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Variable Frequency Drives

Prepared by:
Easton Consultants, Inc.

Northwest Energy Efficiency Alliance
PHONE
503-688-5400
FAX
503-688-5447
EMAIL
email@neea.org

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1.0 Motor Using Industries

This section deals with the installed base of motors in the U. S. This is critical to understanding the market for ASDs, as most are sold as retrofits to existing motor systems. In this section we discuss the following:

- Motor-using industries
- Installed base of motors
- Variable load operation
- Sales of new motors
- Expansion of installed base

1.1 Motor Using Industry Groups

We have divided industrial and commercial motor-using industries into six types. Each one has distinct characteristics as to the size and type of motors in place, and the types of adjustable speed drive opportunities.

- *Light and medium industry* are largely mechanical-process oriented companies, such as auto parts and assembly, food production, semiconductor manufacturing, and light machining. Motor using processes include machining, assembly, packaging, fabrication, and HVAC.

- *Process industry* are those manufacturing industries that process large volumes of materials, such as pulp and paper mills, chemicals plants, oil refineries and steel mills. Motor using processes include, moving and refining liquids, rolling and shaping metals and plastic materials.

- *Other heavy industries* are non-manufacturing activities, such as mining and other extractive processes, oil and gas production, and power plants. Motor using processes are petroleum production, conveying of bulk solids, and air and fuel supply in generating electricity.

- *Water and wastewater* are municipal water and wastewater plants and irrigation districts. Motor-using processes are pumping and aeration of large quantities of wastewater.

- *Commercial HVAC* is the heating and cooling of commercial buildings of all sizes and types. The motor-using processes include compressors for cooling, pumps for the distribution of chilled and heated water, and fans for air movement.

- *Agricultural industries* are processes on farms using motors for irrigation pumping and farm products processing.

1.2 Population of Motors by Size

While most integral[1] motor units are concentrated in commercial HVAC and light and medium industry, most of these are less than 50 horsepower.

Most of the larger motors, that are the primary interest in this evaluation, are concentrated in the process industries, other heavy industries and water and wastewater. Over 85 percent of the motors over 500 horsepower are concentrated in these three groups. In the 200 to 500 horsepower range, these three groups along with commercial HVAC, account for 93 percent of the units (Exhibit 1.1).

EXHIBIT 1.1
US INTEGRAL MOTORS IN PLACE BY SIZE AND USER GROUP [1)]
(000s)

		Population of Motors by HP Range					
Market Segments	**Total Number of Integral Motors**	**Under 50**	**50 to 100**	**100 to 200**	**200 to 500**	**Over 500**	**Total over 50 HP**
Industry							
Light and Medium Industry	**7,157**	6,981	96	58	15	7	176
Process Industry	**4,299**	3,842	232	128	65	32	457
Other Heavy Industry	**1,724**	1,364	206	84	118	32	440
Water and Wastewater	**170**	129	19	25	30	14	88
Commercial HVAC	**35,236**	34,800	260	80	92	4	436
Agriculture	**132**	52	61	13	10	0.5	85
Total	**48,718**	47,168	874	388	330	90	1682

[1)]AC Motors only
Source: DOE Motor Market Opportunities, Industry Reports, Easton estimates, Easton field research

1.3 Number of Motors with Variable Load

To establish a base for the opportunity for adjustable speed drives, we have estimated the number of motors in-place that operate with variable load. We have based the definition of variable load on that used by the 1998 Motor Challenge Study, "United States Industrial Electric Motor Systems Market Opportunity Assessment," which defines

[1] One horsepower or larger

variable load as variability of 30 percent or greater from highest to lowest during the motor's normal operating cycle. This was selected as the threshold of variable load where an adjustable speed drive can be justified economically from electrical energy savings.

In Exhibit 1.2 we have estimated the total motors over 50 horsepower for each of the six user groups, and for each we have estimated the number of motors that are operating under variable load as defined above. Generally, the number with variable load runs from a low of 10 percent in agriculture to a high of 35 percent in other heavy industry. In total, we estimate that of the 1,682,000 motors of 50 horsepower and over in-place, approximately 25 percent of them, or 421,000, operate with variable load.

EXHIBIT 1.2
TOTAL US INTEGRAL MOTORS IN PLACE WITH VARIABLE LOAD
OVER 50 HP [1)]
(000s)

User Groups	Typical Variable Load Application	Total	Number with Variable Load	Percent with Variable Load
Industry				
Light and Medium Industry	**Machine Control HVAC Product Handling**	**176**	47	27%
Process Industry	**Pumps and Fans Rolls, Sheet Handling Conveyors**	**457**	102	22%
Other Heavy Industry	**Pumps and Fans Reduction Equipment Compressors**	**441**	154	35%
Water and Wastewater	**Pumps Aeration Equipment**	**88**	21	24%
Commercial HVAC	**Pumps and Fans**	**436**	87	20%
Agriculture		**85**	8	10%
Total		**1,682**	421	25%

[1)]AC Motors only
Source: DOE Motor Market Opportunities, Industry Reports, Easton estimates, Easton field research.

1.4 The Market for New Motors

The market for new integral motors has grown in the past five years at a compound annual growth rate of 13 percent annually. The sales of all motors over 50 horsepower has grown at a slower rate of 8 percent and the largest motor-size category, those over 1000 horsepower, are growing at 11 percent.

The increase in the installed base of motors has grown slowly. Most new motors are purchased to replace existing motors. Of the new sales of two million annually, approximately 50 percent of the units are sold as replacements for failed motors and an additional 20 to 30 percent are sold as part of OEM equipment that replaces motor using equipment in place. The portion of new motors going to replacement is about the same across the ranges of motor size (Exhibit 1.3). It should also be noted that there is an active motor rewind industry. Most motors over 50 horsepower are rewound several times in their useful life.

EXHIBIT 1.3
US SALES OF INTEGRAL HP MOTORS BY SIZE [1)]
1993 TO 1997 EST.
(000s)

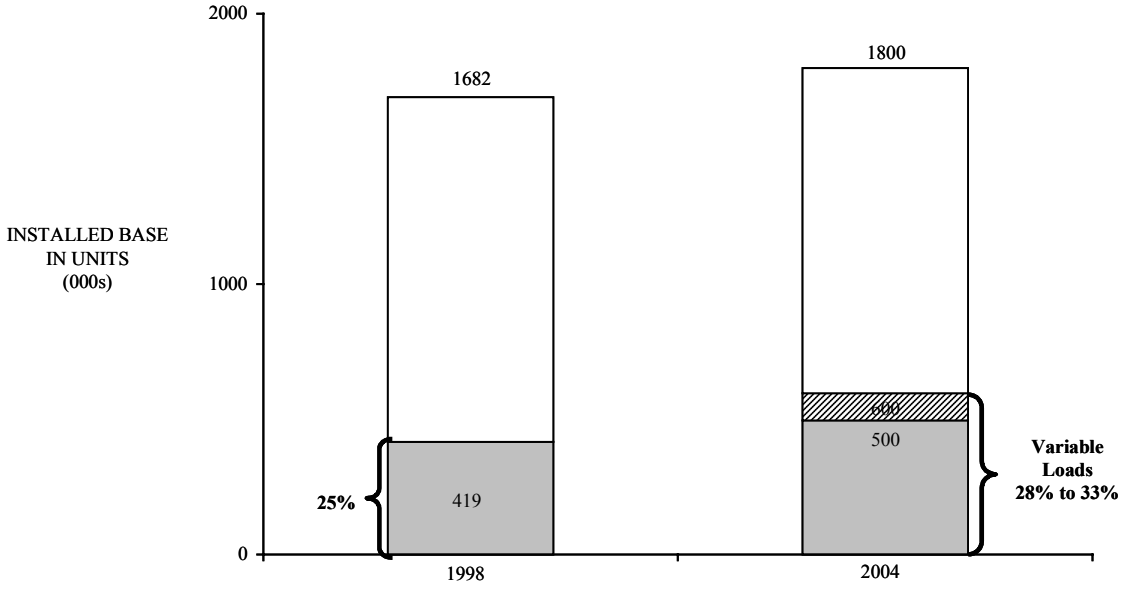
HP	1993	1994	1995	1996	1997	CAGR
Under 50	1,183	1,365	1,573	2,113	1,923	13%
50 to 100	47	50	53	62	64	8%
100 to 200	25	28	32	35	36	9%
200 to 500	15	16	22	17	18	6%
500 to 1000	2	2	2	2	3	5%
Over 1000	2	3	3	3	4	11%
Total	1,274	1,463	1,685	2,232	2,048	13%
Total Over 50 HP	90	99	112	119	125	8%

[1)]AC Motors only
Source: US Dept. of Census report MA36H.

1.5 Growth in the Installed Base of Motors

The installed base of integral motors over 50 horsepower in the U.S. is expected to grow slowly but steadily in the next the five years, from approximately 1,682,000 to 1,800,000 in the year 2004. Of these, the number operating under variable load is expected to expand faster than the total, from 420,000 in 1998 to between 500,000 and 600,000 in 2004. This results from an ongoing search by users for opportunities for finer, more efficient control of their processes. Exhibit 1.4

EXHIBIT 1.4
PROJECTION OF THE INSTALLED BASE OF INTEGRAL MOTORS
OVER 50 HP AND THOSE OPERATING UNDER VARIABLE LOAD
1998 TO 2004



2.0 Market for ASDs

In this section we discuss the market for all ASDs. We include the following:

- Various types of ASDs
- Growth of sales of ASDs
- Energy savings potential
- Penetration of ASDs by industry
- Forecast of overall penetration

2.1 Types of ASDs

There are five types of adjustable speed drives available. Each one has different characteristics in terms of the technical principles used to achieve speed control, and the mix of applications for which it is typically used. The five types are as follows:

1. *Variable frequency drives (VFDs)* are electronic devices that control the speed of the motor by controlling the frequency of the voltage at the motor. These devices are used in a wide range of the applications and are able to provide constant-torque and variable-torque operation, and in the last few years have been developed to achieve position control. They are used in virtually every type of motor system from pumps and fans to web roll control, machine tools, and many others.

2. *DC adjustable speed drives* are electronic devices that control DC motors by changing the voltage applied to the motor. DC ASDs are the traditional ASD device and are used almost exclusively for constant load (cranes, elevators, hoists) and close speed control/positioning (plastic callendering, metal rolling processes and machine tools). DC ASDs have not been considered in depth in this report.

3. *Eddy-current drives* are electrical devices that use an electro-magnetic coil on one side of coupling to induce a magnetic field across a gap creating an adjustable coupling. Eddy-current drives have been in wide use for well over 50 years and have found applications in variable-torque applications, rough duty, and high-starting torque applications. They are found in material handling conveyors, stamping presses, HVAC pumps and fans.

4. *Hydraulic drives* are devices operating much like an automotive hydraulic transmission. Typical applications are found in constant-torque, difficult environments and rough-duty applications. They are found driving large pumps, conveyors, and mining equipment.

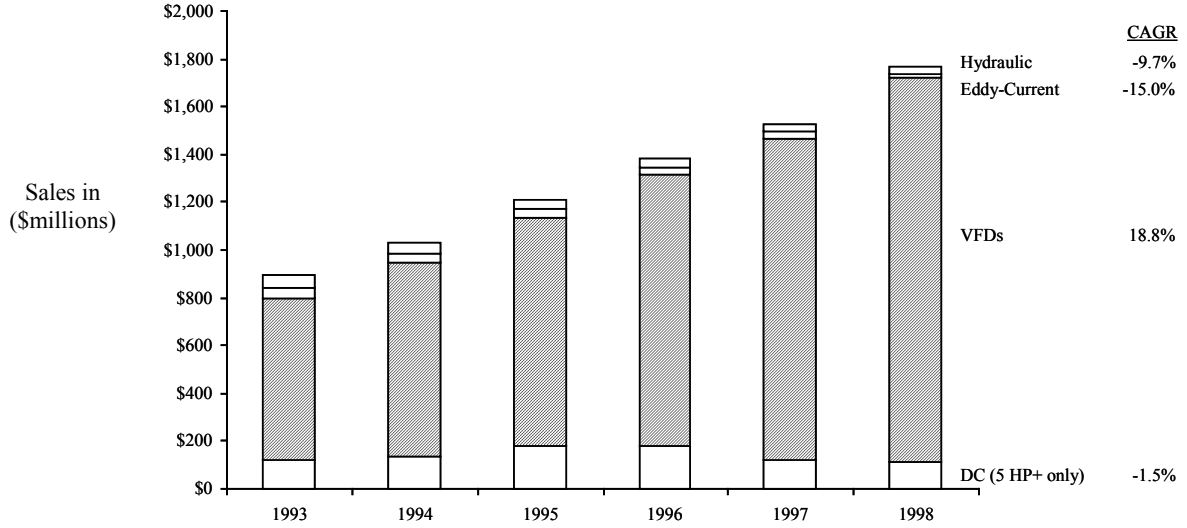
5. *Mechanical devices* can be used to control speed. Mechanical speed control products include gearing, mechanical transmissions and belt drives with variable pitch pulleys. They are the traditional adjustable speed drives and used in a large variety of

machinery. (The mechanical adjustable speed drive has not been a major focus of the study, as they are only marginally competitive with other ASDs.)

2.2 Sales of ASDs

ASDs have expanded steadily in the past five years driven by the growth of VFDs which have taken share from older technologies, and have developed many new applications for adjustable speed based on the great variety and range of applications in which they can be used and their lower cost. In total, the VFD sales in dollars have expanded at a rate of 19 percent per year in the past five years, while the older technologies of DC drives, hydraulic and eddy-current drives have declined substantially (Exhibit 2.1).

EXHIBIT 2.1
SALES OF ASD BY TYPE AT END-USER PRICES
1993 TO 1998

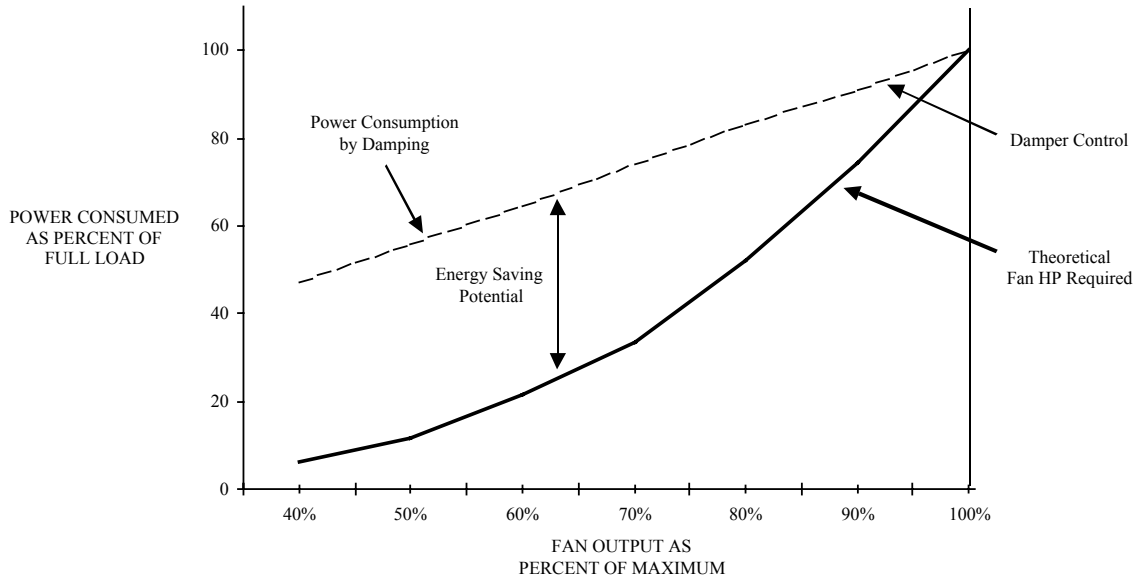


Note: Small DC drives have not been included.
Source: Industry Reports, Easton competitive interviews.

2.3 Energy Savings of ASDs

ASDs have potential to save electrical energy if applied to variable load applications that now use flow restricting control devices, such as throttling, damping, and recirculating to control the process. For example, in Exhibit 2.2 the energy consumed by a typical fan under damper control is compared to the energy theoretically required by the motor for the same fan output. While the energy consumption is the same at 100 percent load, the energy required drops rapidly with part load. The energy savings from an ASD results from eliminating the damping and moving closer to the theoretical minimum requirement.

EXHIBIT 2.2
TYPICAL CENTRIFRUGAL FAN OPERATION
AT PART LOAD



2.4 Penetration of ASDs

In total, about 24 percent of integral motors over 50 horsepower operate with variable loads, but only about nine percent are now under ASD control. Considering the six user groups reveals that light and medium industry have the highest penetration of ASDs at 13 percent, while 27 percent have variable loads. This includes a large number of ASDs used for machine control. Process industries with 22 percent variable load have only seven percent under ASD control. Other heavy industry with 35 percent variable load has only 6 percent under ASD control. Water and wastewater and commercial HVAC each have a strong 11 percent penetration against the 24 and 20 percent estimated variable load applications. Agriculture has the lowest penetration (Exhibit 2.3).

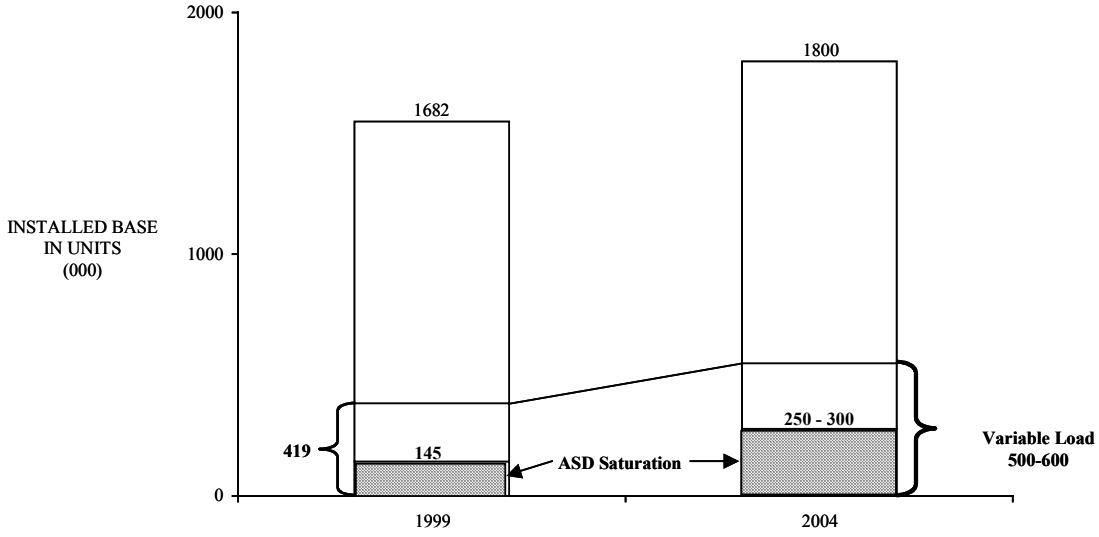
EXHIBIT 2.3
TOTAL US INTEGRAL MOTORS
OVER 50 HP UNDER ASD CONTROL
(000s)

User Groups	Total Number	Number w/Variable Load	Percent Variable Load	Number ASD Control	Percent ASD Control
Industry					
Light and Medium Industry	176	47	27%	23	13%
Process Industry	457	102	22%	34	7%
Other Heavy Industry	440	154	35%	36	6%
Water and Wastewater	88	21	24%	10	11%
Commercial HVAC	436	87	20%	5	11%
Agricultural	85	8	10%	2	2%
Total	1,682	419	24%	145	9%

2.5 Forecasts and Overall Penetration

In total, ASDs are expected to reach a penetration of about half of the variable load applications by 2004. ASDs in place should expand by about 20,000 units per year on motors over 50 horsepower. We estimate that the number of the large motors over 50 horsepower under ASD control will move from 145,000 to between 250,000 and 300,000, or nearly 50 percent of the variable load motor population of 500,000 to 600,000 in that year (Exhibit 2.4).

EXHIBIT 2.4
PROJECTED SATURATION OF US VARIABLE LOAD APPLICATIONS
OVER 50 HP
1999 TO 2004



Source: Easton Consultants estimates, Industry Reports.

3.0 ASD Buying Process

In this section we discuss marketing, distribution and purchasing of ASD, specifically:

- Marketing of ASDs
- Distribution patterns
- Purchasing process

3.1 Marketing of ASDs

ASDs are marketed like other high-value, technical industrial components. This requires the following:

- Direct sales representatives, either salaried or manufacturer's representatives, who prospect for applications with potential end-users and support the distributor network.

- Direct technical specialists who support the field by providing application expertise, detailed pricing of specific applications, and in some cases, installation oversight.

- Specialized distribution, such as motion products, electrical components or motor distributors, particularly for the smaller-sized units.

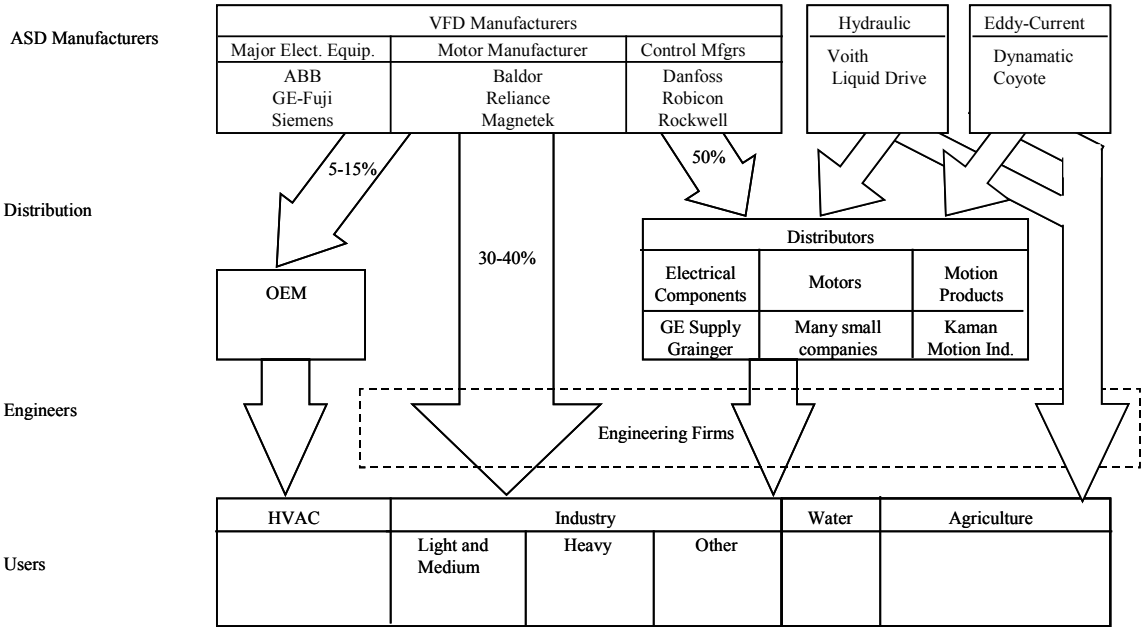
- Headquarters customer service for expediting order taking, as well as telephone technical support to the field -- users, sales reps, and distributors.

3.2 Distribution of ASDs

The distribution of ASDs is made through a combination of direct sales and sales through distributors. Exhibit 3.1. VFD manufacturers sell approximately 50 percent of their volume through specialized distribution -- motion products, motor, or electrical components distributors. Approximately 30 to 40 percent of their sales are direct to the end-user, including a large portion of the over 500 horsepower units. About 5 to 15 percent of sales are sold through OEM manufacturers, a growing channel as VFDs are increasingly being designed into equipment.

Hydraulic adjustable speed drives and the eddy-current drives are sold in a similar fashion, but with a greater portion sold on a direct basis, estimated at 60 to 70 percent, and the rest through distributors and OEMs.

EXHIBIT 3.1
ADJUSTABLE SPEED DRIVES
INDUSTRY STRUCTURE



3.3 Purchasing Process

There are three ways that a user can acquire an ASD -- in-house staff purchase, an engineering firm recommendation, or as part of an OEM purchase:

1. *Most of the purchases of ASDs are made through the in-house staff that is charged with identifying cost saving or process improvement opportunities*. In-house staff involved typically include maintenance, plant or building engineers, and a variety of other related titles. These acquisitions are on a project-by-project basis and are part of the ongoing process/plant improvement program that continually searches for cost reduction and improvements in process. These are often done on a retrofit basis and may be part of a larger process improvement project.

2. *An engineering firm or consultant may identify an opportunity as part of a plant construction project, continuing engineering support, or a building management contract*. In most of these situations the purchase of an ASD will typically be part of a larger project, particularly in plant construction. Use of outside engineering support is usually found with the less sophisticated user groups, such as water and wastewater plants, where engineering firms may be on retainer or in commercial buildings where building owners often hire a contractor to manage the facility.

3. *Purchase as part of an OEM package.* While ASD sales through OEMs are still relatively small, they are growing as users develop increasing comfort levels with their use. With HVAC equipment, for example, there is a growing inclusion of ASDs in larger equipment packages by the major equipment suppliers --Trane, Carrier, and York.

Typically, the purchase of an ASD for plant improvement is justified by a return on the initial investment, calculated as "years-to-payback," or the initial cost divided by the annual net savings. A typical payback objective is two to four years. Some companies have a more sophisticated financial justification model using discounted cash flow and after-tax returns, but a simple payback calculation is the most common. Virtually every ASD project must compete against other projects for a limited pool of capital funds allocated to the facility for ongoing improvement. Usually these capital planning cycles cover one calendar year.

While energy savings is usually a key factor in justifying the purchase of an ASD, other costs savings are considered such as:

- Better control of the process and less wastage of product
- Quality improvement
- Lower maintenance costs through better controls and less mechanical stress on the system
- Increased life of the equipment
- Lower electrical demand charges through reducing start-up, in-rush current.

There are constraints on the purchase and justification of any plant improvement because of downtime planning and disruptions, time to evaluate design and install product, and overall capital budget availability. These constraints and the need for evaluation on a project-by-project basis mean that ASDs are usually purchased as part of one-at-a-time project rather than wholesale replacement.

4.0 The Market for VFDs

In this section we review the market for VFDs, the predominant type of ASD. The VFD accounts for most of the ASD market and is critical to the development of the market in total. Specifically we will discuss:

- Background of the device
- Operation of the VFD
- Cost of the VFD
- Efficiency of operation
- Market for VFDs
- Technical problems with VFDs
- Manufacturers of VFDs.

4.1 Background of the VFD

The VFD is the dominant type of ASD on the market representing over 90 percent of ASD units sold in recent years. The VFD was first introduced in volume in the early 1980s and its use has expanded rapidly due to two factors -- steadily improving performance along with a continual drop in price.

The improving performance of the VFDs has resulted directly from rapidly evolving semiconductor technology. Among the improving performance characteristics are:

- Improving electrical characteristics
- Ability to handle higher power levels
- Easier programming of desired control response
- Steadily increasing reliability and ruggedness
- Smaller size of the unit.

While the performance of VFDs has tracked the improving capabilities of integrated circuits, the cost of the VFDs tracked their falling price. Over the past ten years, the cost of VFDs has dropped on average of four to six percent per year while performance has improved. The decrease in price has come as each manufacturer brings out a newly redesigned VFD line replacing the previous line on a three to five year cycle.

4.2 Operation of the VFD

The VFD converts three-phase AC voltage at a frequency of 60 hertz to AC voltage at a controlled lower frequency. Controlling the frequency controls the motor speed, as the speed of an induction AC motor is proportional to the frequency of the voltage applied. The design has two parts -- first a rectifier that changes the AC current to DC and a

second section that uses an electronic algorithm to convert the DC voltage to AC voltage at the desired frequency.

The VFD can perform a variety of motor control tasks, including the following:

- Variable-torque control to drive a fan or pump under light head.
- Constant-torque control to drive a pump or compressor or other equipment against higher head.
- Constant horsepower to drive a machine tool, such as a lathe or milling machine.
- Motion control for precise control of position needed in rolling steel or calendering plastic sheeting.

In addition, the VFD can be designed for various other characteristics, such as:

- Overload of protection with automatic cut outs for poor quality power feed -- along with automatic restart if needed.
- Soft start of a device starting under load allowing the motor and load to come up to operating speed slowly, reducing in-rush current and/or the need to oversize a motor for start-up.
- Fast and precise response to changes in the control of the system.

The VFD can be designed to operate at low voltage (460 volts), intermediate (2300 or 4160 volts) or high voltage (12,300 volts). The intermediate and high-voltage units are expensive due to the high cost semiconductor devices required for high voltage. The device can also be designed to operate with virtually all sizes of motors from fractional horsepower to over 20,000 horsepower.

While VFD technology is nearly always used to make the motor run slower for controlled part-load operation, it can also be used to operate the motor faster than designed, avoiding the use of a gear train in some cases.

4.3 Cost of the VFD

Generally, at low voltage the installed cost of a VFD varies from about $160 per horsepower at 50 horsepower to $100 at 500 horsepower. At intermediate voltage, above 500 horsepower, the cost rises to about $130 per horsepower because of the higher cost of the components.

The cost of the VFD can vary substantially depending on the specific situation. A complex installation can cost substantially more than a basic installation. For example:

- The basic installation would use a standard VFD for a variable-torque application, NEMA 1 enclosure (for indoor application), operator keypad in the enclosure, temperature control using a fan mounted on the enclosure, overload protection, a line reactor, and fault protection. In these cases users estimate the cost of installation as no more than 15 percent of the cost of the equipment.

- A high-cost installation might require a NEMA 12 enclosure (for wash-down application) or a specially temperature-controlled room, a remote operator keypad, load and line reactors, input line fuses, output contactor options and even a possible requirement for a new motor. In these cases, installation can run substantially more than the basic installation.

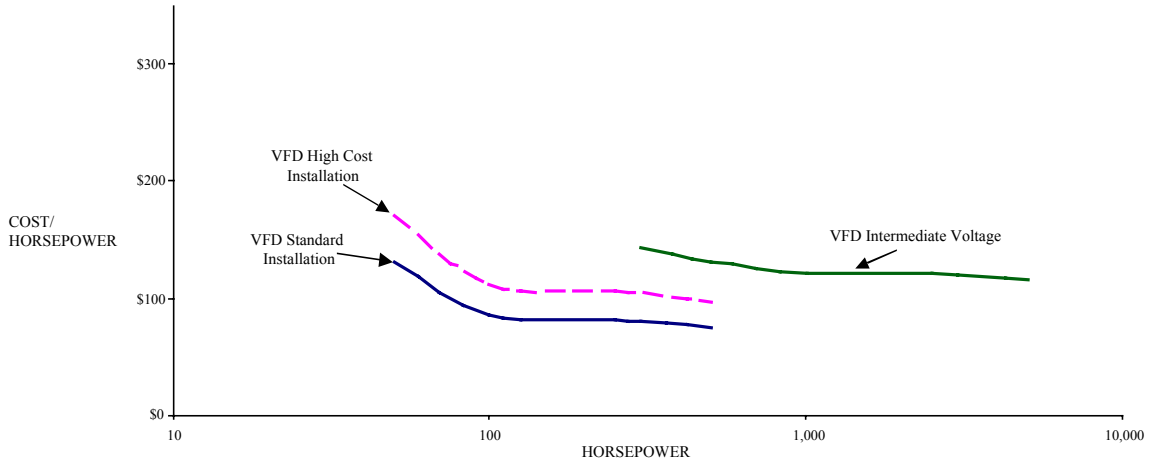
In Exhibit 4.1 we have displayed the cost of a typical VFD for both a basic and complex installation. Further, we have plotted the low voltage and intermediate voltage costs.

While the cost of the VFD can very widely as shown, in reality, most VFD applications are basic and their cost falls in the lower part of the range. For example, most facilities that have used the VFDs in the past will have rooms with the proper air-conditioning already in place. As a result, a new VFD can be installed in these rooms quite easily. Further, most of the supplemental devices, such as fuses, line reactors, and other elements are now packaged with the basic unit. Therefore, while there are applications where the VFD requires a high-cost installation, most do not.

The voltage at which the plant operates larger motors is important in the cost of the VFD for these ranges. Most industrial plants in the U. S. operate their motors at low voltage (460 volts) up through 500 horsepower, as they have found that the trade-off between motor cost and plant transformer and wiring costs crossover at this point. However, an estimated 15 to 20% of industrial plants use intermediate voltage for motors to as low as 250 horsepower. In this situation the cost of a VFD for the 200 to 500 horsepower motor range is expensive.

Another variation on the common pattern is the use of low voltage in motors as large as 2000 horsepower expressly for the purpose of using less expensive, low-voltage VFDs. In these cases custom form-wound motors designed to run at low voltage are installed and are controlled by standard low voltage VFDs. Dow Chemical Co., one of the most sophisticated companies in use of motors, commonly uses this approach with success.

EXHIBIT 4.1
COST PER HORSEPOWER
VFDs

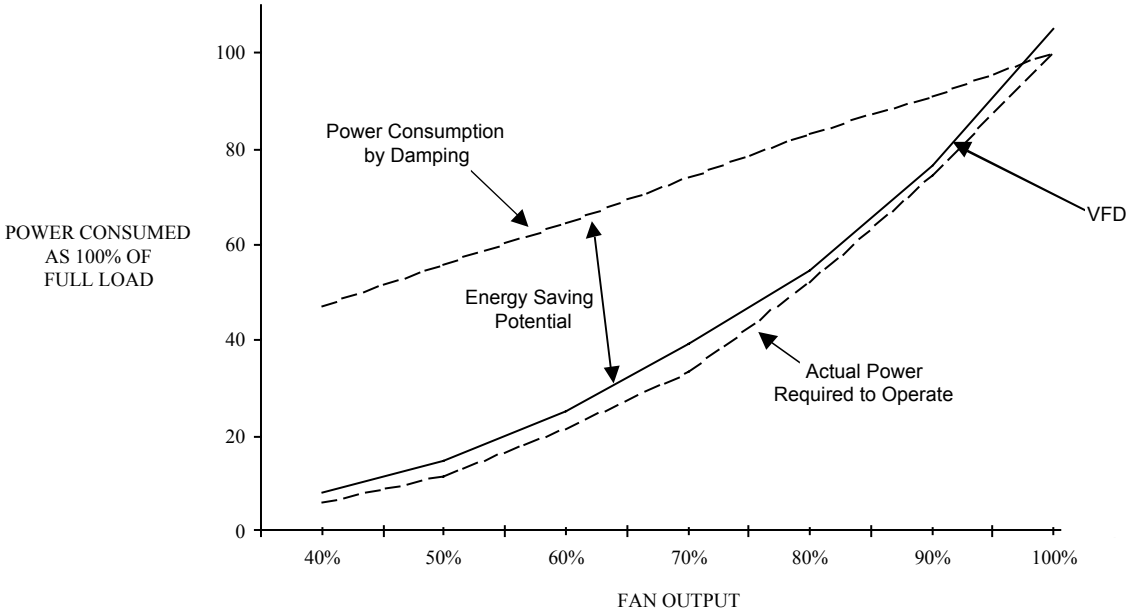


Source: Competitive interviews, field research.

4.4 Efficiency of Operation

VFDs have the potential to save a considerable amount of energy as they closely track the theoretical least-energy requirement of an installation. For example, the lower energy required by a VFD driven fan compared to damper control, the savings are striking as shown in Exhibit 4.2. The small difference in power requirement between the VFD and the theoretical power required reflects the energy required to operate the VFD's electronics. While the VFD savings is particularly striking with fan and pumps systems operating against a friction load, VFDs will also bring energy savings to pumps and fans applications operating against higher-head applications.

EXHIBIT 4.2
TYPICAL CENTRIFUGAL FAN OPERATION AT PART LOAD
USING A VFD



Source: Easton competitive interviews and field research**.**

4.5 Market for VFD

The U.S. sales of VFDs have grown rapidly in the past five years. From a total of 220,000 units in 1993, sales have grown to an estimated 640,000 units in 1998. Exhibit 4.3. While small VFDs, less than 50 horsepower, have grown the fastest at 24 percent per year, the very large units over 1000 horsepower have grown at 21 percent. The growth of the VFD in units overall is more rapid than the growth in dollars because of the steadily declining price of the device.

There is a high concentration of VFDs in light and medium industry where a large number are used for machine control. However, the larger units over a 100 horsepower, and particularly over 200 horsepower, are concentrated in the process industries, other heavy industry, and water and wastewater. While the sales of the VFDs in dollars by sector tracks the unit sales, the value of the larger units is striking. VFDs of over 200 horsepower account for sales of $370 million, nearly 25 percent of the total (Exhibit 4.4).

EXHIBIT 4.3
US SALES OF VFDS
1993-1998
(000s)

HP	1993	1994	1995	1996	1997	1998	Annual Growth
1 to 50	202	252	313	389	483	600	24%
50 to 100	13	16	19	22	25	30	18%
100 to 200	3.0	3.5	4.1	4.6	5.7	6.5	16%
200 to 500	2.3	2.5	2.8	3.2	4.0	3.5	9%
500 to 1000	1.2	1.4	1.6	1.7	1.9	2.4	15%
Over 1000	0.3	0.4	0.5	0.5	0.6	0.8	21%
Total	220	273	338	418	517	640	24%

Source: Industry Reports listed in bibliography, Easton estimates.

EXHIBIT 4.4
US VFD SALES BY SECTOR
($MILLIONS) [1)]

User Groups	1 to 5 HP	6 to 20 HP	21 to 50 HP	51 to 100 HP	101 to 500 HP	201 to 500 HP	> 500 HP	Total
Industry								
Light and Medium Industry	260	179	76	121	35	14	-	684
Heavy Industry	84	78	42	70	25	32	124	456
Other Industry	9	7	7	<5	6	18	41	88
Water and Wastewater	20	18	10	13	11	18	104	194
Commercial HVAC	48	38	24	38	10	18	-	176
Agricultural				<5	<5			<10
Total	421	320	158	242	87	100	270	1,598

[1)] End-user price

4.6 Technical Problems with VFDs

During the 20 years that VFD's have been available, there have been a variety of technical problems in their application that have discouraged many users from using them. At the same time there has been considerable progress in correcting these problems. The primary problems that have plagued VFDs and the steps taken to correct them are as follows:

- *Overly complex electronics* -- electronics have been simplified by increasing use of integrated circuits, easier programming, and other design improvements.

- *Harmonics created that reflect back up line* – low cost input reactors have been developed that filter out harmonics. The algorithms that create motor voltage have been improved, decreasing harmonics.

- *Spikes causing breakdown of motor insulation* -- output reactors have been developed to reduce spikes and improved algorithms are creating motor drive voltage closer to sinusoidal form.

- *Motor bearing failure because of random high-frequency current in the rotor that flows to ground through the bearings* -- improved algorithms have reduced these and in steps can be taken to ground the motor shaft.

- *Limits to the distance from the VFD to the motor with early designs requiring the drive to be within 50 feet of the motor* -- steps have been taken to increase the distance between VFD and motor with output line reactors. The VFD can now be installed as far as 500 feet from the motor.

- *Input power spikes causing overload that shuts down the VFD* -- new designs use DC bus filters reducing the possibility of spikes, and automatic reset is available.

- *Requirement for temperature controlled environment* -- new designs, particularly the 500 horsepower and below, are routinely designed with a cabinet that is fan cooled with ambient air. Many larger units are offered with a built-in chilled water cooling system. Neither situation requires a separate climate controlled room.

- *Large space requirements for the larger units in the over 500 horsepower range* -- with Insulated-Gate Commutated Thyristors (IGCT) replacing Insulated-Gate Bipolar Transistors (IGBT) in large units at intermediate voltage, the size of the required cabinet has been reduced to approximately a quarter of that required by previous designs.

While VFD manufacturers have made steady progress in reducing problems, many segments of the market have been slow to recognize the improvements and many

potential users are still reluctant to install VFDs. This was found to be particularly true in less technically sophisticated user groups.

4.7 VFD Manufacturers

There are more than 25 manufacturers of the VFDs serving the U.S. market. We have divided the principal ones into three types of companies reflecting their basic business and how VFDs fit into that business. These groups are:

1. *Broad-line electrical equipment companies* sell a wide range of electrical equipment and devices and offer VFDs as an important part of this product line. These companies include ABB, General Electric Industrial Controls Division, and Siemens. Together these companies have a market share of about 35 percent on a dollar basis. They concentrate on the large-size drives and account for most of the intermediate voltage units. General Electric also has a distribution agreement with Fuji of Japan for smaller-size drives.

2. *Electric motor manufacturers* sell VFDs as part of their motor line. These companies have approximately 25 percent of the market and include Baldor, Magnetech, and Emerson. Also, Toshiba, which is a heavy electrical products manufacturer on a global basis, concentrates on the motor market in this country.

3. *Automation products companies* use the VFD has a key part of their controls product offering, which may include - machine controls, motors starters, switching devices, PLCs, and other control products. This group includes Rockwell (who also owns the Alan Bradley and Reliance lines), Cutler Hammer, and Robicon. These companies have concentrated on the smaller-sized units, generally under 500 horsepower. The exception is Robicon, which offers several models in large sizes, and will soon offer units in the 12,400-volt range. In total, these companies have a 40 percent share of the market.

The sales, market share, VFD product line description and industry focus of these companies are summarized in Exhibits 4.5, 4.6, and 4.7.

EXHIBIT 4.5
BROADLINE ELECTRICAL EQUIPMENT COMPANY
VFD SALES

Name and Location of VFD Operations	Est. VFD Sales (millions)	Est. Share of Market	Product line Emphasis	Industry Strength
ABB New Berlin, WI	$200-240	20%	Full range of product from fractional to a recently introduced intermediate voltage unit to over 5,000 HP	Chemical Pulp HVAC Water and wastewater
General Electric (GE Industrial Control Systems Group) Salem, VA	$80-90	7.5%	A range of product in the lower voltage range – torque-control, speed control, vector drives. Joint venture with Fuji provides deep small unit offering. Expanding higher voltage line.	Refineries HVAC Water and wastewater
Siemens Albany, NY	$50-60	5%	Product in the low voltage range primarily; list a drive up to 5000 HP+.	Refineries Metals

Source: Company Annual Reports, Easton competitive interviews and field research, Industry Report listed in the bibliography. Sales in manufacturer prices

EXHIBIT 4.6
ELECTRIC MOTOR MANUFACTURER
VFD SALES

Name and Location of VFD Operations	Est. VFD Sales (millions)	Est. Share of Market	Product Line Emphasis	Industry Strength
Baldor Ft. Smith AR	$50-60	5%	Broad line of products for low voltage	Across Industry
MagneTek (A.O. Smith) Milwaukee, WI	$50-60	5%	Broad line of low voltage products – private brands Yaskawa products	Automotive
Emerson Electric St. Louis, MO	$50-60	5%	Has acquired a broad line of electrical controls – servos, AC and DC controls from small to 1500 HP	Metals Process Control HVAC
Toshiba Houston, TX	$50-60	5%	A higher cost line in the low voltage	Refinery Metals

Source: Company Annual Reports, Easton competitive interviews and field research, Industry Report listed in the bibliography. Sales in manufacturer prices

EXHIBIT 4.7
AUTOMATION PRODUCT COMPANY
VFD SALES

Name and Location of VFD Operations	Est. VFD Sales (millions)	Est. Share of Market	Productl ine Emphasis	Industry Strength
Rockwell Automation (Allen Bradley-Reliance) Mequon, WI	$230-250	22%	Extremely broad range of VFDs up to 400 HP.	Automotive Chemical Pulp and Paper HVAC Food and Beverage Water
Danfoss Rockford, IL	$30-35	3%	Range of products generally oriented to machine control; has a heavy-duty line to 500 HP.	HVAC Food and Beverage
Cutler Hammer (Eaton Corp.) Oldsmar, FL	$20-25	2%	480 volt units from small to 1100 HP sold with motor starters, overload devices, etc.	HVAC
Robicon New Kensington, PA	$50-60	5%	Range of products including growing line of intermediate voltage.	Water and Wastewater Food and Beverage

Source: Company Annual Reports, Easton competitive interviews and field research, Industry Report listed in the bibliography. Sales in manufacturer prices.