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Efficient Alternatives for Electric Drives

G. Alan Comnes
Richard W. Barnes

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EFFICIENT ALTERNATIVES FOR ELECTRIC DRIVES

G. Alan Comnes
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EFFICIENT ALTERNATIVES FOR ELECTRIC DRIVES

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ABSTRACT

This analysis of industrial electric motors describes the current motor stock, its energy use and operating characteristics, and innovations that could change current use patterns. It provides calculations characterizing the economic attractiveness of several existing and potential options. One attractive option given particular attention is the adjustable-speed drive which can replace throttles or valves for many pumping operations. A major conclusion is that, throughout industry, options that are both energy-saving and economically attractive appear to penetrate markets more slowly than would be socially optimal. The final section examines characteristics of industry that may contribute to slow market penetration.

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1. INTRODUCTION

This report examines alternative technologies that improve the efficiency of electric drive systems. The goal of this report is to evaluate each alternative's energy efficiency, economic efficiency, and possible effect on future electricity demand. Three technologies are examined: energy-efficient induction motors, new motor designs, and adjustable-speed drives (ASDs).

Although it is relatively easy to identify technologies that offer significant energy efficiency improvements to drive systems, the great diversity in the type, size, and use of electric motors, and the lack of comprehensive data to characterize the existing motor stock make it difficult to determine the economic efficiency of an "average" application. In all technologies evaluated, an effort is made to consider typical applications. However, common variations are also evaluated to show the sensitivity of the economics to these variations.

The examples do not attempt to evaluate all the factors necessary to determine accurately the true economic efficiency of a technology. To do so, one would have to show that the operator of a motor process is using that process in an economically optimal manner and that the prices that the user pays for electricity and for capital accurately represent the costs incurred by their producers. Although these factors--especially electricity pricing--can cause significant economic distortions that prevent the optimal utilization of an energy-efficient technology, they are not examined here. Rather, the economics of each technology is evaluated by primarily using a payback analysis of actual end-user costs for capital and electricity. In order to differentiate between this limited view of optimality and a more global view, the terms "economic attractiveness" and "cost effectiveness" are used rather than "economic efficiency."

Evaluating the effect that new technologies will have on electricity demand is difficult due to the lack of data on existing motor stocks and also due to the lack of sales or penetration data on the technologies examined. Although the data are insufficient to allow accurate prediction of electricity demand effects, all available data are presented herein, and important variables necessary for determining demand effects are identified. Also existing research previously preformed on demand effects is summarized.

Besides the main section (Section 4) that evaluates specific technologies, the report has three more general sections that examine important engineering and economic conditions affecting motor energy consumption. Below is a brief description of each of the Sections 2 through 6.

Section 2 characterizes the current U.S. motor population, electricity consumption, and applications (end-uses). From the general patterns of motor use presented, particular users who have control over large amounts of motor capacity and who are sensitive to electric motor operating costs are identified.

Section 3 describes the environment in which electric motors are employed, the basic energy conversion principle of an electric motor, and the design of three different types of motors, with a focus on the alternating current (ac) induction motor. This section gives background for the technology options investigated and explains why ac induction motors dominate in industry.

As described above, Section 4 details the energy efficiency, economics, and demand effects of efficient motor technologies.

Section 5 discusses four general factors that affect decisions concerning the purchase of electric motors--future product demand, capital availability, split incentives, and information availability and reliability. The section shows that factors not included in the economic analyses of Section 4 can affect decisions concerning motors, and that these factors can lead to a suboptimal choice for the industrial motor user.

Section 6 summarizes the report.

2. CHARACTERISTICS OF U.S. ELECTRIC DRIVE STOCK

Electric drive (motors) is the largest general end-use of the electric energy produced by utilities.* To date, the most definitive work on motor stock characteristics is a 1980 study sponsored by the Department of Energy (DOE) entitled Classification and Evaluation of Electric Motors and Pumps.[1] The study estimated the consumption of electrical energy by motors for different sectors, industries, and motor size classes. A primary result of the study is presented in Figure 1, which shows the proportion of total electricity consumption of motors by major industry groups and households in 1977. The figure shows that, except for the residential sector, motors consume the large majority of all electricity produced. Electric motors consume 80% of the electricity purchased by the industrial and commercial sectors and 58% of the electricity sold to all sectors.

The primary fuel required to produce the electricity for all motors is nearly 20% of U.S. primary energy consumption. Thus, any technological improvement available to the entire class of electric motors could have a significant impact on U.S. electricity consumption. Unfortunately, no one technology would be applicable to all motors. The models, sizes and design of motors number into the tens of thousands. Motors are used by pumps, compressors, fans, mechanical processes, and transportation vehicles and are operated for varying periods of time (duty cycle). The end-use of an electric motor has just as much importance in determining its energy consumption as does the efficiency inherent in its design.

Thus, in order to determine an industry's electricity demand impact from adopting new motor technologies, more than just the absolute amount of motor electricity consumption by the industry must be considered. An industry's distribution of motor types, sizes, and duty cycles must also be known or estimated in order to determine the effect of a new technology.

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* Electric drive is a general term for any electrically powered system that provides motion for a process. The principal component of most electric drives is an electric motor, but other parts of an electric drive include the power supply, control system, and any gearing or speed-control components. Electric drive and electric motor are generally used synonymously although electric drive sometimes refers solely to the components powering the motor. In this report, the term electric drive is primarily reserved for situations where more than the motor of a system is being considered.

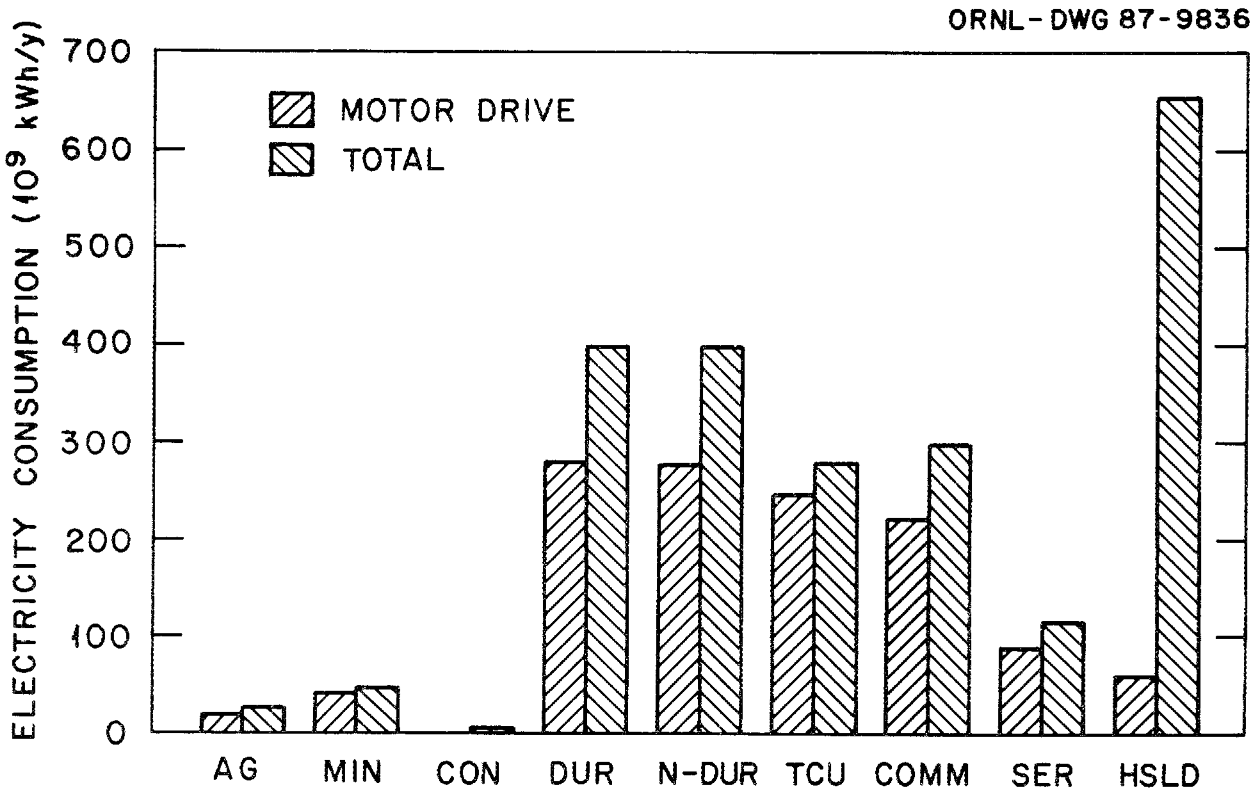

Fig. 1. Motor and total electricity consumption.
(Breakdown by major industry group, 1977.)

One way of predicting the importance an industrial technology change will have on electricity demand is to examine the average motor size of the industry's stock. Table 1 shows the average rated motor size for each of the major industry groups presented in Figure 1. It shows that mining; durable manufacturing; non-durable manufacturing; and transportation, communication, and utilities have significantly higher average motor sizes. Average motor size is an important characteristic for analysis because the largest motors, as a class, consume the greatest amount of electricity. This can be seen in Figure 2 and Table 2 which show the population and yearly electricity consumption for electric motors by size class. Although the greatest number of motors fall into the smaller size categories, their small sizes and light duty cycles make their energy consumption almost negligible. The class of motors larger than 125 hp consumes the most electricity even though it makes up less than 0.05% of the national inventory. Thus, the decisions made by industry groups who use large, average motor sizes will have the greatest effect on electricity demand.

Table 1. Average rated motor size of major industry groups--1977

Industry group	Average rated size	
	(hp)	(kW)
Agricultural	3.9	2.9
Mining	14.5	10.8
Construction	1.0	0.7
Mfg. non-durable	20.0	14.9
Mfg. durable	24.0	17.9
Transportation, communication, utilities	150.0	111.9
Commercial	6.0	4.5
Services	2.0	1.5
Households	0.4	0.3

Also an important measure of an industry's motor intensity is its proportion of yearly motor operating costs to total sales. Table 3 shows the industries with the six highest ratios for 1977. These industries are primarily from the non-durable manufacturing industry group. These industries are also a part of the industrial classification known as process industries. Process industries are typically considered to be the six industries listed in the table along with food processing and petroleum refining.

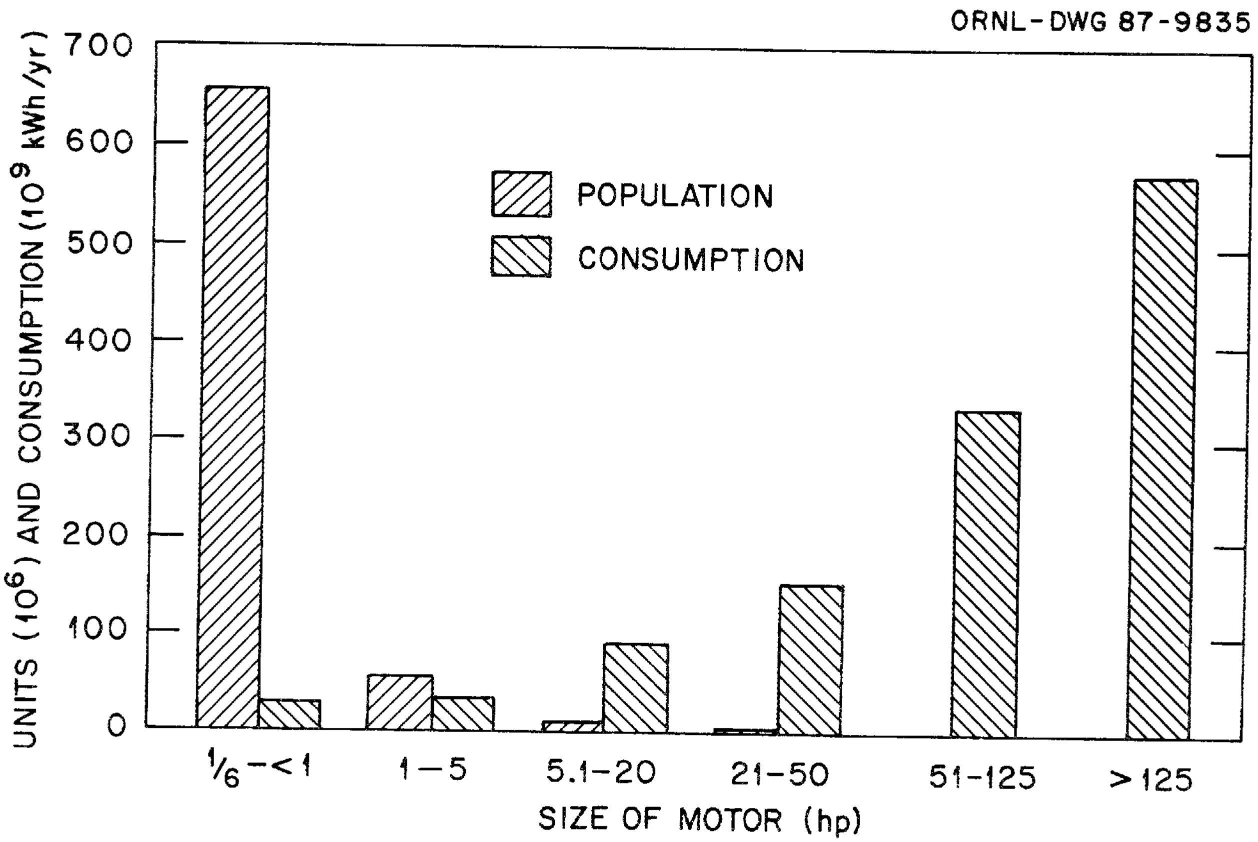

Fig. 2. Population and electricity consumption.
(U.S. motor stock: breakdown by size, 1977)

Table 2. National inventory, total electricity consumption, and sales characteristics of U.S. electric motor stock -- 1977

Size class		Population		Consumption (per year)		Motor and rebuilt sale rates (% of national inventory)		
(hp)	(kW)	(10^6)	(%)	(10^9 kWh)	(%)	New	Replace	Rebuilt
1/6-<1	0.12-0.74	658.0	90.4	30.0	2.5	3.0	4.7	0.0
1-5	0.75-3.7	54.6	7.5	33.8	2.8	3.0	2.8	0.0
5.1-20	3.8-14.9	10.4	1.4	91.3	7.5	3.0	2.2	1.2
21-50	15-37.3	3.3	0.5	155.2	12.7	3.0	1.6	4.7
51-125	37.4-93.2	1.7	0.2	337.7	27.7	3.0	0.5	7.7
>125	>93.3	0.1	0.0	573.2	46.9	3.0	0.4	9.0
TOTALS:		728.1		1221.2				

Source: U.S. DOE report DOE/CS-0147 (Ref. 1), Table 3-14.

Table 3. Motor drive costs as a percentage of total sales of selected industries - 1977

Industry	(%)
Primary Metals	3.0
Pulp and Paper	2.6
Chemicals	2.2
Stone, Clay, and Glass	2.0
Textile Mill Products	1.4
Rubber, Misc. Plastics	1.3
Avg. for All Manufacturing	1.0

Source: Adapted from U.S. DOE Report DOE/CS-0147 (Ref. 1), p. 3-63.

Process industries are also the major users of pumps, compressors, and fans. A later section in this report will show that these applications have options available to them that can significantly improve their motor drive efficiency.

The data presented here indicate that process industries are substantially more sensitive to motor electricity consumption than the average for all manufacturing. Thus, they are likely to have a significant effect on electricity demand when adopting new technologies. Consequently, this report will focus primarily on options available to process industries.

3. THE ENVIRONMENT AND DESIGN OF ELECTRIC MOTORS

3.1 THE ENVIRONMENT OF ELECTRIC MOTORS

Comparing the mechanical work output to the energy input, industrial motors have higher efficiencies than many other energy processes (usually 80% or above). However, a motor's incoming energy is electricity which requires significant energy losses when it is generated. Also, other parts of the motor system may have energy losses greater than that of the motor.

Table 4 breaks down losses for a typical motor-driven fan or pump system. It shows that a system may produce a desired mechanical work output of only 13% of the original primary energy input. Although the motor drive alone has an intrinsic efficiency of 84%, extrinsic efficiencies are much smaller. Nominal electricity generation from fossil fuel is only 31% efficient, and the rest of the system in this example is only 52% efficient.

Ideally, a process designer is interested in the most cost-effective way of reducing losses. The most economical option may or may not involve the motor. For example, a fluid system with fouled pipes would benefit from a more efficient motor in that total power requirements would be reduced but it might save as much energy and be less expensive to simply clean the system's pipes. Another example of an option not involving the motor is fuel switching. Some large drive systems are powered by steam or gas turbines; however, when the cost of liquid fuels rises relative to electricity and the uncertainty surrounding the cost and regulation of coal combustion continues, there will be pressure for marginally efficient users to switch to electricity.

If the boundaries of a motor system are broadly defined, the number of available technology options will increase. To focus on options that have the widest application, those evaluated here are the options that closely involve a system's motor.

3.2 THE DESIGN OF ELECTRIC MOTORS

The design of an electric motor determines its important energy characteristics. Below are descriptions of three motor types - ac polyphase induction motors, direct current motors, and synchronous motors. The basic energy conversion principle and popular applications for each type are included. The main focus will be on ac polyphase induction motors because they dominate motor electricity consumption.

An electric motor consists of a stationary component, known as the stator, and a moving component, known as the rotor or arma

Table 4. Component efficiencies of a typical electric drive system

System component	Output/ utility input (%)	Efficiency of component (%)	Major component group	Average group efficiency (%)
Gross primary energy consumption of motors	104			
Purchased by electric utilities for motors	100	96	Electric utility	31
Generation	33	33	Electric utility	31
Distribution	30	94	Electric utility	31
Shaft output (motor & gearing or belts)	25	84	Electric drive (intrinsic)	84
Pump, compressor, or fan	16	64	Rest of system (extrinsic)	52
Controls (e.g., throttling)	15	94	Rest of system (extrinsic)	52
Piping	13	87	Rest of system (extrinsic)	52

ture. These components react with each other to create a torque on the moving component.

3.2.1 Alternating Current (ac) Polyphase Induction Motors

The three phases in the electrical line current supplied from a conventional generator are run through different poles in the motor's stator, thus generating a rotating magnetic field. This field is able to induce a current in the rotor if the rotor turns at a speed slightly slower than the rotating field in the stator. The induced current in the rotor generates its own magnetic field, and this field reacts with the stator field to create the mechanical force. Most induction motors have rotors made up of bars between non-conducting laminations on the rotor. The shape of these bars has caused this type of ac motor to be called a "squirrel-cage" or "cage" motor.

The ability of a motor to induce its own rotor current is a very attractive features. There are no electrical connections between the rotor and the stator. Also, the three-phase nature of the line current serves as a readily rotating force. No device to maintain electrical connection with a rotating field (called a commutator) is necessary. This makes for a relatively inexpensive and durable piece of equipment. Induction motors are also characterized as being self-starting, having a constant speed (although varying slightly at different loads), and having a relatively strong starting torque.

These characteristics have led to the dominance of induction motors in medium and large (larger than 5 hp) industrial applications. DOE's <u>Classification</u> report[1] estimated that 93% of all existing motor capacity consists of induction motors larger than 5 hp.

Losses for a typical motor are graphed as a fraction of rated load in Figure 3.[2] Three loss components - friction, windage, and magnetic core losses - are constant with the load of the motor. Thus, as load is increased, these losses decrease in proportion to the mechanical energy output of the motor. Two components-current (I^2R) in Figure 3 and stray load losses - increase with the square of the load on the motor. The result is an efficiency curve that typically looks like the curve shown in Figure 4. Note that the efficiency drops off significantly if the load on the motor is less than 50% of its rated load.

Strategies to increase induction motor efficiencies are not new. Since a 1% increase in efficiency for a motor with an existing efficiency of 90% represents a 10% reduction in losses, any efficiency improvement is difficult. In general, incremental efficiency improvements are made by increasing the active metals in the motor, which decreases the current and core losses. The

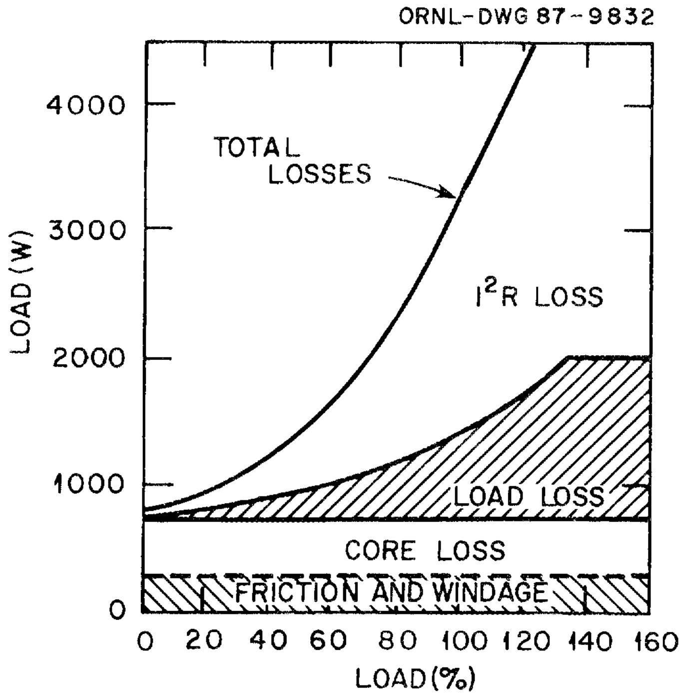

Fig. 3. AC polyphase induction motor losses vs percent load breakdown by loss type.

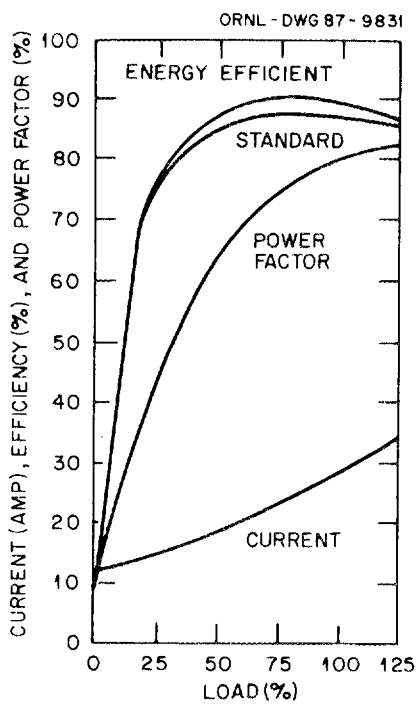

Fig. 4. Efficiency of standard and energy efficient motors vs load.

result is a motor similar to those commonly produce twenty years ago--more efficient but heavier and more expensive.

Although not directly measured by efficiency, an important energy-loss characteristic of an induction motor is its power factor. A motor's power factor is the ratio of the in-phase, or active current to the total current in the line. For nonmotor electric devices, the power factor is equal to unity. Induction motors, by virtue of their design, produce a magnetic field. This field creates a reactive current that adds to the total current in the plant and distribution lines. When reactive current enters the distribution system, higher losses occur in the system's lines and transformers. Accordingly, most industries are charged at a higher rate for their electricity, if their power factor is significantly lower than unity.

The power factor of a typical standard motor is graphed in Figure 4. Note that the power factor quickly drops off at loads less than full load. Energy-efficient motors usually have higher power factors, but they also exhibit this same drop-off at reduced load.

Industrial plants can reduce their power factor from actions within the motor and in series with it. Most energy-efficient motors have inherently better (higher) power factors, which feature adds to their value (and initial cost). The power factor of a plant can be reduced outside the motor by installing capacitors in series with the motor or by simultaneously running a synchronous motor that has a power factor greater than unity (see 3.2.3 below).

3.2.2 Direct Current (dc) Motors.

A dc motor runs electrical current through both its stator and its armature. Current is brought through the armature via brushes mounted on the commutator at the end of the armature. Unlike an ac motor, the magnetic field in the stator remains stationary. In order to maintain a constant direction of torque, the direction of the current in the armature is reversed via the commutator when it passes between the poles of the stator, thus producing a magnetic field which continuously reacts with the stator field.

For dc motor operations where dc electricity supply is not available (the usual situation), incoming ac power must be converted to dc via a motor-generator set or a rectifier. Although this adds to the drive's total cost, these components are usually able to vary the voltage, giving the drive the added feature of speed control. Although adjustable speed can be a very desirable feature in many applications, dc motors are more costly to produce and require more maintenance; therefore, they have been used mainly where speed control is essential. Also, dc motors have very high starting torques, making them necessary for hard-to-start and very slow-moving applications.

3.2.3 Synchronous Motors.

Another type of ac motor is the synchronous motor. It has direct current in its rotor and polyphase current in its stator to create the necessary magnetic fields. Direct current (dc) excitation of the rotor allows the motor to "lock-in" with the frequency of the ac line current, giving the machine constant, precise speed. Like the dc motor, however, a synchronous machine needs dc current and a brush commutator to transmit the current to the rotor. It is, therefore, more costly and less durable.

Synchronous motors are used where precisely constant speed is needed over varying loads or in systems needing power factor correction.

Although the widely used induction motors show superiority over dc motors and other types of ac motors for the reasons noted above, there is still room for improvement of induction motor efficiency and speed control. Thus, the technologies considered in the next section are primarily alternatives to or refinements of the induction motor.

4. ENERGY-EFFICIENT OPTIONS FOR ELECTRIC MOTORS

4.1 ENERGY-EFFICIENT INDUCTION MOTORS

Figure 5 shows the range of efficiencies available from standard and energy-efficient motors in sizes from 5- to 100-hp (3.7- to 75-kW). The figure shows that typical efficiencies for standard motors are relatively high, ranging from 82% to 93%. The efficiencies of readily available energy-efficient motors range from 88 to 94%. Although the incremental improvement brought by energy-efficient motors may seem small, the yearly electricity savings are large compared to the incremental costs between the two types of motors. An induction motor operating with a duty cycle typical for the process industries will consume 5 to 10 times its capital cost in operating costs every year. Thus, even a 1% increase in efficiency is likely to be advantageous compared to the extra cost (premium) of buying a more efficient motor. Figure 5 also shows typical purchase cost premiums between standard and energy-efficient motors. As illustrated in the figure, this premium is typically 10 to 25% of the original capital cost of a standard motor.

The following is an example of the energy savings and the economic effects of choosing an energy-efficient motor over a standard motor for a 25-hp load. From the following typical characteristics one can compute the yearly energy saved by converting to an energy-efficient motor:

- motor size: 25 hp = 19 kW (1 hp = 0.7457 kW)
- standard motor efficiency: 87.5%
- energy-efficient motor efficiency: 91.4%
- duty cycle: 4000 h/yr, full load.

The yearly energy savings for this example is 3636 kWh/yr. To determine the total dollar value of the savings from the energy-efficient motor, the following information is needed: the present and future cost of electricity, taxes affected by equipment purchases and net income, and the discount rate or the required rate of return. Table 5 lists one set of values chosen for these variables and summarizes the calculations of the net present value (NPV) of energy savings[3] (see Appendix B). The values for initial electricity price and real yearly price escalation are average values taken from Energy Information Administration (EIA) surveys and forecasts.[4] Three real discount rates--5%, 10%, and 15%--are used as examples of the required rate of return necessary for a low, average, and high-risk investment. Note that the "effective discount rate" is the discount rate adjusted for the escalation of electricity prices.

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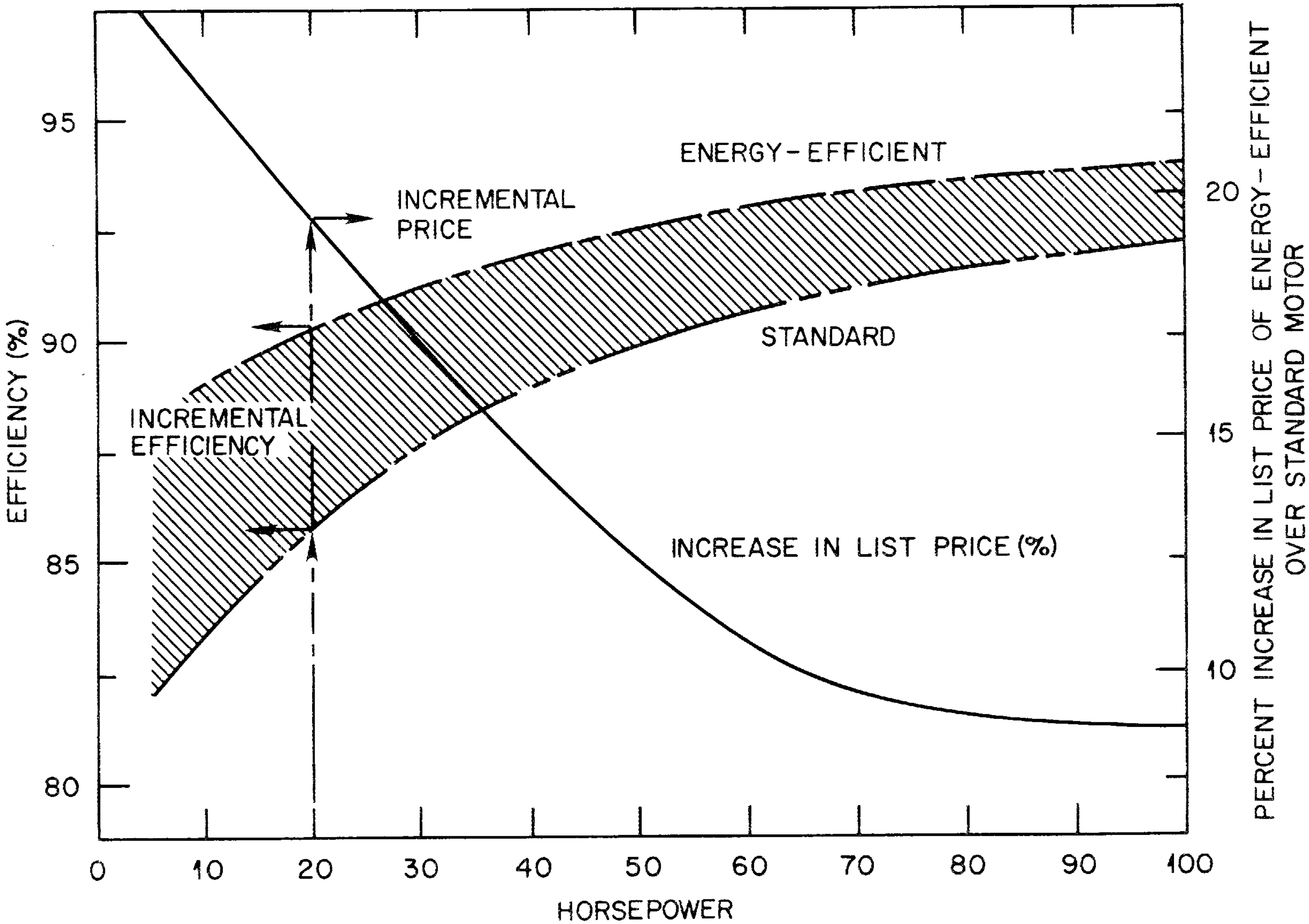

Fig. 5. Comparison of the efficiencies and prices of standard and energy-efficient motors vs size.

Table 5. Cumulative net present value (NPV) of energy savings: 25-hp motor, avg. duty, avg. electrical cost

Variables	Chosen Value
First year's savings, kWh	3636
Electricity price escalation, %/yr	0.5
Initial cost of electricity, $/kWh	0.0553
Tax rate on net income, %	40
First-year tax credit on premium, %	10
Length of depreciation, yrs	10

---------- Summary of Calculations ----------

Cost of money	Effective discount rate	Time horizon (yrs)	Cumulative Net Present Value (NPV) of conserved energy ($)
5%	4.5%	1	131.42
		4	537.76
		8	1082.03
		12	1551.87
		16	1912.54
		20	2215.25
10%	9.5%	1	125.25
		4	474.76
		8	862.43
		12	1136.55
		16	1312.73
		20	1435.49
15%	14.4%	1	119.64
		4	423.10
		8	705.90
		12	871.83
		16	961.77
		20	1014.23

The NPV data from Table 5 for the 10 and 15% discount rates are graphed and compared to typical premiums for energy-efficient motors in Fig. 6. Premium A, $200, is a typical price for the extra cost between a standard and energy-efficient 25-hp motor.* The payback period is very short--less than two years at any discount rate. Such premium would apply to situations where new capacity is being installed or worn-out (and retired) motors are being replaced.

Premium B, $750, represents the premium required for choosing a new energy-efficient motor over rewinding a standard motor. It is recommended in one report that rewinding a motor should only occur if it can be done for approximately 50% of the replacement cost of the motor.[5] Thus, this premium is the addition of one-half the standard motor cost plus the premium between the two types of motors. It shows a payback ranging from 6.5 to 9 years.

Using the sales information for 1977 listed in Table 2, one can calculate that the combination of new capacity and replacement sales occurred at an annual rate of 3.7% of existing motor capacity. The average rewinding rate was 7.4%.** Thus, the portion of the existing stock to which these types of premiums apply is, at most, 11% per year.

Justifying the replacement of a properly operating motor would require that savings exceed the installed cost of the new motor minus the salvage value of the scrapped motor. Premium C, $1300, is the total cost of an energy-efficient 25-hp motor and is representative of the cost associated with complete replacement. Figure 6 shows that the payback of this situation is 15.6 years at a 10% discount rate and greater than 20 years at a 15% discount rate.

Motors have long lives, often lasting longer than 20 years. Thus, except for the retrofit made under a 15% discount rate, upgrading to an energy-efficient motor is economically justifiable if one is certain that the motor will be used for its full life. However, industry will usually make long-term capital improvement investments only if the investment is part of an overall capacity expansion program. In cases of retrofit, there is increased risk

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* Cost data were taken from a GE motors catalog and from Figure 5.

** The new capacity, replacement, and rewinding rates of each motor size class (see Table 2) were weighted by the electricity consumption of the size class when the average rates were calculated.

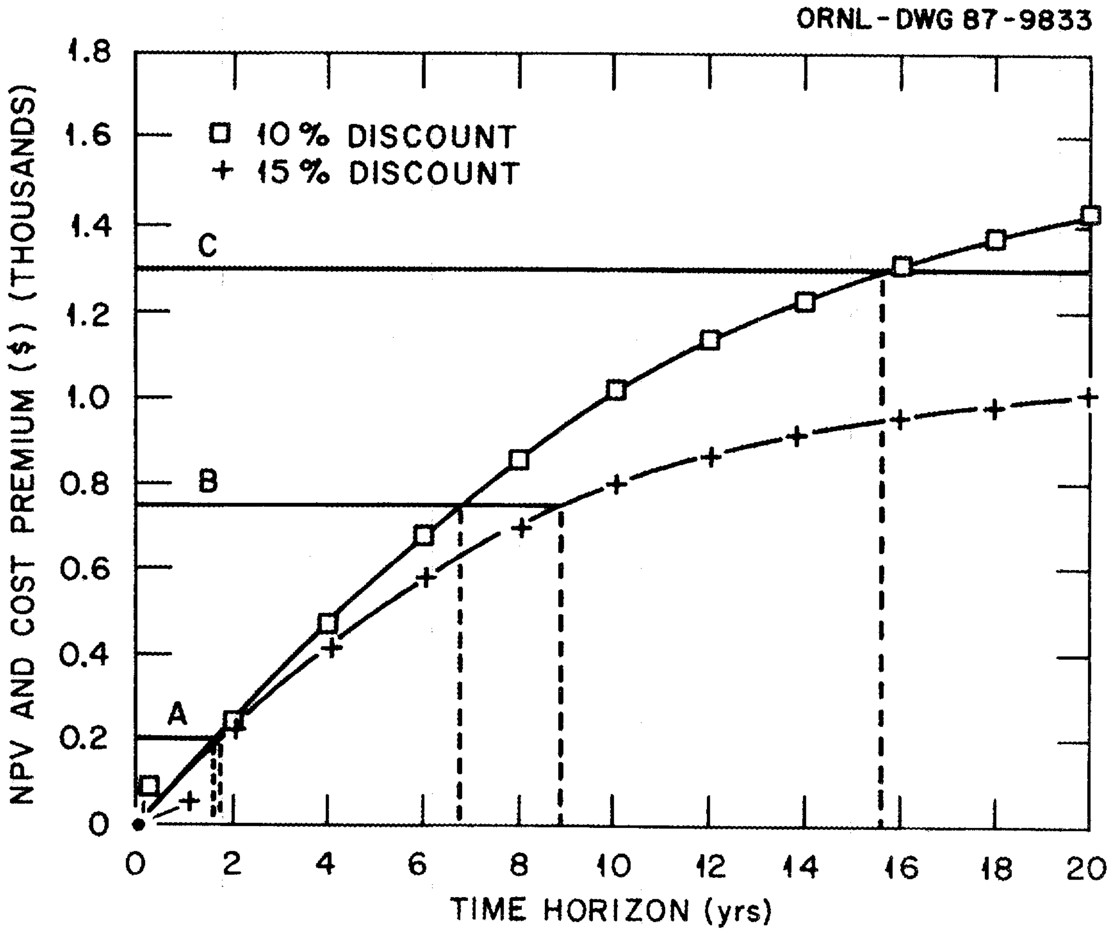

Fig. 6. Cost premiums and NPV of savings.
(EE motor, average duty, average power cost)

associated with the life of the process, and less funds are available for capital purchases, so the industry constrains itself to only the most attractive investments. Often, this constraint requires that the retrofit pay for itself in two years or less. By imposing this short time horizon on the savings from the energy-efficient motor, an industrial decision-maker would not consider the retrofit or rewinding options to be economically attractive.

There is much variation in both the duty cycles of motors and electricity costs among different industries and regions in the United States. Thus, the results of the payback analysis in the example above could totally change in different regions or industries. Figure 7 demonstrates this variation among regions and duty cycles by listing the savings that would be made for a 25-hp motor running on a 1500-h/yr duty cycle (typical for a 40-h/wk operation) and using power generated at a cost typical for the Pacific Northwest. In this example, the first year's dollar savings are decreased approximately 75%. The figure shows that the payback for premium A increases from less than 2 years to 9 to 15 years. Although the premium should still be justifiable in cases of new capacity, conversion would obviously not be performed as frequently. Figure 7 also shows that the premiums required by the rewinding or retrofit options would never have a payback within the 20-year nominal motor life.

4.2 EFFICIENCY AND LABELING STANDARDS FOR INDUCTION MOTORS

In view of the small efficiency increments between standard and energy-efficient motors, the standards that apply to performance testing and labeling play as much of a role in improving motor efficiency as do the efficient technologies themselves.

Standards for efficiency testing have been set by the Institute of Electrical and Electronic Engineers (IEEE) and the National Electrical Manufacturers Association (NEMA). IEEE has defined several testing methods and NEMA has adopted one of the standards, IEEE standard 112b (NEMA standard MG-12), as being the preferred test procedure.* It calls for direct testing of efficiency with a dynamometer. Other methods of performance testing are more indirect and tend to give results with higher efficiencies. Although most U.S. manufacturers comply with the NEMA standard, some foreign producers do not. For medium-to-large induction motors, foreign made were approximately 5% of total domestic use (1973-77). Thus, the lack of a universal standard could create distortions in performance information, as shown in DOE CS-0147, Table 3-10.[1]

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* NEMA standards are distributed by the VSMF microfilm service, cartridge No. 4020.

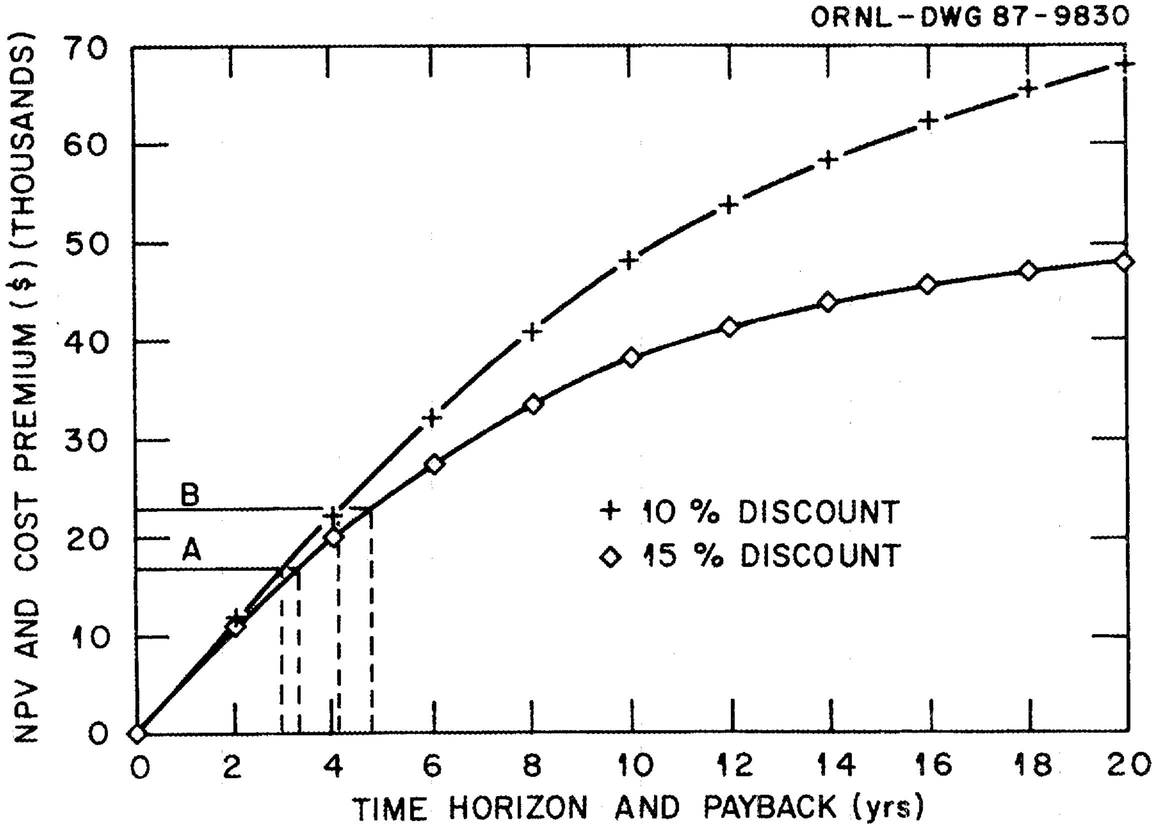

Fig. 7. Cost premiums and NPV of savings. (ASD, average pump duty, average power cost)

Labeling standards play a crucial role in providing reliable performance test information to the decision-maker considering the purchase of an electric motor. Currently, NEMA standard MG1-12.53b calls for efficiency labeling on the terminal box of each motor. The standard specifies that the average result of the performance testing is to be labeled as the motor's average, or nominal, efficiency. Thirty-three incremental efficiencies are allowed starting at 95% and continuing downward in approximately 0.5% increments. Along with the nominal efficiency, the standard calls for the labeling of a minimum efficiency. The minimum efficiency is the resulting efficiency if the average losses measured are increased 20% which is considered sufficient bounds to allow for variation among motors as actually sold.

It is important to note that conformance to these standards is not required by NEMA. Also, the labeling standard calls for labeling only on the terminal box of the motor. No standard exists for listing efficiency information in motor catalogs which are the key medium for transmission of information on motors. As a result, efficiencies for standard motors are difficult to obtain, often only available in publications separate from normal ordering catalogs.

4.3 ENERGY-EFFICIENT MOTORS AND THEIR EFFECT ON ELECTRICITY DEMAND

There have always been induction motors available with high efficiencies, but only since the late 1970s have manufacturers developed motor product lines specifically marketed as being energy-efficient. DOE's Classification report[1] (page 3-43) estimated the technical conservation potential of energy-efficient motors to be 2.4% of U.S. electricity consumption, but the previous section indicates that only a limited number of applications are economically attractive. Since energy-efficient motors are now readily available to potential users, current data on energy-efficient motor sales should indicate the actual market penetration that these motors have had at current capital and energy costs.

Unfortunately, sales data are difficult to obtain. Although data for domestic production of polyphase induction motors have been kept by the Bureau of the Census[6] since 1960, the sales of standard and energy-efficient motors are not separated.* Sales data for energy-efficient motors are now being collected by NEMA, but their survey was started in 1982, and only a limited number of manufacturers participate. Also, there has been no industry-wide testing to see if the rated improvement in efficiency results in a similar demand reduction in the field.

From the few data that are available, it appears that energy-efficient motors are having little success penetrating the induction motor market and, therefore, are having little effect on electricity demand patterns. Figure 8 is a graph of total sales for energy-efficient motors in the 1- to 200-hp, 0.74- to 149-kW range, a size group that has a high potential for energy efficiency improvement. Also shown in Fig. 8 are the sales data available from NEMA on energy-efficient motor sales for 12 manufacturers.[7] This group of manufacturers probably represents 50 to 100% of the production of all motors sold in energy-efficient

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* Census Bureau data are published the year following the date of the statistics. Most recent data available as of this writing are for 1982. Note that the SIC codes for ac polyphase induction motors are 36212-29.

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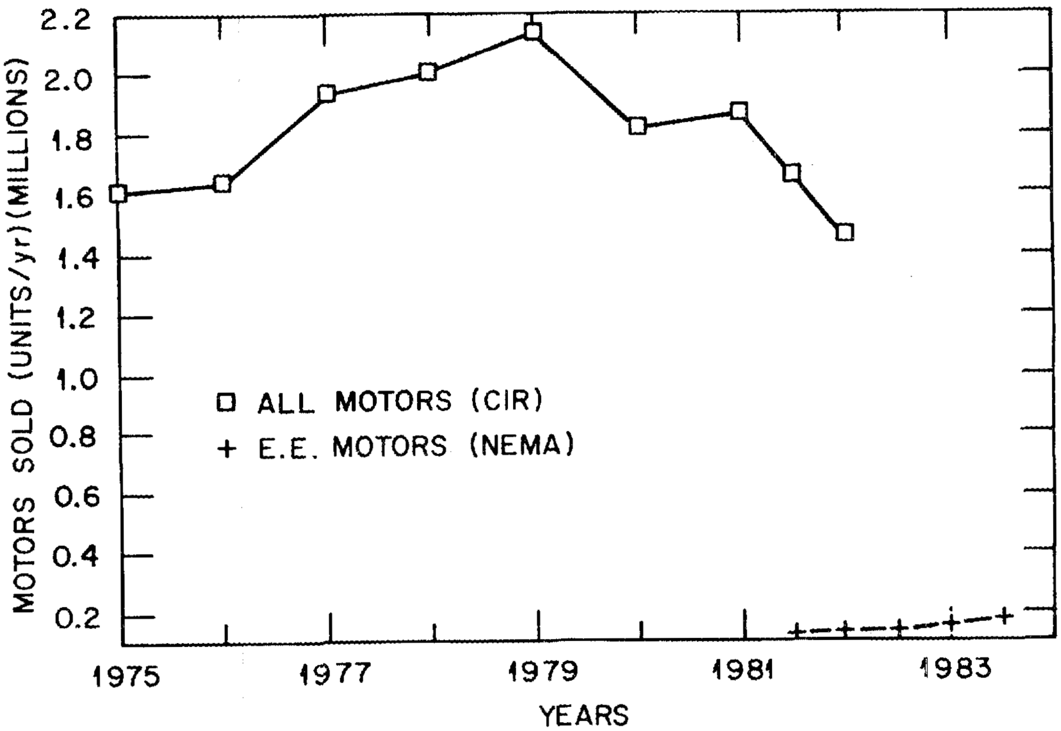

Fig. 8. Sales of ac polyphase induction motors. (Domestic production only, 1-200 hp)

product lines.* For the one year that the sales data overlap, Fig. 8 indicates that energy-efficient motors may constitute 10% of total induction motor sales.

Table 6 estimates the effect that one year's sales of energy-efficient motors is having on electricity demand based on sales

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* As of this writing, NEMA was unable to estimate what fraction of the energy-efficient motors are represented by the companies reporting. The companies are: Baldor Electric, Doerr Industries, Electra (Dresser), General Electric, Century Electric, Lincoln Electric, Lois Allis (Litton), Marathon Electric, Reliance Electric (Siemens Allis), US Electric Motors (Emerson Electric), and Westinghouse Electric. This is a large, if not complete, portion of the energy-efficient motor market.

Table 6. Estimated electricity demand reduction from energy-efficient motors - 1982, based upon sales data for that year

Size class (hp)	Size class (kW)	Avg. size (kW)	Standard & EE motors sold (1982)	NEMA EE motors sold (1982)	EE portion of total (%)	Duty cycle (hr/unit/yr)	E.E. motor savings (%)	Demand reduction (kWh/yr)
1-5	0.75-3.7	1.5	962031	81024	8.4	1500	10.4	18850914
5.1-20	3.8-15	8.9	327740	42609	13.0	1500	7.1	40606573
21-50	16-37	23.9	116023	13660	11.8	3000	4.3	42048890
51-125	38-92	64.9	45177	7361	16.3	4000	1.8	34383708
126-200	93-149	126.8	14941	1612	10.8	5000	0.3	3065274
Totals and avg's			1,465,912	146,266	10.0			138,955,359

data from NEMA and Current Industrial Reports.* Since sales data are recorded in size groups, it is possible, by using stock characteristics estimated in DOE's Classification report[1], to translate the sales data into energy savings. The table shows that for one year's sales, 16 MWY (1 MWY = 8.76 million kWh) of electricity was saved by using energy-efficient motors instead of standard-efficiency motors. The industrial sector's electricity consumption in 1982 was 88,600 MWY, so the savings estimated here are very small compared to the total requirement for the sector.[8]

4.4 NEW MOTOR DESIGNS

As noted before, polyphase induction motors dominate industrial motor use, comprising 93% of all advances in material design, will create alternatives to the induction motor in some applications. These new designs have improved efficiencies over the most efficient induction motors in their class. Below are some highlights of the latest developments.

4.4.1 Permanent Magnet Motors

General Electric, under a contract from the Power Systems Technology Program of the Energy Division, Oak Ridge National Laboratory (ORNL), has designed an industrial grade ac motor that utilizes permanent magnets instead of electromagnetic fields.[9] Losses in the stator due to magnetization are inherent in an induction motor because electrical current is used to create the magnetic field. By replacing the electromagnetic field component with a permanent magnet, a significant loss factor is eliminated.

The study reported that for an increase in material cost of 20% over that of a nominal energy-efficient motor, efficiency could be increased 1 to 2%. The payback period on the premium was estimated to be less than a year for a motor operating with a 50% duty cycle. Permanent magnets are feasible for motors in the 7.5- to 25-hp power range and could meet speed-torque characteristics similar to induction motors. Also, permanent magnet motors provide improved power factor over other energy-efficient ac motors.

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* Table 6 estimates from DOE's Classification report for average motor size of each size class, the percent energy saved, and as a basis for the average duty cycle for motors in each size class. Duty cycles higher than average were chosen because energy-efficient motors tend to be chosen for applications with high duty cycles. Sales data are taken from NEMA. Dec. 1982 and from Bureau of the Census, 1982.

It should be noted that the results of the above study were based solely on an engineering model, and no prototypes were built to test the performance predictions.

4.4.2 Reluctance and Doubly-Excited Reluctance Motors

Reluctance motors are designed similarly to synchronous motors except that there is no electrical excitation of the rotor. Some of the bars in the cage have been removed at symmetric intervals to cause the motor to run synchronously at full speed. No current is induced in the rotors, thus eliminating core losses and increasing efficiency. A doubly-excited reluctance motor has dc and ac excitation of the stator which further increases motor efficiency.

Under an ORNL subcontract with the Westinghouse Electric Corporation, the efficiencies of these motors have been experimentally tested.[10] This work found efficiency improvements of 1 to 3% and estimated the market cost to be 86% greater than the cost of a typical energy-efficient motor. Even with this high premium, payback for a normal duty cycle was less than two years. Also, since these motors do not induce current in the rotors, they have high power factors.

The principle behind a reluctance motor is not new, but these new designs are making reluctance motors more efficient at a lower price. They offer precise speed maintenance and durability equal to or greater than an induction motor. Current literature indicates that they are being marketed with variable frequency controllers for speed control. It is not clear, however, whether they offer a significant cost-to-performance advantage over variable speed ac induction motors (discussed in the subsection on ASDs).[11]

4.4.3 Amorphous Metal Motors

Amorphous metals are alloys that are cast in a non-crystalline form. They exhibit excellent magnetic properties. A report by General Electric for a project subcontracted from ORNL claims that core losses in a motor could be reduced 80% as a result of using amorphous metals.[11] Based on relative sizes of motor losses shown in Fig. 5, an 80% reduction in core losses would result in an increase of motor efficiency of approximately 1%.

The performance of amorphous metals is potentially quite good; however, the development of such motors has been impeded by current casting technology. The project developed new casting techniques that formed the amorphous metals into ribbons useful for electric motors. This technology is still in the developmental stage, and there has been no report of a detailed design or analysis of an actual motor.

Although the three new motor designs described above offer superior performance over induction motors, they have not been developed enough to allow an estimate of their ultimate effect on electricity demand. As with any alternative motor technology, their penetration will depend on the actual cost and performance of manufactured units.

4.4.4 Superconducting Motors

At the time this report was published, superconductivity had not been evaluated as a technology for improved motor efficiency. It appears that the application of the recently discovered high-temperature superconductors may allow the development of motors that have energy loses some 40 to 60% less than present designs. These very preliminary loss estimates include the operation of the necessary refrigeration system. Thus, a 1500-hp induction motor operating at 95% with conventional technology may potentially operate at 97 to 98% efficiency with superconducting technology, assuming that certain control and materials problems can be resolved.

Table 7 is a summary of the predicted cost and performance of the new designs.

4.5 ADJUSTABLE SPEED DRIVES

The alternatives examined thus far reduce the intrinsic losses of the motor. As illustrated earlier, motor losses are usually only a part of a system of power conversions and power losses. One type of technology that reduces losses in the overall system rather than in just the motor and that has wide application in the process industries is variable or adjustable speed drives (ASDs).

ASDs have been used for years in processes where speed control is essential. Such control is necessary for applications such as conveyors and textile looms. However, many processes control the flow of fluids with pumps or fans. In these applications, flow can be controlled by varying the speed of the motor drive or by restricting the flow. Traditionally, controlling flow has been done with a valve or throttle rather than by reducing the speed of the pump or fan. This restriction causes a significant amount of power to be lost in the form of heat. Flow restriction has been widely used, however, due to its reliability and its low cost compared to the controls required for speed control.

Table 7. Estimated cost and performance of new motor designs

Design Type	Size range (hp)	Absolute efficiency improvement (%)	Cost premium (% over EE motor)	Typical payback (yrs)
Perm. magnet	7-25	1-2	20[a]	<1
Reluctance	>5	1-3	86	<2
Amorphous	-	1	-	-
Super-conducting	>125	2-3	b	c

Source: ORNL/Sub-1745271(Ref. 9), ORNL/Sub-95013/1(Ref. 10) and ORNL/Sub-81/70519/1(Ref. 11).

[a] Based on material costs only.
[b] Could be in the range of 0-40%.
[c] Could be less than 2 years if development problems are solved.

Converting flow applications to ASD control has the potential for large energy savings. Pumps consume 50% of the electrical motor energy in the United States. Of the total national inventory of pumps, 75% are estimated to be centrifugal pumps which have a good potential for electricity savings with ASD. Also overall average pump sizes are larger than average motor sizes in many industries, indicating that pumps are the primary application of large motors.*

An illustration of how system power requirements can be reduced is shown in Fig. 9.[12] This figure portrays a generalized relationship between output flow, output pressure ("Head") and energy use for a typical centrifugal pump. Equilibrium between the pump flow and the energy load occurs where the pump and load curves intersect. Flow can be varied by either throttling the system, which shifts the load curve inward, or by reducing the

* Compare average motor and pump sizes by industry in Tables 3-11 and 4-15 in DOE report DOE/EC-0147 (Ref. 1).

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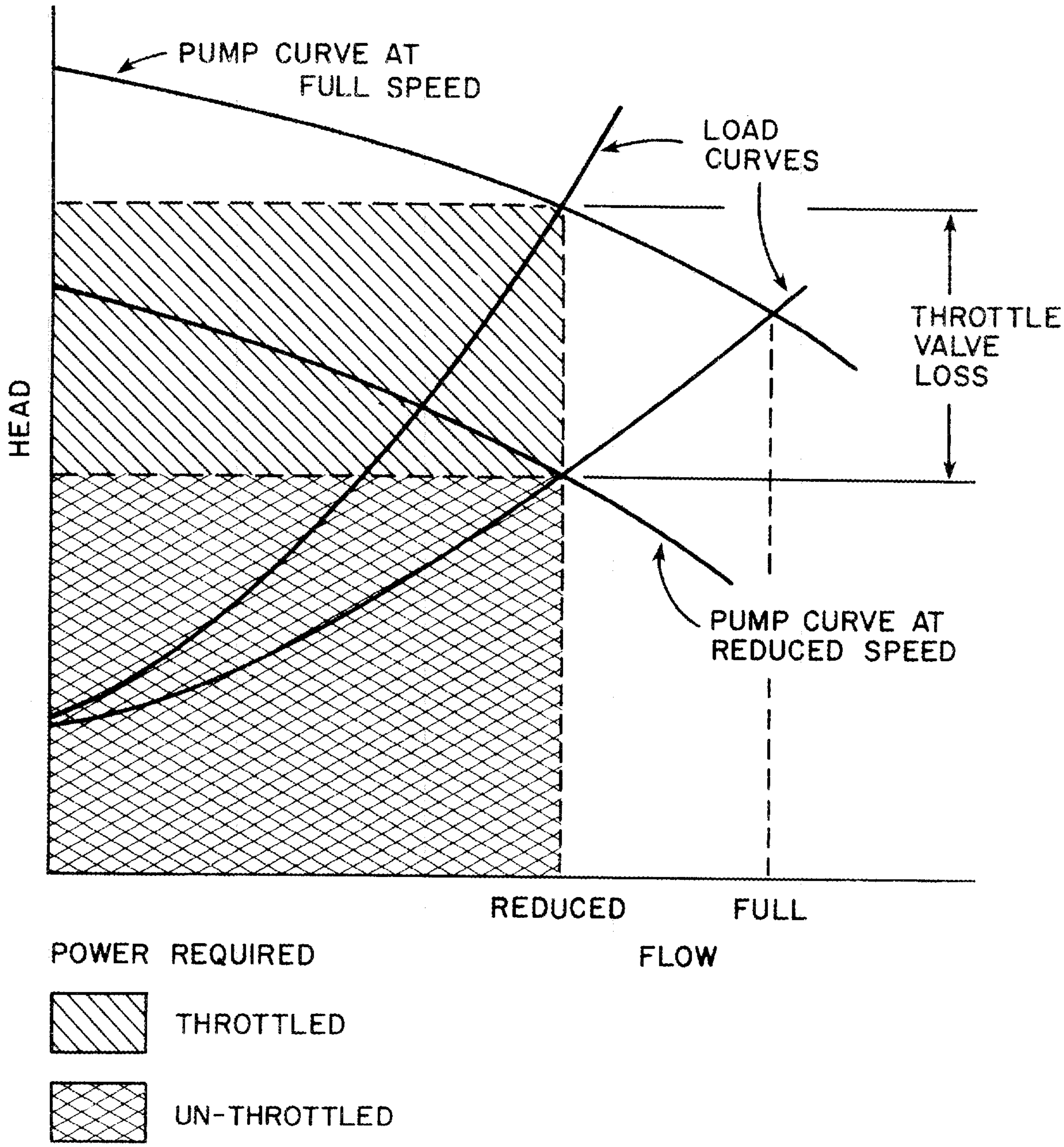

Fig. 9. Typical pump and system load curves for a centrifugal pump system.

pump's speed, which lowers the pump's operating curve. The power required to drive either system is equal to the flow times the pressure and can be measured graphically by the hatched and the cross-hatched areas in Fig. 9. The figure shows that the system power required is substantially lower for variable speed control (cross-hatched) than for throttle control (hatched plus cross-hatched).

There are several types of ASDs. As discussed before, dc motors are used for applications requiring precise speed control. Although they are manufactured in large sizes (greater than 125 hp), they have not become popular for use in flow processes. Most literature on the subject notes dc drives' brush maintenance requirements as being a prime reason for their unpopularity in flow applications.

For applications that require only two fixed flow levels, double-winding ac motors are used because they can be run at two speeds. Large applications have traditionally used mechanical or hydraulic controls in combination with an ac induction motor. Another popular type of control is an eddy current speed controller. An eddy current controller is a coupling installed on the shaft of the motor that allows reduction of full shaft speed (slip) by varying the magnetic "grip" in the coupling. The majority of the controls identified above are not very efficient and require periodic maintenance. Thus, their penetration in flow situations has been very small.

The type of speed control that has a great deal of potential for penetration in flow applications is the variable frequency controllers. Rather than change the speed of the drive at the shaft of the motor as do most of the ASD controls described above, variable frequency controllers can control the speed of an induction motor directly because the motor speed is directly proportional to the frequency of the incoming ac current.

Recent improvements in power electronics have greatly increased the present efficiency and reliability of the adjustable frequency type of ASD control.[13] Also known as ac synthesizers (ACSs) and ac frequency controllers, they give induction motors superior attributes for many drive applications. Like the dc drive, ac frequency controllers can vary their output without the addition of a device on the shaft. Unlike dc drives, however, ac frequency controllers are used with induction motors that are free of the commutators and brushes that dc motors must have.* Also, electronic ASDs can now control almost any size induction motor. Previously, speed control of motors greater than 50 hp usually required mechanical, hydraulic, or eddy current controls. Although reliability of the new controllers has been uncertain due to their novelty in the larger sizes, recent news indicates that process industries are adopting them for many applications.[14,15]

Another reason that electronic ac frequency controllers have significant economic attractiveness is that they can be installed on a large portion of existing ac induction motors for a relatively low installation cost. In retrofit situations, dc ASD drives require replacement of the motor. Mechanical and hydraulic controls used in retrofits also incur extra costs because they often require that the motor's base be moved to fit the new controller.

The remainder of this section focuses on an example of the energy savings and cost-effectiveness of an adjustable frequency ASD application, a summary of 13 industry case studies examined in a previous study, and a summary of current opinions on such ASDs from industry personnel.

4.5.1 Example of an Adjustable Speed 125-hp Pump

An example of the energy savings from an ac adjustable frequency drive controlling a 125-hp centrifugal pump are computed and summarized in Table 8. The duty cycle chosen (column 2) is considered typical from reports on ASD applications[16,17]. The table shows that yearly energy requirements are reduced by approximately 25%.

The savings as a function of flow are graphed in Fig. 10. The difference between the lines represents the power reduction between the two control techniques (i.e., ASD vs throttling). Note that the savings increase as the flow decreases, so the

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* The reasons for ac's popularity over dc is not that clear to some people in the industry. One product manager claims that dc variable speed drives are actually less expensive in larger sizes and that the only reason that flow-intensive industries purchase ac variable speed drives is because they are familiar with ac induction motors and are skeptical of anything else. This cost claim is reasonable considering that the variable speed control for a dc motor is inherently simpler than for an ac control because the ac control must rectify and invert three phases. The maintenance requirements of a dc motor are, however, a genuine discouragement for use in any process where drive failure could have disastrous consequences.

Table 8. Summary of ASD savings system

			Throttle				Adjustable Speed				
Fraction of full flow (%)	Duty cycle (%)	Duty cycle (hours)	System power (hp)	Pump/ motor effi. (%)	Total power req'd (kW)	Annual energy (10^5 kWh)	System power (hp)	Pump/ motor/ inverter effic'y (%)	Total power req'd (kW)	Annual energy (10^5 kWh)	Yearly energy savings (10^5 kWh)
100	40	3200	104.0	75	104.0	3.34	104.0	73	106.0	3.39	-0.05
75	40	3200	81.0	68	85.3	2.73	48.3	70	51.2	1.64	1.09
50	20	1600	56.1	60	69.6	1.11	20.4	58	26.1	0.42	0.69
Totals		8000				7.18				5.45	1.73

Source: John C. Andreas (Ref. 16) and EPRI/EM-2037 (Ref. 17).

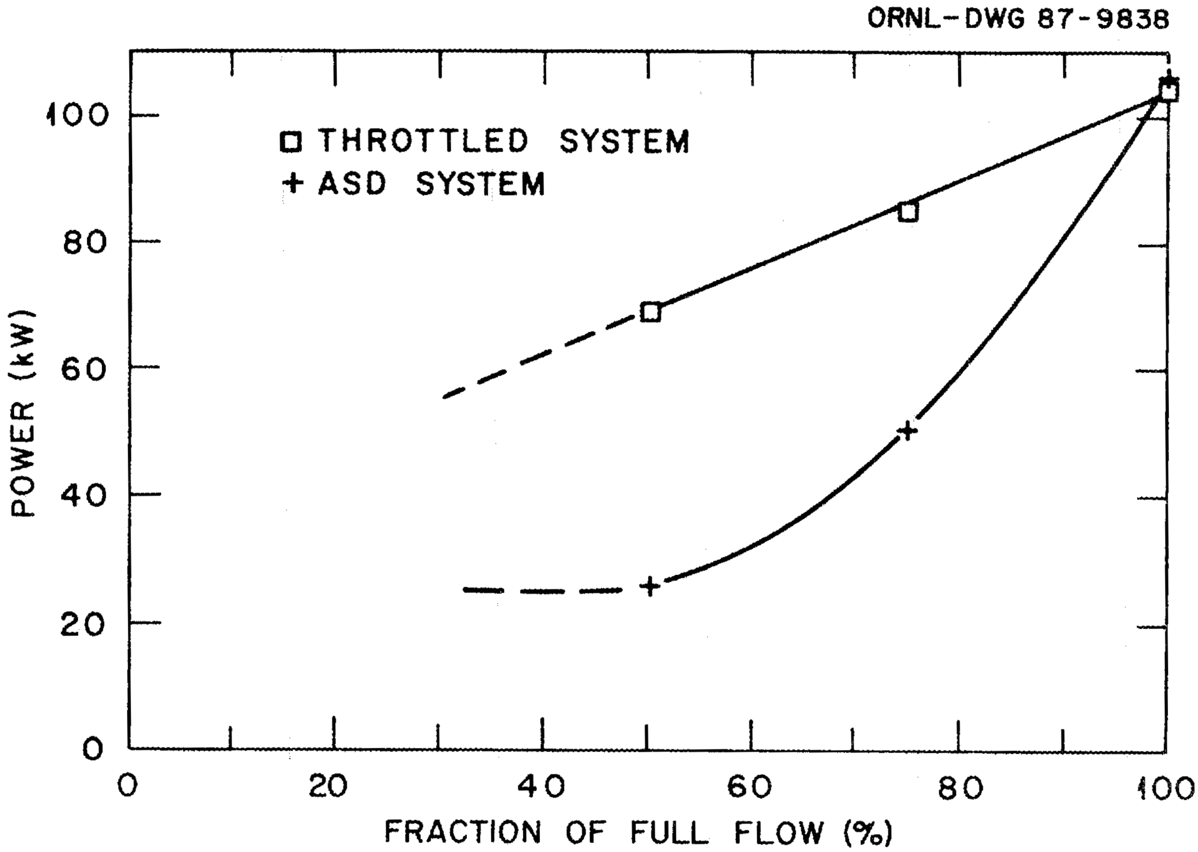

Fig. 10. Power required for flow control using variable frequency ASD vs throttling. (Systems: 125 hp centrifugal pump)

system's load pattern is the most important factor in determining the energy savings.

Given the duty cycle chosen in Table 8 and using the same electricity costs and tax rates of the first energy-efficient motor example (Table 5), the net present values of the energy savings are computed and summarized in Table 9. The table shows a first year savings of approximately $6,000.

To determine the payback of this example, it is necessary to know the cost of an ASD control. Costs of electronic ASD controls have dropped significantly since their introduction in larger sizes in the late 1970s. Estimates are that the prices have dropped 40 to 50% in the last two years.[14] Figure 11 is an estimate of current electronic ASD controls for ac motors, based on recent publications and an informal survey of manufacturers and end-users. Note that the data labels "M1..4" stand for prices received from four different manufacturers. "E-U1" was a cost estimate received from an end-user in the pulp and paper industry. "NEMA" labeled data points came from ac ASD sales data that NEMA collected from a limited number of manufacturers in 1984.*

From the figure, it can be computed that the cost of an uninstalled controller for a 125-hp motor is currently around $17,000. Figure 12 compares the energy savings of the ASD system to the cost of the control. Premium A (the cost of the uninstalled controller - $17,000) represents the cost required to install an ASD in new capacity or worn-out replacement situations. The payback in this example is approximately three years. If the motor is to be retrofitted with an electronic ASD control, installation costs must be added to the cost of the control. Installation cost estimates are around $5,000 to $6,000 and premium B ($23,000) represents the total cost of a retrofit.[18] The payback in this case is 4 to 5 years.

The example above indicates that the economics currently appear very good for ASD controls. It should be noted, however, that the cost of retrofit in Fig. 12 assumes that the existing motor is used and that the current drive system can accommodate the ASD control. Electronic ASD controllers tend to make the motor run hotter, and some older motors cannot be considered reliable after adding an ASD control. Also, some application, such as certain commercial HVAC motors, are inaccessible for retrofit.

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* NEMA, "Domestic and Net Orders and Sales of Drive Systems," Product Statistical Bulletin for Industrial Control and System Section (4-1S), (unpublished document), Washington, D.C. first quarter 1984.

Table 9. Cumulative net present value (NPV) of energy savings: ASD, avg. pump duty, avg. electricity cost

Variables	Chosen Value
First year's savings, kWh	173,000
Electricity price escalation, %/yr	0.5
Initial cost of electricity, $/kWh	0.0553
Tax rate on net income, %	40
First-year tax credit on premium, %	10
Length of depreciation, yrs	10

---------- Summary of Calculations ----------

Cost of money	Effective discount rate	Time horizon (yrs)	Cumulative Net Present Value (NPV) of conserved energy ($)
5%	4.5%	1	6,253
		4	25,586
		8	51,483
		12	73,837
		16	90,998
		20	105,401
10%	9.5%	1	5,960
		4	22,589
		8	41,034
		12	54,077
		16	62,460
		20	68,300
15%	14.4%	1	5,693
		4	20,131
		8	33,587
		12	41,481
		16	45,761
		20	48,257

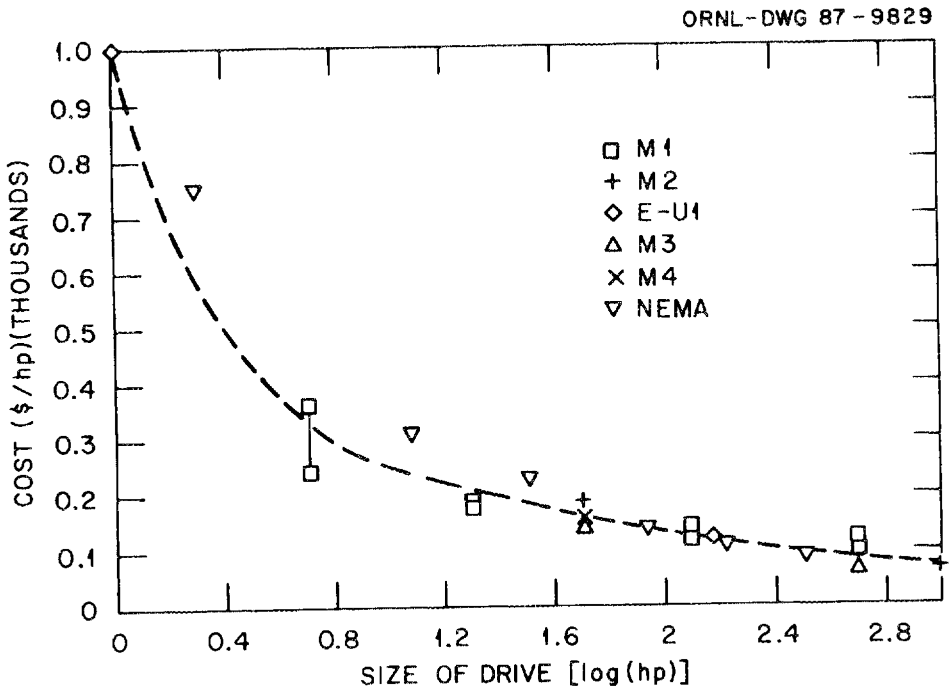

Fig. 11. Cost of Electronic ASD controls--1984.
(End-user cost, uninstalled)

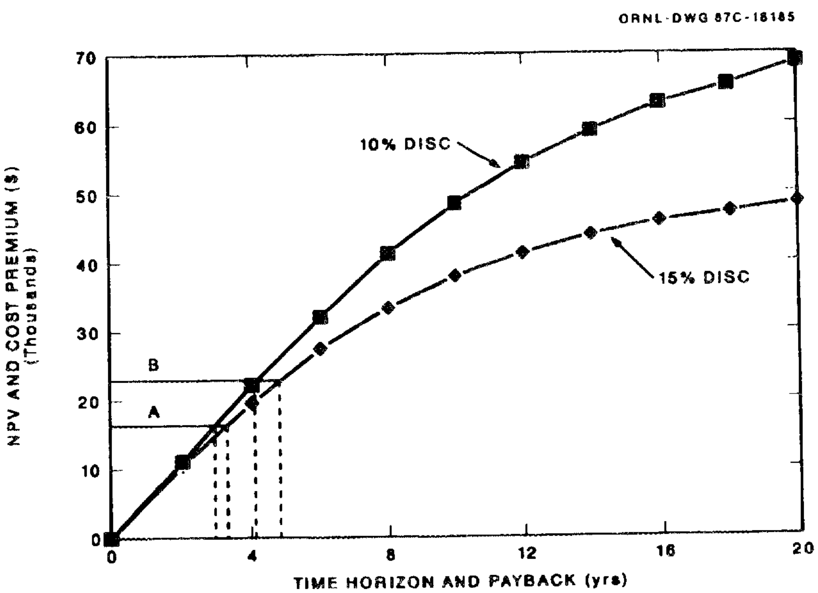

Fig. 12. Cost premiums and NPV of savings.
(ASD avg. pump duty, avg. power cost)

As with energy-efficient motors, not all applications make sense for ASDs. Figure 13 is a graph of the paybacks of the same system with a higher duty cycle and lower power costs. The first-year energy saving in this example is reduced 25% from the previous example. The range of payback for the additional cost for new installations (premium A) is from 8 to 11 years. The payback of the retrofit cost (premium B) is now greater than 12 years.

4.5.2 ASD Industry Case Studies

A study released by Westinghouse in 1983 examined the energy and economic potential of ASDs in pump applications at thirteen plants in five different industries.[19] Their work represents the most thorough examination of ASD potential in industry to date. Table 10 is a summary of their results for 55 specific applications. The range of energy savings from the ASD control typically ran from 10 to 30% of total energy use. These savings were divided into the cost of the ASD for new capacity or retrofit to determine the simple paybacks. Westinghouse examined the payback for several different types of ASD controls, including electronic ac control (AFAC in Table 10).

It is difficult to see from Table 10 the type of applications that have the most potential for energy savings because each one had its own particular duty cycle not listed in this summary table. However, almost all applications have good potential in new capacity or replacement situations. Other case studies in the utility, chemical, and pulp and paper production industries also have shown very good paybacks (less than 2 years) in retrofit situations.[13,14]

Electronic controls as presented in Table 10 do not always have the best paybacks because the study found that the costs of electronic controls were higher than the cost of mechanical or hydraulic controls. However, the costs therein for electronic controls are from 50 to 150% greater than the current costs plotted in Fig. 11.* Thus, the economics of the variable frequency controls appear to have improved substantially since the year that the Westinghouse applications were studied.

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* Compare Figure 11 with Triezenberg (Ref. 18), Fig. 2-4.

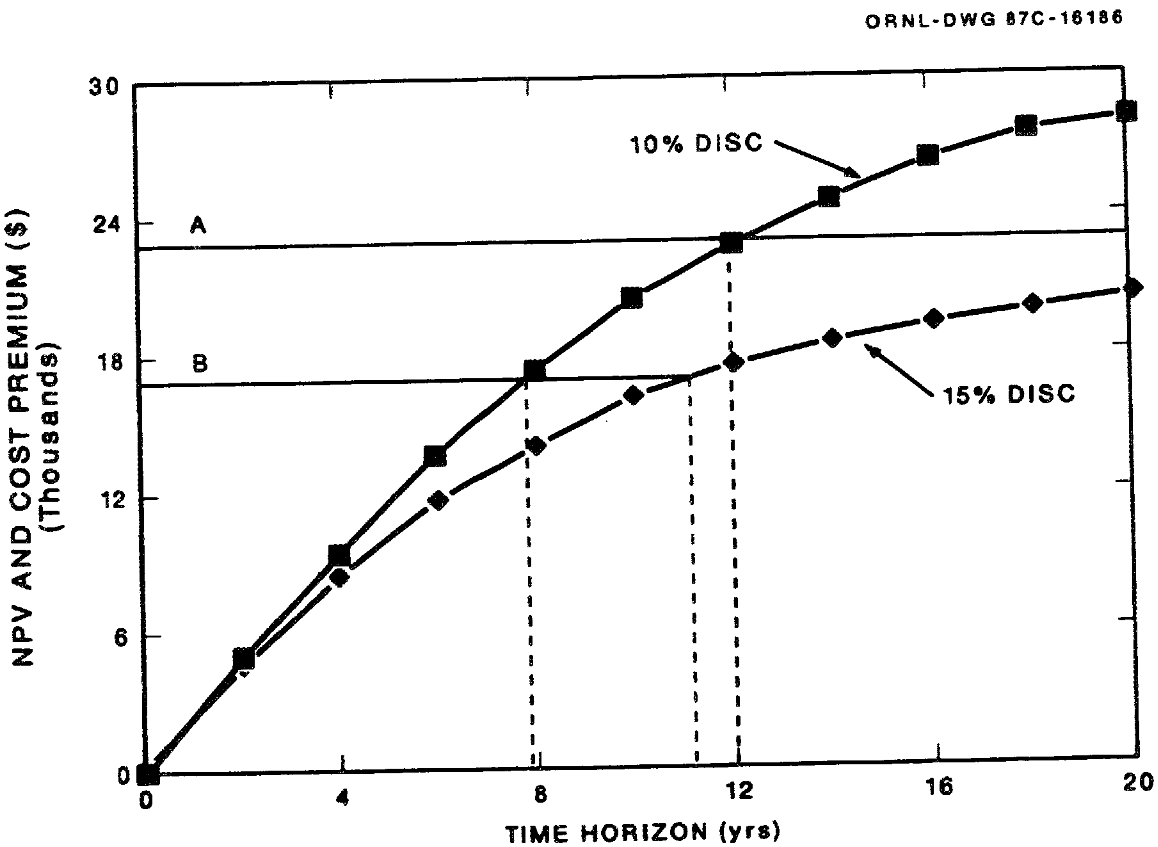

Fig. 13. Cost premiums and NPV of savings.
(ASD, high pump duty, low power cost)

Table 10. Simple payback times for pump applications - 1982

	Horsepower (hp)	Shortest retrofit payback (yr)	AFAC[b] retrofit payback (yr)	Shortest new payback (yr)	AFAC[b] new payback (yr)
POWER PLANT PUMPS					
Mississippi Power					
1. Condensate	3 x 900[a]	0.7	1.1	0.4	0.9
2. Cooling tower make-up	2 x 200[a]	<0.1	<0.1	<0.1	<0.1
3. #5 Sump	30[a]	11	43	4.6	28
4. #6 Sump	30	>10	never	>10	never
Los Angeles Department of Water and Power					
5. Condensate	3 x 200	0.7	1.1	0.2	0.9
6. Condensate booster	3 x 250	0.7	1.3	0.1	1.0
7. Boiler feed booster	3 x 600	0.5	1.8	0.3	1.7
United Illuminating					
8. Fuel oil burner	3 x 75[a]	0.6	1.7	0.1	1.2
9. Salt water	2 x 200[a]	0.4	0.4	<0.1	<0.1
10. Evaporator feed	2 x 60[a]	1.0	1.7	<0.1	<0.1
Louisiana Power & Light #3					
11. Condensate	3 x 350	3.2	3.9	1.1	3.1
12. Boiler feed	3 x 1500	6.9	>100	6.3	>100
13. Heater drain	2 x 125[a]	0.5	2.0	<0.1	1.4
Louisiana Power & Light #4					
14. Condensate	2 x 1250	2.5	4.0	1.6	3.4
15. Heater drain	700	2.4	4.8	0.4	3.9
16. Circulating water	3 x 2000	1.6	1.6	1.6	1.6
PIPELINE STATIONS					
Colonial Pipeline					
17. #1 Pump	500	6.3	never	4.7	never
18. #2 Pump	1500	17.2	never	16.4	never

Table 10. (Continued)

	Horse-power (hp)	Shortest retrofit payback (yr)	AFAC[b] retrofit payback (yr)	Shortest new payback (yr)	AFAC[b] new payback (yr)
Mobil Pipeline					
19. Typical pump	900	23.5	never	22.9	never
Sun Pipeline					
20. Only pump	900	1.3	4.8	0.5	4.0
COOLING WATER DISTRIBUTION IN BUILDINGS					
Westinghouse STG Division Building					
21. Distribution pumps	3 x 15	3.6	11.3	1.6	7.9
CHEMICAL PLANT PUMPS					
Union Carbide South Charleston					
22. Ash slurry	40[a]	0.5	2.2	<0.1	0.8
23. Cooling water	8 x 500	0.5	0.8	0.3	0.7
Union Carbide Seadrift					
24. Catalyst injection	30	0.6	2.7	<0.1	1.6
25. Reactor feed	75	0.5	2.0	0.1	1.3
26. Domestic water	50	0.4	1.6	0.1	1.1
27. Treated water	200	0.5	1.5	<0.1	1.1
28. Cooling water	21 x 450	1.2	1.9	1.1	1.8
29. Reflux (hypoth)	25	1.6	4.5	<0.1	0.6
PAPER MILL PUMPS					
Union Camp Montgomery					
30. White water to s/a	75	5.3	22.5	2.1	32.0
31. Separator #5	20	6.9	45.1	0.6	37.3
32. Uhle box water	15	1.4	4.3	0.6	2.1
33. 50% pine liquid transfer	25	11.7	52.2	11.4	11.4

Table 10. (Continued)

	Horse-power (hp)	Shortest retrofit payback (yr)	AFAC[b] retrofit payback (yr)	Shortest new payback (yr)	AFAC[b] new payback (yr)
<u>Union Camp Montgomery</u>					
34. Hdwd. 1st eff. condensate	15	14.2	>100	1.2	41.0
35. Pine 1st eff. condensate	20	>100	never	>100	never
36. Skim liquor return	20	3.3	10.0	<0.1	2.3
37. Condensate transfer #1	150	>100	never	never	never
38. 65% black liquor #1	30	5.2	21.5	0.6	6.6
39. Green liquor transfer #1	30	3.4	15.6	0.6	4.7
40. Precipitator liquor #1	50	7.0	31.3	3.6	13.6
41. Hot water	35	4.3	19.8	<0.1	11.3
42. Hot water	60	3.9	17.3	1.0	4.2
43. Hot water (pine)	40	6.7	33.6	<0.1	20.6
44. Liquor filter feed	20	2.2	7.8	0.7	0.7
45. Weak black liquor	125	1.4	3.3	<0.1	1.4
46. Weak black liquor	200	1.4	3.6	<0.1	0.5
47. Secondary screen rejects #1	25	2.9	7.0	<0.1	0.6
48. Secondary screen rejects	15	3.0	13.3	0.6	2.1
49. Weak liquor to storage	15	1.9	6.0	<0.1	<0.1
<u>Louisiana Pacific Antioch</u>					
50. Cold blow	150	0.5	2.5	3.0	1.73
51. Wash circulation	25	1.4	2.9	<0.1	.69
52. Bottom circulation	125	0.9	1.9	<0.1	.87
53. Makeup liquor	250	0.5	1.2	0.1	1.0
54. Centrisorter dilution	200	1.0	2.6	<0.1	1.6
55. Washed stock	200	never	never	never	never

SOURCE: Summarized from Trienzenberg and Lakhavani's Westinghouse Report No. 83-2J6-VSPUM-R1 (Ref. 18).

[a] Substitute a smaller motor for ASD operation.
[b] Electronic Speed Control

4.5.3 Current ASD Trends

Recent conversations, with an industrial energy manager and a process engineer employed in the petroleum refining and pulp and paper industries respectively, confirmed the attractiveness of ASDs in these industries. Terms like "bullish" and "tickled pink" were used to describe their opinion of ASDs. They confirmed that ac variable frequency controllers could be installed in most applications without motor replacement. The manager from the petroleum industry also noted the reduced maintenance costs that come from switching to ASDs because there were fewer valves to wear out. However, the engineer in the pulp and paper industry stressed the increased maintenance commitment that electronic controls require. Although they do not need regular maintenance as do valves, they are a sophisticated piece of equipment that requires an increase in the amount of technician training and spare parts kept in stock.*

An interesting question is whether or not ASDs reduce system losses to the extent that they could begin to compete with the very large (greater than 10,000-hp) applications that have traditionally used steam or gas turbines as drives. As noted at the beginning of Section 4, this would be an example of how an efficient drive technology could increase electricity demand.

The economics of such a conversion depend greatly on whether the situation is a new capacity or a retrofit installation. An engineer for one manufacturer of large ASDs felt a small number of ASDs sold as new capacity were going to applications that have traditionally used turbines in the past.** Thus, any forecasts of the effect of new capacity sales of ASDs on electricity demand should, ideally, take the effect of fuel switching into account. The amount of fuel switching occurring at this time, however, appears to be small.

In situations of retrofitting existing turbines with electric ASDs, the economics depend greatly on the value of the gas turbine or the steam turbine and the associated steam-producing capacity that is scrapped. For a steam retrofit, very little steam may be saved due to the existing requirements of other parts of the plant. The engineer who was interviewed confirmed that he knew of no ASDs that were installed as replacements for existing turbines.

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* Opinions are from telephone conversations in September 1984.

** Telephone conversation with a representative from General Electric, September, 1984.

4.6 ADJUSTABLE SPEED DRIVES AND THEIR EFFECT ON ELECTRICITY DEMAND

Since electronic ASDs are entering new markets with their decreasing prices and increasing reliability, it could be possible to estimate their effect on energy demand by tracking the sales of units entering into industrial processes. Unfortunately, even less sales data exist for adjustable-speed drive controls than for energy-efficient motors. NEMA started at the beginning of 1984 to survey manufacturers for sales of ac ASD controls in units and by size. Until now, total ac ASD sales have been lumped together with dc ASD controls in data collected by NEMA and in Current Industrial Reports (CIR).* Estimates of the total market for the past two years have varied widely. Sales for both ac and dc controls as reported in CIR have been between $250 and $270 million for the past two years. One market research firm projected that the ac ASD controls market was $178 million in 1982, and the total ac and dc controls market was $653 million. Their definition of the dc portion of the market, however, included the motor as well as the control.[20] One manufacturer's ASD product manager estimated the market for 1983 to be $100 million.**

Even if the size of the entire ac ASD market is known, one cannot directly determine the effect that ASD sales are having on electricity demand. Unit sales by size class are necessary to make such an estimate. Assuming a total market size of $100 million in 1983, Table 11 roughly calculates the unit sales of ASD controls by size class. Estimates of how the market is distributed over different size classes as a percentage of the total market have been developed by a market research firm in a recent study, and their results are adapted in this table (column 2).[20] Knowing dollar sales made in a particular size class, one can compute the units sold by dividing dollar sales by the average cost of an ASD control for that size class (column 6). Note that to convert end-user cost (Fig. 11) to manufacturer's price, a mark-down factor was included for drives less than 126 hp to account for distributor price mark-up. According to ASD manufacturers' representa-

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* ASD controls sales figures have been tracked since 1970 by the Bureau of the Census, Current Industrial Reports: Switchgear, Switchboard Apparatus, and Industrial Controls, MA36A (70. 71. .. 82, 83), 1971-1984. Note that the SIC product code is 36222 96. NEMA has collected similar ac and dc ASD controls sales data for its reporting companies since 1982 in their "Industrial Controls and Sales," Product Statistical Bulletin.

** Telephone conversation with a Westinghouse representative, September 1984.

Table 11. Characteristics of electronic ac ASD control market - 1983, breakdown by size

Size class (hp)	Portion of market (%)	Mfg'rs sales (mil $)	End-user cost ($)	Markdown factor (%)	Manufacturers price ($)	Estimated units sold (1983)
1-5	10	10	1100	70	770	12,987
5.1-20	15	15	2600	79	2,054	7,303
21-50	15	15	5300	79	4,187	3,583
51-125	16	16	10000	92	9,200	1,739
126-200	20	20	19000	100	19,000	1,053
>200	24	24	60000	100	60,000	400
Total Market (>1 hp)		$100				

tives, a significant portion of ASDs smaller than 50-hp are sold through distributors or other intermediates.

Using the units sold data as derived above, the effect that ASD sales have had on electricity demand is computed and summarized in Table 12.* As in the analysis of energy-efficient motor sales, estimates were made for the average size of the motor in each class, the duty cycle, and the energy savings realized. The table shows that ASD sales in 1983 may have led to 49 MWY of electricity savings compared to a baseline of nonspeed-controlled flow systems. Considering that the market for electronic ac ASD controllers is very young and growing, this estimation is encouraging.

The attractiveness of ac ASD systems has led to several studies attempting to predict the size of the market in future years. Two market research firms have released studies on the ac and dc ASD drive markets, and they periodically update their work.** Their studies, however, predict only dollar sales.

Two engineering penetration models have been developed as part of research projects in the past four years, one sponsored by EPRI and the other by Westinghouse. The first one was performed for EPRI by Stanford Research Institute (SRI) in 1980.[21] SRI estimated the effect of electronic ac ASD drives in the end-uses of pumps, compressors, blowers and fans, and commercial HVAC. They concluded that ASDs would reduce electricity demand in the year 2000 by 2.5% of the projected total from a baseline of 4% compounded growth. Their penetration model used an SRI end-use data base developed in the early 1970s, and the report indicates that little research went into determining their estimated penetration rates of ASDs. Thus, their model's results may be quite unreliable.

The Westinghouse study[12] developed a simple penetration model as a part of the same report that performed the case studies summarized in Table 10. The penetration of ASDs in new and retrofit pump applications is based upon a sigmoidal payback-penetration relationship that predicts significant penetrations (greater than

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* Table 12 data are based on average motor sizes and duty cycles from DOE (Ref. 1), Table 3-11. Estimates of portion of sales going to flow applications are based on a telephone conversation with an ASD product manager, September 1984.

** Besides Ducker, Summary Report, Ducker has a full report and is expecting a revision to be performed in 1985. Also, Frost and Sullivan, Inc. will release an update in late 1984 of The Variable Speed Drives Market, Report #A815. New York.

Table 12. Estimated demand reduction of electronic ac ASD controls - 1983, based upon sales data for that year

Size class (hp)	Size class (kW)	Avg. size (kW)	Estimated units sold (1983)	Duty cycle (hr/unit/yr)	Flow Portion (%)	ASD Savings (%)	Demand Reduction (kWh/yr)
1-5	0.75-3.7	1.5	12,987	1500	50	20	2,905,325
5.1-20	3.8-15	8.9	7,303	1500	50	20	9,802,288
21-50	16-37	23.9	3,583	3000	60	20	30,775,486
51-125	38-92	64.9	1,739	4000	60	20	54,157,273
126-200	93-149	126.8	1,053	5000	80	20	106,752,842
>200	>149	706.2	400	5000	80	20	225,984,000
				Total Savings (kWh/hr)			430,377,214

Source: Based on data regarding average motor sizes and duty cycles from DOE/CS-0147 (Ref. 1), Table 3-11.

20%) when the simple paybacks are less than 3 years. These rates were reviewed and altered appropriately by industry experts in an informal survey. The penetration calculations are not done explicitly in the model, however, so the actual values of average industry savings and current and future costs of ASD controls are not indicated.

The model does not estimate the energy saved by ASD pumps. It only predicts the number of units of ASD pumps in the year 2000 for a selected group of industries. The study makes no estimate of the average energy savings of ASD systems or how unit penetrations might affect electricity demand. This is unfortunate because their case studies represent the most thorough analysis to date on the savings possible from ASDs.

Table 13 is a summary of the results of the model and an estimation of the electricity savings that would result from a baseline of nonspeed-controlled pumps.* The nine industries selected in their model represent 75% of all pump electricity consumption according to DOE's <u>Classification</u> report.[1] The table shows a 21% penetration of ASDs in the year 2000 resulting in 32,700 GWh of electricity saved, based on an average electricity savings of 15% per unit. For perspective, 32,700 GWh is 4% of industrial electricity consumption in 1983.

The model's definition of pump stock included only pumps that were estimated to be able to save energy and not to be constrained by some other design consideration (e.g., strict reliability requirements). Thus, the total stock penetration percentages listed in Table 13 are for a base that is technically convertible to ASDs. The model also assumes that the penetration of ASDs in the first year (1982) is zero.

It should be emphasized that the Westinghouse model focused only on pump applications for the industries selected. Other flow applications that have good economic potential--compressors, blowers, and fans--are not included. The SRI model, which looked

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* National inventories for pumps ASD units in the year 2000 were taken from Triezenberg and Lakhavani (Ref. 19), p. 5-4. Estimates for average pump load, average hours of operation, and average savings achieved are based either on the case studies in Ref. 18 or on DOE (Ref. 1), Table 4-15. Average pump size was estimated to be larger than average pump sizes in DOE (Ref. 1), since ASDs would tend to have higher penetration in larger sizes. Note that the savings estimate of 15% is lower than the 20% estimate used in Table 12. This is because it is assumed that ASD applications in 1983 went to applications with the greatest potential and that the average savings achieved will be reduced by the year 2000.

Table 13. Predicted penetration and electricity demand reduction of ASD pumps for selected industries - 2000

Industry	Pump stock 1982	Stock growth rate (%)	Pump stock 2000	ASD pump stock 2000	Portion of stock pen'trtd 2000 (%)	Avg. pump load (hp)	Avg. pump load (kW)	Avg. duty cycle (h/yr)	ASD savings (%)	Demand reduction (kWh/yr)
Base load power plants	9,460	2.7	13,375	665	5	600	447	7000	15	312,411,015
Load following power plants	10,260	2.7	14,507	8,996	62	600	447	2500	15	1,509,371,370
Multiple pump pipeline station	2,671	0.0	2,671	77	3	1000	746	6000	15	51,677,010
Single pump pipeline station	1,802	0.0	1,802	162	9	1000	746	6000	15	108,723,060
Cooling water distribution in buildings	270,000	1.1	311,264	17,387	6	15	11	2000	15	58,344,687
Four types of chemical plant pumps	231,000	2.0	298,823	125,798	42	200	149	8000	15	22,513,816,464
Paper mill pumps	66,000	1.8	82,697	17,203	21	200	149	6000	15	2,309,089,878
Primary metals	121,000	0.0	121,000	20,763	17	200	149	7000	15	3,251,423,511
Mining and oil field	60,000	1.7	74,701	3,100	4	200	149	7000	15	485,450,700
Petroleum manufacturing	69,000	0.0	69,000	11,840	17	200	149	8000	15	2,118,981,120
Totals and Avg.'s	841,193		989,840	205,991	21			(kWh/yr)		32,719,288,815

at these other major applications, predicted that pumps would save one third of the total amount of energy saved.

5. ECONOMIC AND BEHAVIORAL FACTORS THAT AFFECT INDUSTRIAL DRIVE DECISION-MAKING

When DOE's Classification report[1] was published in 1980, there simultaneously appeared quite a number of articles on motor efficiency in process industry trade journals. At that time, DOE was considering performance standards for appliances and the Classification report recommended mandatory labeling and performance standards for motors. However, no performance standards and no labeling standards, other than the voluntary NEMA standard, were created. From the tone expressed in many of the articles, both motor manufacturers and end-users resisted all mandatory standards.[22] Many, including NEMA, felt that voluntary labeling was sufficient to induce significant penetration in all the applications that made economic sense.

There are many factors to support the belief that industry is responsive to new energy technologies and changes in energy prices. For example, industry has significantly changed its energy intensity in the past decade. Nonelectrical energy demand has decreased in absolute terms in the past decade and electricity demand per unit of constant dollar GNP has decreased to its lowest level since 1968.[23]

Table 14, taken from an ORNL report on industrial energy use, lists the changes in energy intensity that have occurred in industry and separates these changes into those attributable to efficiency or process improvements and those attributable to changes in industry's product mix.[24,25] The table shows that the change in electrical intensity is primarily due to efficiency and process improvements.

Even though industry is responsive to energy prices, there are still factors that prevent industry from reaching an economically optimal use of its energy and plant capital. Uncertainty of future product demand, unreliability and scarcity of information, limited access to capital, and multiple incentives are four major factors that affect plant investment decisions. The economic effects of these factors are often not incorporated into the economic analyses typically used to predict plant capital purchases (as exemplified in Section 4). However, these factors greatly affect the economic climate surrounding plant investment decision-making and should, therefore, be incorporated in energy demand analysis whenever possible.[26]

Below, the four major factors are explained in more detail. Some of these factors affect motors uniquely, and other are common to industrial capital purchases in general.

Table 14. Change in energy intensity in the manufacturing sector, 1975 to 1980

	Total energy use (%)	Nonelectrical energy use (%)	Electrical energy use (%)
Total reduction in energy intensity	18.8	20.9	8.5
Reduction in energy intensity from efficiency improvements	14.4	15.8	7.9
Reduction in energy intensity from product mix changes	4.4	5.1	0.7

Source: Garland Samuels, ORNL (to be published) (Ref. 23).

5.1 PERCEPTION OF FUTURE PRODUCT DEMAND

Meeting the needs of current and future product demand is the primary goal of industrial plant capital purchases. Every industry has a portion of the market and a prediction of its future market share. The prediction that product demand will grow beyond current production capacity is the primary impetus for acquiring new plant equipment. Because regular wear-and-tear rarely provides the incentive for replacement of electrical motors, plant expansion is the primary time when new motor purchases are considered. Plans for retrofitting existing capital rarely reach strategic planning agendas. More often, retrofits occur in the form of early retirement of existing capital at times when a company intentionally builds new capacity in excess of the expected growth. In these situations, however, total productivity is the driving reason for early retirement rather than solely for the improvement of a new process's energy efficiency.

Conversely, if an industry is facing uncertain demand for its product, there is a high risk associated with retrofitting the existing production process. Only in cases where the industry is facing severe price competition will building new, more productive capacity be considered. For example, a recent study predicts that utilization of the energy-efficient continuous casting process by the steel industry will increase from its current 16% of total capacity to 22% by 1990. During the same time, however, foreign competition and reduced demand will decrease total domestic capacity 7%.[27,28] Again, the decision to build new capacity and possibly install more efficient motor capacity is governed by the total productivity of the process rather than by the energy efficiency of its individual components.

The importance of product capacity expansion was emphasized by an engineer in the pulp and paper industry who said that while many of their ASD installations were static (retrofit) replacements, funding was received for the projects only because of the plant's general capacity expansion program.*

5.2 CAPITAL AVAILABILITY

Plant investment, both in existing or proposed plants, is strongly affected by the amount of available internal capital, the cost of external capital, and, the budgeting practice used. The effect of budgeting methods on the decision-making of industry is as important in affecting plant purchases as is the prevailing cost of money. All the examples of energy savings in the previous section used payback analyses of the energy-efficient technologies; the incremental cost of a new type of motor system was compared to the net present value of the future savings. This accounting is not common in plant operations. Often, the budget for the capital and operations and maintenance (O&M) budgets are separated. Thus, no single decision-maker has the necessary responsibility and control to make an efficient motor purchase. Also, organizational studies have found that capital improvement budgets are constrained more than regular O&M budgets.[29]

Even when an investment decision can be justified with external financing, the ability to borrow may be constrained by the corporation's existing debt load. Banks become more reluctant to lend (or change higher interest rates) when debt load is high and stockholders are sensitive to changes in the debt load of a corporation.

5.3 MULTIPLE INCENTIVES

The separation of capital improvement budgets and O&M budgets is an example of multiple incentives. The distribution of purchasers and sellers of electric motors also creates separate incentives for the original purchaser of the motor and the ultimate operator. Figure 14 illustrates characteristics of motor sales for 1977. Figure 14 shows that original equipment manufacturers (OEMs) and architectural and engineering (A&E) firms

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* Telephone conversation with a representative from Boise-Cascade, September 1984.

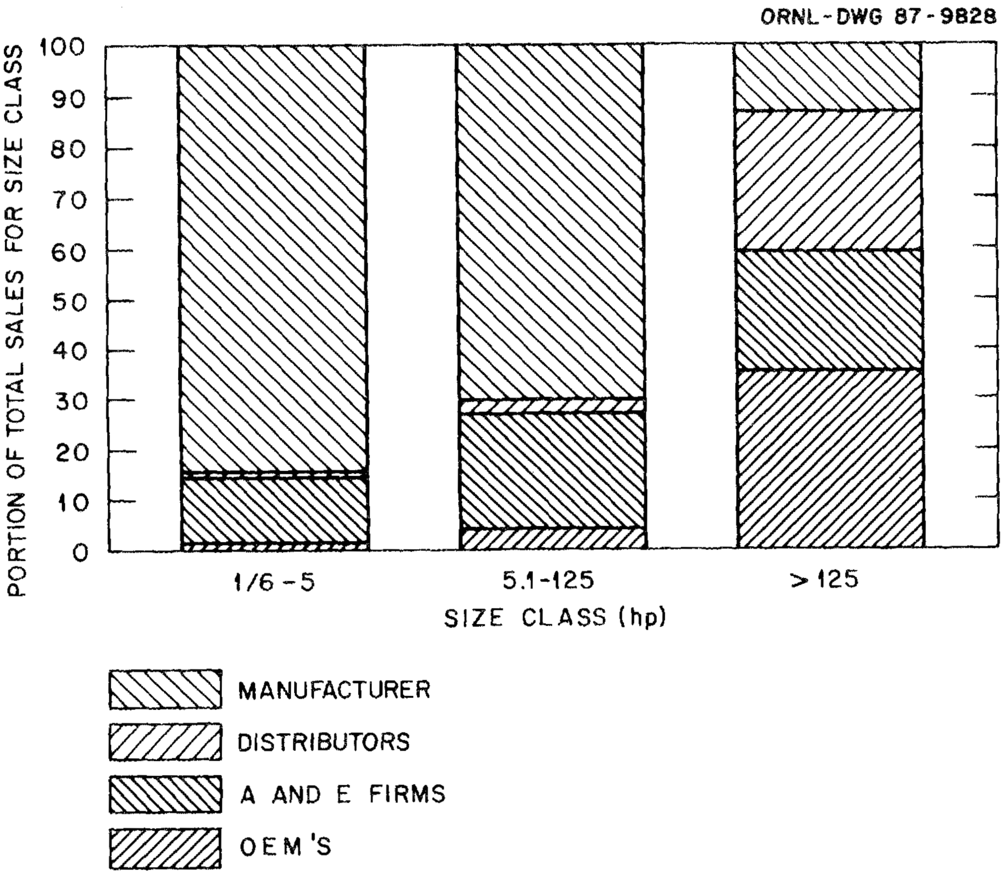

Fig. 14. Suppliers to motor end-users--1977. (Breakdown by general size class)

dominate sales to end-users in all but the largest size classes. OEMs have less incentive to consider efficiency since they do not operate the product. Similarly, A&E firms consider meeting construction budgets more important than optimizing life-cycle costs.

End-users have a difficult time evaluating life-cycle costs in this environment. As mentioned before, labeling and efficiency standards only exist for the original motor manufacturers, and this information is usually only available through them or distributors of motors.

5.4 INFORMATION AND RELIABILITY ISSUES

Lack of reliable information is a factor that constrains the use of any new technology. First, a potential user of a more efficient technology must be made aware of the opportunity of a new technology and, secondly, must be convinced that the risk of adoption is worth taking. The importance of the latter consideration should not be underestimated. Reliability is second in importance only to adequate sizing when it comes to drive selection.

Energy-efficient motors are recognized for their reliability which is largely attributable to the fact that they run at cooler temperatures. Electronic ASDs, however, are still relatively new and reliability has been a constraint in some applications. One engineer who was interviewed said that the risk of every ASD installation was evaluated separately. In some cases, ASD controls were backed-up with the old throttle valve and a line current override. In one installation, at a critical point in the process, a complete back-up ASD control was installed. Thus, reliability needs add to the tangible cost of the technology in some applications.*

Recognizing the constraint created by the perception of reliability, EPRI's Energy Management and Utilization Division has started an information program for its member utilities and their large industrial users. One of the program objectives will be to produce a national directory of ASD suppliers. Another objective is the documentation of actual ASD installations in power plants and in the process industries. Performance and reliability will be measured for the purpose of providing objective reliability data for utilities and industries considering ASDs. EPRI expects this work to be available in 1985.**

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* Conversation with a representative of Boise-Cascade, September 1984.

** Telephone conversation with an EPRI representative, September 1984.

6. SUMMARY

There are several technologies available today that can improve the efficiency of electric drive systems. However, the diversity of duty cycles and applications of motors makes it difficult to evaluate the typical cost-effectiveness of these technologies.

The demand sector with the greatest potential for savings is the process industries. These industries consume large amounts of electricity for their electric motors, have large average motor sizes, and are relatively sensitive to their motor operating costs.

A typical motor-driven industrial process has significant energy inefficiencies in each of its components. Thus, technologies that improve the efficiency of processes may or may not improve the efficiency of the motor. Efficiency improvements in electrically powered systems may increase electricity demand if the increased efficiency leads to increased utilization of the process.

Because of their durable design, low cost, and reasonably high efficiencies, ac induction motors dominate the stock of U.S. motors. Accordingly, alternative technology options with the greatest potential for affecting electricity demand are those that improve the efficiency of systems that are currently using induction motors.

"Cost-effectiveness" for industry is hard to predict and cannot be characterized accurately by a simple measure such as payback time. Energy-efficient technologies receive greater consideration for use and are allowed longer payback times when new motor processes are being installed by industry. For retrofit installations to occur, however, the savings must be significantly larger. Industries will often require a simple payback within two years in retrofit situations.

Compared to the yearly operating costs of a typical industrial induction motor, the initial cost of the motor is quite low. A motor operating with a typical duty cycle will have a yearly operating cost amounting to five to ten times its initial capital cost. This creates a potential for cost-effective savings if the efficiency of a motor can be improved at a reasonable cost. Under current motor and electricity costs, energy-efficient motors can have a payback within two years for new installations and for replacement of worn-out motors operating with average duty cycles.

Available data on energy-efficient motor sales indicate that their penetration into industrial motor stock has been low. Sales of energy-efficient ac induction motors were approximately 10% of total sales for induction motors in 1982. The effect that these motors have had on electricity demand is also small. The electricity saved by all energy-efficient motors sold for that year was roughly 16 MWY (1 MWY = 8.76 million kWh), a negligible amount compared to total industrial electricity consumption of 88,600 MWY.

New motor designs exist that offer significant performance improvements over energy-efficient induction motors. Permanent magnet motors eliminate losses created by the electrical magnetization of the stator of induction motors. Reluctance motors eliminate rotor losses by operating without rotor excitation. Amorphous metals will be a superior material for use in motors if the technology can be developed to cast them into usable forms. However, these new designs are not expected to cause a significant impact on electricity demand in the near future because there have been no reports of the manufacture of any of them in large quantities. Superconducting motors offer even greater efficiency gains, but significant technical issues will likely block their market entry in the foreseeable future.

Adjustable speed drives (ASDs) show the greatest economic potential of any of the technologies examined. They have shown great vitality, considering their novelty. Sales of ASDs are estimated to be at least $100 million (approximately 27,000 units) in 1983. These sales translate into roughly 50 MWY of electricity saved due to the sales in 1983. This savings is three times greater than the estimated savings by energy-efficient motors in 1982.

Whether or not ASDs will affect energy demand so as to require a change in the way future energy demand is predicted cannot be ascertained with the data currently available. Better data are needed on the sales of ASDs and on the existing stock of motors--especially those controlling flows. Most likely, ASDs are a part of a general trend of decreasing energy intensity in the process industries that has been going on for over a decade. The material presented here is another piece of evidence to support the prediction that these trends will continue.

The attractiveness of a technology option for an electric drive system can be difficult to measure by any simple standard such as payback time. Availability of capital, information availability and reliability, future product demand, and multiple incentives are important factors often neglected in the economic analysis predicting the future penetration of an alternative. Some of these factors, like information availability, can be expected to change as technologies penetrate their markets. Others, like capital availability, reflect the harsh economic environment in which efficient technologies must perform and such are not likely to change in the future.

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APPENDIX A

APPENDIX A

PROFESSIONAL CONTACTS IN ELECTRIC DRIVE MANUFACTURING AND END-USE INDUSTRIES

The following is a list of people who were contacted during this study for advice on the technical and marketing aspects of the technologies described in this report. These people were very helpful in giving their time and candid responses. The list of alphabetized by the organizations represented.

Allen Bradley, Drives Division, Cedarburg, WI, (414) 377-1200 x 220. Jim Bonham, Application Engineer, designs applications for ac adjustable speed drives (ASDs).

Boise-Cascade, Rumford, Maine Paper Mill, (207) 364-4521. Leonard Roy, Electrical Engineer. Leonard strongly advocates ac ASDs as part of the plant's general modernization project.

Department of Energy, Office of Policy, Safety, and Environment, Washington, D.C. (202) 586-4449. Dick Holt is the project sponsor for the project entitled "Economic Efficiency Alternatives for Meeting Energy Demands."

Ducker Marketing Research, Ann Arbor, MI, (313) 644-0086. Nicholas A. Gutwein, Project Manager, was a co-author on Ducker's report on the variable speed drives market.

Electric Power Research Institute, Palo Alto, CA (415) 855-2557. Ralph Ferraro, Project Manager in the Energy Management and Utilization Division is managing several projects on ASDs including the creation of a national directory of ASD manufacturers.

Frost and Sullivan, New York, NY, (212) 233-1080. Eleanor Burnett sells F&S's report on ASDs.

General Electric, Erie, PA, (814) 875-2663. Ed Kitas is the product manager for GE's small to medium-large size (<400 hp) ac and dc ASDs.

General Electric, Salem, VA (703) 387-7000. Ron Squires is an engineer for GE's Drive Systems Operations which produces GE's large (>500 hp) ASDs.

National Electrical Manufacturers Association, Washington, D.C. (202) 457-8400. Gerry Boyd is NEMA's statistician for the data collected on energy-efficient motors and ASDs.

Oak Ridge National Laboratory, Energy Division, Oak Ridge, TN, (615) 574-5152. Dave Bjornstad is the ORNL Project Manager for "Economic Efficiency Alternatives for Meeting Energy Demands."

Oak Ridge National Laboratory, Power System Technology Program, Oak Ridge, TN, (615) 574-0291. Tom Hudson is a Project Manager for several projects that investigated new motor designs.

Reliance Electric, Electric Drives Group, Cleveland, OH, (216) 266-7000. Jeff Ipser is a Market Researcher for RE's line of ASDs.

Square D, Columbia, SC, (803) 776-7500. Frederick W. Goekerman is a Product Manager for Square D's line of ASDs. SD sells ASDs less than 40 hp in size and, therefore, focuses on the HVAC market. Most sales are through distributors.

Trane, Tyler, TX, (214) 581-3200. Although no one was contracted at Trane, they are an important actor in the ASD market because they are developing what may be the first commercially-sold ASD residential heat pump.

Westinghouse, Vectrol Division, Oldsmar, FL, (813) 855-4621 x 260. Mike Branda is the Product Manager for Westinghouses's ASD product line and is very knowledgeable about the current ac ASD market.

A P P E N D I X B

APPENDIX B

NET PRESENT VALUE OF SAVINGS

The net present value (NPV) of savings[3] is the total benefit to be expected from energy and tax savings as a result of adopting a more efficient motor technology. NPV can be expressed as a function of the first year's energy savings (kWh), the initial cost of electricity ($/kWh), the tax rate on net income (%), the first year's investment tax credit (%), the real discount rate (%), the real electricity price escalation rate (%), the expected life of the motor or time horizon (years), and the depreciation life of the motor (years).

Ignoring the effect of taxes on net income, investment tax credits, and depreciation, the savings accrued is called the present value (PV) of energy savings and can be expressed as

$$PV = E * Ce * ((1 + R)^{N-1})/(R * (1 + R)^{N}) \quad ,$$

where

E = first year's energy saving
CE = initial cost of electricity
R = effective discount rate = $(1 + i)/(1 + r) - 1$

where i = real discount rate
r = real electricity escalation rate

N = motor life or time horizon. N cannot be greater than the expected life of the motor.

The PV is the cumulative present value of energy savings (in $) that will be achieved in N years by switching to an efficient technology. The NPV takes the effect of taxes, depreciation, and first year's tax credit into account and can be expressed as

$$NPV = PV * (1 - T) + Cc * (I + T/D * F) \quad ,$$

where

T = tax rate on net income
Cc = present value of the cost of new technology
I = first year's investment tax credit
D = depreciation life of the motor
F = present value depreciation factor = $((1 + r)^{N<=D-1})/r * (1 + r)^{N<=D})$

where

$N <= D$ = the value of the time horizon up to, but not exceeding, the depreciation life of the motor. Values equal D for N greater than D.

Note that the discount rate (r) is used rather than the effective discount rate (R) in the present value depreciation factor because the depreciation savings from a capital purchase is independent of electricity price escalations. The expression assumes straight-line depreciation over the depreciation life of the motor. If the depreciation life of the motor is shorter than the expected life of the motor, the depreciation is considered "accelerated".

When there are several costs for a single technology or when the cost of a technology is not readily known, it is desirable to be able to compute the NPV without having to known the initial incremental cost. This can be done with little loss in accuracy by substituting the present value of the cost of the new technology (Cc) with the after-tax (or net) energy savings (PV * (1-T)). This substitution is intuitively reasonable because the most one would want to pay for an efficient technology would be the savings that they would gain. Making this substitution, NPV becomes

$$NPV = PV * (1 - T) * (1 + I + T/D * F) .$$

The above expression closely approximates the savings that would be achieved during the "payback" year of a technology. During the year that the payback is achieved, the net energy savings will be approximately the cost of the new technology and the simplifying substitution made above will be a valid one. Thus, this expression can be equated with the initial cost of the technology and solved for the year that payback occurs (N).

This analysis is adapted from Energy Efficient Electric Motors (Ref. 3).

INTERNAL DISTRIBUTION

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EXTERNAL DISTRIBUTION

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