2}$$



$$\frac{\text{Head}_1}{\text{Head}_2} = \left(\frac{\text{RPM}_1}{\text{RPM}_2}\right)^2$$

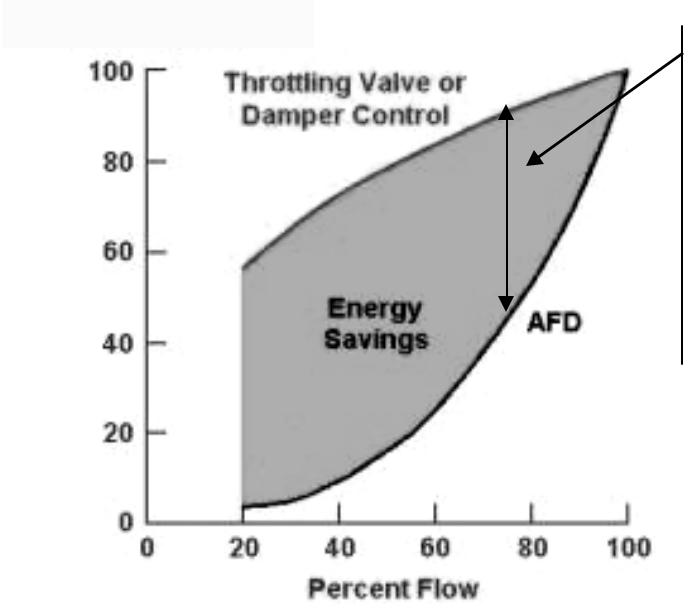


$$\frac{\text{Power}_1}{\text{Power}_2} = \left(\frac{\text{RPM}_1}{\text{RPM}_2}\right)^3$$

For variable torque loads, motors are sized for the horsepower of the application as if they were on a sine wave across the line starter. Because pressure decreases with the square of the speed motor current flow is insignificant at low operating frequencies. For this reason there is little concern for motor overheating at low speeds. VFD's can give several advantages to centrifugal type applications including:

- Soft start and stop, prevents water hammering in pump applications and prevents sagging of the power line from high inrush that would occur with across the line starting.
- Mechanical wear and tear on belts & drive train components such as gearboxes are reduced.
- If a valve or damper is used for process control by restricting flow, significant energy savings can result by using a VFD instead.
- If 2-speed motors are utilized, some energy savings can be achieved.
- Limiting speed when temperature changes occur in the air stream can control fan loading.
- Better process control than dampers or valves.

Utility companies and the HVAC industry have widely accepted that drives save energy when applied to centrifugal loads. The graph below demonstrates how a drive can dramatically save energy when used on a fan or pump with variable flow rates. The power savings and system efficiencies are much greater than those that utilize 'throttling valve' or 'damper control' for flow control.



A 20% drop in speed results in a savings of 40-45% in power consumption as compared to a throttling Valve or Damper Control system.

Energy Savings Calculator:

A tool Toshiba created to help calculate the energy savings that can be realized from using a VFD system instead of 'inlet guide vane' or 'outlet damper or throttling valve' is shown below. Motor information, VFD cost, and load profile (flow requirements) are all entered by the user, and the spreadsheet calculates the energy savings for the different types of flow control options.

Power Consumption Cost of Fixed Speed versus Damper / Valve, Inlet Vane Guide and ASD

Motor, Load and System Info

Motor HP	100		
FL RPM	1776		
	FL	3/4	1/2
Motor Efficiencies	95.4%	95.6%	95.3%
Load at 100% flow	100	(HP)	
Power Cost	5	(cents / KWHR)	
Operating hrs/day	24		
Days per year	365		

Load Profile

Operation Hours	Percentage of Flow
0	100%
2	90%
6	80%
7	70%
3	60%
5	50%
1	40%
0	30%
0	20%
0	10%
0	0%
24	

Cost Comparison per year

Fixed Speed	$34,250
Outlet Damper or Valve	$30,384
Inlet Guide Vane	$22,778
ASD	$12,270

Simple Payback

ASD Cost	$11,000
Install Cost	$4,000

ASD vs Fixed Speed	0.7	(years)
ASD vs Outlet damper	0.8	(years)
ASD vs Valve (on pump)	0.8	(years)
ASD vs Inlet Guide Vane	1.4	(years)

Yearly Energy Savings

ASD vs Fixed Speed	$21,981
ASD vs Outlet damper	$18,114
ASD vs Valve (on pump)	$18,114
ASD vs Inlet Guide Vane	$10,509

Note - Eddy Current Coupling efficiency profile is very similar to Inlet Guide Vane control.

2-Speed Motors

In order to take advantage of reduced power consumptions at lower flow rates some Original Equipment Manufacturer's (OEM's) have chosen to use two speed motors. Two-speed motors do help reduce power consumption at the lower speed, however these special motors cost more, only provide two operating speeds, and have significant reductions in performance values. On 2-speed motors the motor design is a compromise in that the winding is optimized for only one of the two speeds. For example a 1800RPM/900RPM motor, the winding design is based around the 1800RPM winding, the 900RPM winding performance values are sacrificed significantly, therefore seriously affecting the overall system efficiency. Furthermore, both power factor and efficiencies are lower than the values of a single speed design, for both the 1800RPM winding and especially the 900RPM winding. Toshiba created the calculator below to help users with 2-speed motors realize the increased efficiencies and benefits that one can obtain by using a VFD system instead of the two speed motor.

Power Consumption Cost of '2-Speed Motor' and 'VFD'

Motor, Load and System Info

Motor HP	100		
Upper Synchronous Speed (RPM)	1800		
Lower Synchronous Speed (RPM)	900	Flow %	50.00%
	FL	3/4	1/2
Single Speed Motor Efficiencies	95.4%	95.6%	95.3%
Power Factor	84.1%	81.2%	74.3%
2-Speed Motor: Efficiencies (Upper Speed)	95.1%	94.6%	93.1%
Power Factor (Upper Speed)	80.0%	75.5%	66.0%
2-Speed Motor Efficiencies (Lower Speed)	92.3%	91.5%	89.2%
Power Factor (Lower Speed)	54.5%	48.5%	38.0%
Load at 100% flow	100	(HP)	
Power Cost	5	(cents / KWHR)	
Operating hrs/day	24		
Days per year	365		

Load Profile

Operation Hours	Percentage of Flow	2-speed Load Profile
12	100%	
0	90%	Upper
0	80%	Speed
0	70%	
0	60%	
12	50%	
0	40%	
0	30%	Lower
0	20%	Speed
0	10%	
0	0%	
24		

Cost Comparison per year

Fixed Speed	$34,250
Two Speed Motor	$29,593
ASD	$19,748
Yearly Energy Savings	
ASD vs Two Speed	$9,845

Simple Payback

(New Application) Cost Diff 'VFD System' vs '2-Speed System'	$8,000	
VFD vs Two Speed Payback	0.81	(years)
(Retrofit Existing) Approx. Cost for New 'VFD System'	$18,000	
New VFD System Payback	1.8	(years)

Conclusion

Variable Frequency Drives (VFD's) are becoming very common in most industrial applications. Drives have advanced with many improvements and are now very application insensitive. The HVAC industry have adopted VFD's because of their ability to significantly reduce power consumption during off peak times. Other applications use them for speed control purposes, and even fixed speed applications are considered for drives to allow large motors to start and stop more often. Furthermore the advancements in Vector control have improved performance so much so that DC equipment is rarely considered if not required at all anymore. With caution for voltage stress and bearing currents, an AC application with a high quality motor and VFD can give years of reliable performance with virtually no maintenance.