Adjustable Speed Drive
Part-Load Efficiency

An adjustable speed drive (ASD) is a device that controls the rotational speed of motor-driven equipment. Variable frequency drives (VFDs), the most common type of ASD, are solid-state electronic motor controllers that efficiently meet varying process requirements by adjusting the frequency and voltage of power supplied to an alternating current (AC) motor to enable it to operate over a wide speed range. External sensors monitor flow, liquid levels, or pressure and then transmit a signal to a controller that adjusts the frequency and speed of the motor to match process requirements.

Variable Torque Loads
Pulse-width-modulated (PWM) VFDs are most often used in variable torque applications in the 1 to 1,000 horsepower (hp) motor size range. For centrifugal fans or pumps with no static lift, the fan or affinity laws state that the fluid or airflow provided varies directly with the pump or fan rotational speed. The input power requirement varies as the cube or third power of the speed ratio, as shown in Figure 1. Small decreases in equipment rotating speed or fluid flow yield significant reductions in energy use. For example, reducing rotating equipment speed (flow) by 20% can reduce input power requirements by approximately 50%.

\[
\text{hp}_2 = \text{hp}_1 \times \left( \frac{\text{RPM}_2}{\text{RPM}_1} \right)^3 = \text{hp}_1 \times \left( \frac{\text{Flow}_2}{\text{Flow}_1} \right)^3
\]

Where:
- \(\text{hp}_1\) = driven-equipment shaft horsepower requirement at original operating speed
- \(\text{hp}_2\) = driven-equipment shaft horsepower requirement at reduced speed
- \(\text{RPM}_1\) = original speed of driven equipment, in revolutions per minute (RPM)
- \(\text{RPM}_2\) = reduced speed of driven equipment, in RPM
- \(\text{Flow}_1\) = original flow provided by centrifugal fan or pump
- \(\text{Flow}_2\) = final flow provided by centrifugal fan or pump

Figure 1. Power requirement for variable torque loads

Constant Torque Loads
A constant torque load is one where the torque requirement is independent of speed. Because horsepower requirements equal the product of required torque and speed, input power varies linearly with speed for constant torque applications. Examples of constant torque loads include cranes, hoists, conveyors, extruders, mixers, positive displacement pumps, reciprocating air compressors, and rotary screw air compressors.

Determining Energy Savings
To establish the energy savings that are possible when a VFD is applied to a variable or constant torque load, you must determine the load duty cycle, or percentage of time that the driven equipment operates at each system operating point. You must also know the efficiency of the variable speed drive and the drive motor when the motor is operating partially loaded and at a reduced speed to satisfy variable flow requirements.

When considering PWM VFDs, you may use manufacturer’s data or Table 1 to obtain efficiency values for drives of various ratings that supply power to motors connected to either variable or constant torque loads. Note that motor efficiency is also reduced at light loads and when the motor is supplied with a nonsinusoidal waveform.
VFD efficiency decreases with decreasing motor load. The decline in efficiency is more pronounced with drives of smaller horsepower ratings. As shown in the following example, this reduction in efficiency is not as detrimental as it first seems.

**Example**

Consider a VFD coupled to a motor that requires 16.4 kilowatts (kW) to deliver 20 shaft hp to an exhaust fan when operated at its full rated speed. At half its rated operating speed, the fan delivers 50% of its rated airflow but requires only 1/8 full-load power. Even with a reduced motor efficiency of 77.8% and drive efficiency of 86%, with adjustable speed operation the power required by the fan and the VFD is only 2.8 kW. For this example, input power requirements are reduced by 82.9%.

\[
\text{kW at 50% load} = 0.746 \times \text{kW/ hp} \times \left(20 \text{ hp} \times \frac{1}{2}\right) \div \left(0.778 \times 0.86\right) = 2.8 \text{ kW}
\]

Remember that the system efficiency is the product of the VFD efficiency, the motor efficiency at its load point, and the driven equipment efficiency (\(\eta_{\text{system}} = \eta_{\text{VFD}} \times \eta_{\text{Motor}} \times \eta_{\text{Equipment}}\)). Efficiencies for integral horsepower NEMA Design A and B motors at full and part load can readily be obtained from the U.S. Department of Energy’s MotorMaster+ 4.0 software tool. Efficiencies for driven equipment must be extracted from the appropriate pump or fan performance curves.

**Additional Information**


### Table 1. Adjustable Speed Drive Part-Load Efficiency*

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<thead>
<tr>
<th>Variable Drive hp Rating</th>
<th>Efficiency (%)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Load, Percent of Drive Rated Power Output</td>
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<tr>
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</table>

*These efficiency values may be considered representative of “typical” PWM VFD performance. There is no widely accepted test protocol that allows for efficiency comparisons between different drive models or brands. In addition, there are many ways to set up a VFD that can affect the operating efficiency. Source: Saftronics, Inc.

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**Resources**

National Electrical Manufacturers Association (NEMA)—Visit [www.nema.org](http://www.nema.org) for information on motor standards, application guides, and technical papers.

U.S. Department of Energy (DOE)—For more information on motor and motor-driven system efficiency and to download the MotorMaster+ software tool, visit the Advanced Manufacturing Office (AMO) website at [manufacturing.energy.gov](http://manufacturing.energy.gov).

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Washington, DC 20585-0121
manufacturing.energy.gov

DOE/GO-102012-3730 • November 2012