

# ADJUSTABLE FREQUENCY/VARIABLE TORQUE DRIVES

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## ABSTRACT

A renaissance is occurring in the HVAC general market today; that being the utilization of adjustable frequency drives for controlling the flow of air or water. This paper will discuss the advantages and features of adjustable frequency drives versus typical mechanical methods. A brief overview of the variable torque loads versus A.C. motor capabilities will also be presented. The energy savings is also shown comparing adjustable frequency drives versus inlet vane and output damper control.

## GENERAL

The HVAC and pumping industry until recently designed their systems to require the motor to run at top speed continuously and they would mechanically control the input or output air or water flow to satisfy the demand. While this approach is somewhat simple, it is

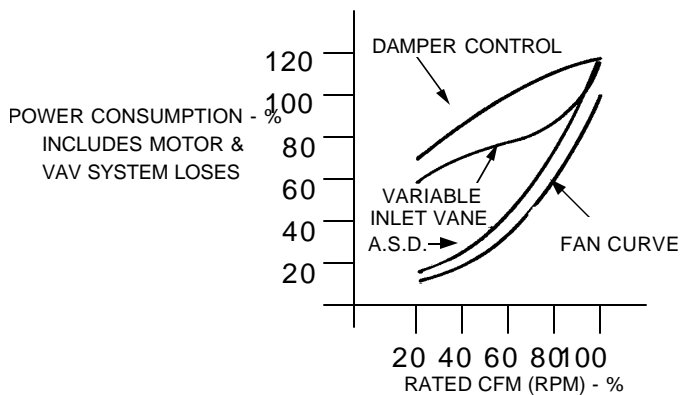


FIGURE 1

not cost effective for the User.

The AC adjustable frequency drive offers the ability to optimize the energy usage depending on the load (torque) requirements. Figure 1 illustrates the load characteristics of a typical variable torque application such as centrifugal loads, i.e. fans, blowers and centrifugal pumps, and compares the load requirements of three types of control. It should be noted that the fan curve and adjustable frequency power consumption curve are in basic harmony over the working range of 20-100% speed. This ability to work in harmony offers the user both a high overall efficient system (typically 95% or higher for the Inverter approach) and an energy savings as compared to variable inlet vane or damper

control. It should be noted that there is only one point that the power efficiencies for all three types of control are relatively the same - that being at maximum speed. At this point only, with the RPM (maximum CFM or flow) at 100%, the power consumption is basically

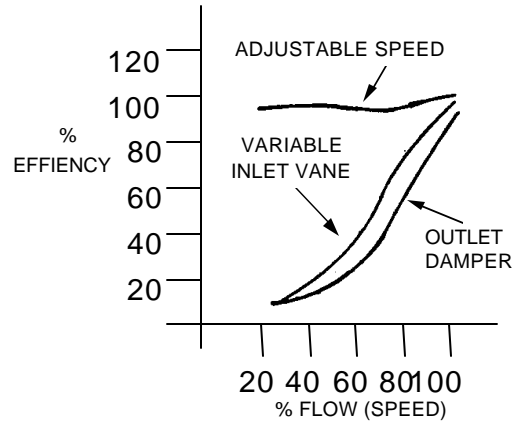


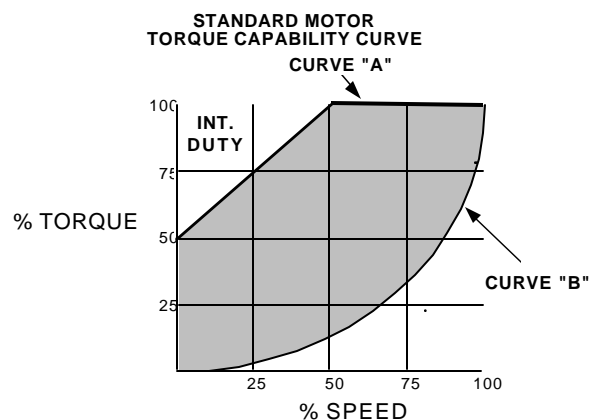
FIGURE 2

equal for both adjustable frequency and the mechanical means of control.

Figure 2 represents the efficiency of the three types of control method only over a 5:1 speed range (20-100% speed/flow). It should be noted that since all methods of control at top speed have similar system losses, these losses were not considered in the efficiency curve and therefore, at 100% a unit of 1 was utilized.

## THE MOTOR CONSIDERATIONS

The basic design of the motor allows it to provide rated torque at full speed. When utilizing a mechanical means of controlling the air or water flow/pressure, the motor remains at top speed continuously. When an Inverter is utilized, the motor is run at reduced speeds



variable torque load.

**FIGURE 3**

Figure 3, Curve "B" represents the torque requirements of a variable torque load illustrating that as the speed is reduced, the torque requirements of the load decrease substantially.

The shaded area in Figure 3 represents the area of safety margin that exists between the continuous torque capabilities of the motor versus the torque requirements of the load. This supports the fact that A. C. motors on new and existing applications with inverters need not be derated from a torque application standpoint.

**TYPES OF INVERTERS UTILIZED**

There are two basic types of inverters utilized in HVAC and pump drives.

Current Source Inverters (CSI) - This is utilized typically in 150-500 HP. One main reason for this is the inherent current limiting as a result of a large and costly inductor. The CSI is not ideal for selectable mult-motor applications and produces high voltage spikes to the motor.

Voltage Source Inverter - This method is typically utilized in 3-400 H.P. Being a voltage control type, it is ideal for multi-motor applications and works well with variable torque applications.

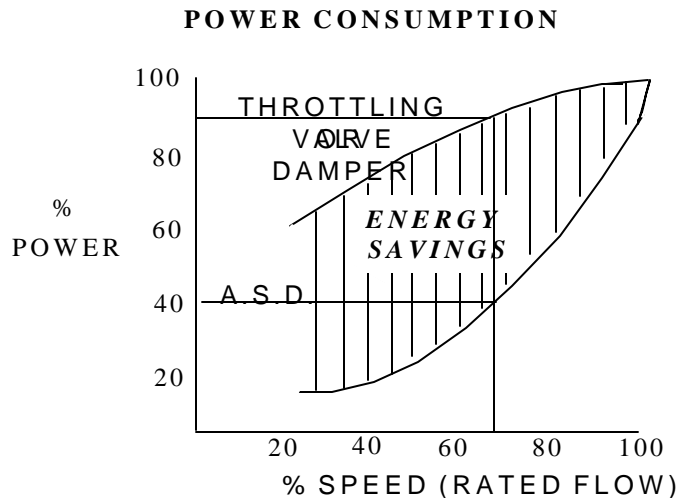
In addition to the previously mentioned types of Inverters, there are two basic methods of accomplishing an output.

Pulse Width Modulated (PWM) - This type produces a high frequency constant amplitude modulated wave to the motor which if not filtered, can possibly produce an annoying audible noise from the motor which may be transmitted through the air ducts. This result is due to the high harmonic content of the output of the inverter. This noise can actually be destructive to fan blades if resonant situations develop between the fan blades and the harmonic output of the inverter. This is a definite concern for air handling equipment.

S1x-Step Inverter - This method is typically utilized in 3-150 H.P. and is the simplest in circuit design. The six-step Inverter has a lower power factor than the PWM, but the concern is negligible as the KVAR required is reduced 60% at 70% speed.

**FAN OR PUMP ENERGY SAVINGS FOR VARIABLE TORQUE**

Most HVAC and pump applications are designed to spend a greater percentage of running time at reduced speed or output. Due to the nature of the load at reduced speed, the horsepower and torque requirements are greatly reduced resulting in possible significant energy savings for the user of the equipment. When an inverter is used with a variable torque load at



70% speed, it has a 60% reduction of power required as compared to a 20% reduction on a motor running at full speed utilizing damper control.

**FIGURE 4**

Figure 4 represents a comparison based on power consumed between typical mechanical means of air flow control versus a variable frequency type of control.

The following is an example of how an energy savings calculation is made utilizing a 50 H.P. system and at 70% speed. The actual savings would vary depending on such variables as duty cycle, percent of operating time versus real time, and the basic cost of the inverter utilized.

**TYPICAL ENERGY SAVINGS CALCULATIONS**

1. Convert fan drive motor H.P. to KW.

$$\text{Three Phase KW} = \frac{V \times A \times \text{PF} \times 1.732}{1,000}$$

2. From the fan graph, the relative power required (KW) for the designed flow rate for adjustable speed drives at 70% speed is:

$$\text{KW} = \frac{322 \times 26 \times .87 \times 1.732}{1,000} \quad \text{KW} = 12.6$$

V = With a variable frequency drive, typical voltage for a

given speed is directly proportional, thus:

$$(460V @ 70\% \text{ SPEED} = 460 \times .7 = 322V).$$

A = With a variable frequency drive, current (amps) is directly proportional with power required (typically 40% of total power at speed - Figure 4), thus:

$$50 \text{ H.P Full-Load Amps} = 65 \text{ Amps}$$

$$(65 \text{ AMPS @ 70\% SPEED} = 65 \times .4 = 26).$$

$$\text{P.F.} = .87 @ 70\%$$

3. From the fan graph, the relative input power required for the designed flow rate for the throttling, damper, valve etc. method at 70% speed.

$$\text{KW} = \frac{460 \times 58 \times .95 \times 1.732}{1,000} \quad \text{KH} = 43.90$$

4. Subtract the relative KW (Throttling method) from the relative KW (adjustable speed method) to result in the energy saved at 70% flow.

$$43.9 - 12.6 = 31.3 \text{ KW SAVED by utilizing a variable frequency system.}$$

5. An air handling fan operating 5 days a week for 10 hrs./day = 2600 hrs./yr.

6. The annual cost savings utilizing a cost factor for electricity of .06¢ per KWH. is;

$$31.3 \text{ KW} \times .06/\text{HR} \times 2600 \text{ HRS.} = \$4883.00$$

SAVINGS by utilizing adjustable frequency method.

Now that the apparent cost savings is calculated, it has to be compared to the cost of the variable speed drive. Typical Inverter cost for a 50 H.P. varies between five and seven thousand dollars. When this cost is compared to an energy savings of \$4,883.00, it is relatively easy to conclude that the payback of a 50 H. P. system is approximately 15 months (utilizing an Inverter cost of \$6,000.00).

It should be pointed out that this calculation is looking at one aspect of the overall system - that being the inverter cost versus energy savings. Air/water temperature and its effect were not considered in this sample calculation. This is a computation based for the User of the the equipment and not the OEM/

reseller. Since the OEM does not utilize the equipment, they will not receive any benefit of savings based on reduced power consumption; however, mechanical life of the equipment is extended.

### **DESIRABLE FEATURES UTILIZED IN HVAC**

When adjustable frequency drives are utilized for air or water handling, there are many features that are ideal from a variable torque application standpoint. The following are a few ideal standard features and some desirable optional features.

#### **Standard Features**

Automatic Restart - For unattended operation, this feature, when programmed, allows for an automatic restart after loss of line power or selected drive faults. After the controller has shut down due to a loss of line power, it will automatically attempt to restart. If the shutdown was due to an Inverter fault, it will attempt a restart three to five times after which it will remain off and provide an output for remote use. The restart circuit will reset after a predetermined period of successful operation.

Capable of Starting Into a Spinning Motor (Anti-Windmilling) - The controller may be programmed during its start-up sequence to apply DC power to the motor with an adjustable time and power level to insure that the motor is at rest before the inverter is started. This feature guarantees uniform starting conditions regardless of external status, i.e., windmilling.

Load Matched Timed Overload - The variable speed AC drive should monitor actual speed/torque operating levels and provide system protection at any given speed for detecting mechanical malfunctions such as bearing wear-out. A variable torque AC controller with an electronic timed overload circuit that is programmed by output frequency to detect unnaturally high loads over the complete speed range provides a maximum level of system protection.

Phase Loss Protection - The controller must detect phase loss and inhibit normal operation as necessary to prevent drive malfunction or damage. If the phase is lost, the controller interprets this as a power loss and shuts down the drive. Automatic restart is programmable if desired.

Power Loss Ride-Through - The controller should have sufficient energy stored in its logic power supply to maintain control of the motor for at least 20 milliseconds if the AC power source is temporarily interrupted. Upon reapplication of AC

line power, the motor should resume its set speed with a minimum of disturbance. The amount of speed droop during the power outage will be determined by the actual motor loading and other mechanical time constants.

### **Optional Features**

Line Bypass - Provides the capability to transfer the motor from controller to AC line operation in the event of drive failure. Line bypass may be manually selected to allow maintenance or troubleshooting activity or be fully automatic for unsupervised operation.

Resonance Eliminator - This feature is of particular concern in ventilation air handling system. Pulse width modulated (PWM) controls produce rapid voltage changes to the motor windings which produce high frequency audible motor noise with high harmonic content. The six-step control produces relatively little motor noise but mechanical resonance can still be a problem at some speeds. The resonance eliminator provides the capability to avoid operation at several independently adjustable speed settings and thereby prevent resonant operation.

Diagnostic Instrument - A first fault test instrument should be available to monitor and report on all important drive parameters. The instrument should be able to measure internal control voltages, output frequency, incoming line voltage and drive status and fault indication. Indication of external malfunctions via freezestats, smoke detectors, etc., is desired to further enhance fault detection. More sophisticated system installations may incorporate computer communication via RS232/RS485 serial port.

### **SUMMARY**

Personal comfort is why there is an HVAC industry. Effective use of power to achieve the maximum efficiency is the reason for adjustable frequency in the HVAC industry. Greater mechanical life will also be realized due to running the fan/pump at reduced speed to satisfy system demand and not at a continuous high speed. The moderate cost and high reliability of solid state equipment provide great incentive to utilize adjustable frequency drives.

### **REFERENCES**

(1) E.A.S.A., "Variable Frequency Drives".

(2) J. R. Prechtel, "Variable Torque Adjustable Frequency Drive For the Textile Industry", presented at the IEEE Textile Conference in Charlotte, North Carolina, May 6-7, 1986.