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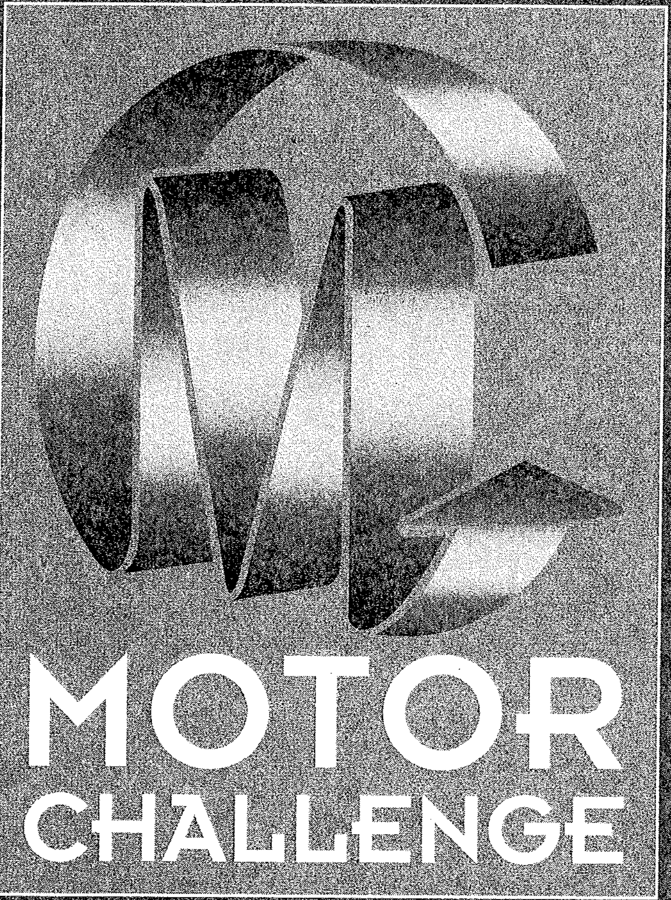
Energy Efficient Electric Motor Selection Handbook



The energy savings network – plug into it

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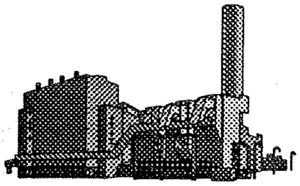

BPA Report Summary

Industrial Technology

TITLE

ENERGY EFFICIENT ELECTRIC MOTOR SELECTION HANDBOOK

SUMMARY

Substantial reductions in energy and operational costs can be achieved through the use of energy-efficient electric motors. This handbook was compiled to help industry identify opportunities for cost-effective application of these motors. It covers the economic and operational factors to be considered when motor purchase decision are being made. Its audience includes plant managers, plant engineers, and others interested in energy management or preventative maintenance programs.

BPA PERSPECTIVE

This R&D project is one of a number of activities which support BPA's Market Transformation efforts. Market Transformation is a strategic effort initiated by BPA to induce lasting structural or behavioral changes in the market that result in the adoption and penetration of energy efficient technologies and practices.

BACKGROUND

The efficiency of an electric motor can only be improved through a reduction in motor losses. Improvement in the design, materials and construction have resulted in efficiency gains of 2 to 6 percent which translates into a 25 percent reduction in losses. A small gain in efficiency can produce significant energy savings and lower operating costs over the life of the motor. Consequently, the higher purchase price of high-efficiency motors (15 to 30 percent) can, in most cases, be recovered in two years through cost savings in energy and operation.

Because energy-efficient motors are a proven technology in terms of durability and reliability, their use should be considered for new installations, major modifications, replacement of failed motors or those that require repair, or extreme cases of oversized or underloaded motors.

OBJECTIVE

To assist the industrial sector in identifying cost-effective opportunities for application of energy-efficient motors.

RESULTS

The Handbook contains a discussion on the characteristics, economics, and benefits of standard versus high-efficiency motors in the 1 to 500 horsepower range. The Handbook shows you how to assess energy savings and cost effectiveness when making motor purchase decisions. It also discusses field data acquisition techniques, high-efficiency motor speed/load characteristics, performance under part-load conditions, and operation with an abnormal power supply.

Steps are outlined for launching a motor improvement program, which includes a worksheet to determine potential energy savings and the economic feasibility of an energy-efficient motor project.

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ORDERING INFORMATION

Report Number: DOE/GO-10096-290

For additional copies of this report or information on the Motor Challenge, call the Motor Challenge Information Clearinghouse at (800) 862-2086. Access the Motor Challenge Website on the Internet at www.motor.doe.gov.

Energy Efficient Electric Motor Selection Handbook

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Funded by
The Bonneville Power Administration
United States Department of Energy

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August 1996

Acknowledgments

The authors wish to thank the Bonneville Power Administration for funding this project. Particular thanks are due to Craig Wohlgemuth of Bonneville's Technical Assessment/R&D Group for his encouragement, direction, and support. Appreciation is also extended to Austin Bonnet of U.S. Electrical Motors, Ziba Kellum of the Industrial Electrotechnology Laboratory at North Carolina State University, Howard Penrose of Dreisilker Electric Motors, Ted Atkins of Baldor Electric Company, Markus Zeller of Demand Side Energy Consulting, and Richard L. Nailen of Wisconsin Electric Power Company for information and/or reviews provided.

The U.S. Department of Energy's Motor Challenge Program would like to thank the Bonneville Power Administration for their efforts in producing this document. This publication originally was developed and published by the Bonneville Power Administration. It has been revised and reproduced by the Motor Challenge Program.

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Preface

Efficient use of energy enables commercial and industrial facilities to minimize production costs, increase profits, and stay competitive. The majority of electrical energy consumed in most industrial facilities is used to run electric motors. Energy efficient motors now available, are typically from 2 to 6 percent more efficient than their standard motor counterparts. This efficiency improvement translates into substantial energy and dollar savings. For instance, a recent study of Northwest industrial sector energy conservation measures revealed a potential for 52.7 MWa of energy savings by replacing standard motors with high-efficiency motors. This savings is annually valued at $13.8 million given an electrical rate of only $0.03/kWh.

The price premium for an energy efficient motor is typically 15 to 30 percent above the cost of a standard motor. Over a typical ten year operating life, a motor can easily consume electricity valued at over 57 times its initial purchase price. This means that when you spend $1,600 to purchase a motor, you are obligating yourself to purchase over $92,000 worth of energy to operate it. A price premium of $400 is negligible compared to saving 3 percent of $92,000 or $2,760. Purchasing new or replacement energy efficient motors makes good economic sense.

The efficiency gains associated with energy efficient motors are obtained through the use of refined design, better materials, and improved construction. Many motor manufacturers offer an extended warranty for their premium-efficiency motor lines. Yet less than half of motor sales nationwide are of high-efficiency units. Because of our low-cost electricity, this percentage is undoubtedly even lower in the Northwest region.

Durable and reliable energy efficient motors can be extremely cost effective with simple paybacks on investment of less than two years - even in the Northwest. Energy efficient motors should be considered in the following instances:

- For new facilities or when modifications are made to existing installations or processes
- When procuring equipment packages
- Instead of rewinding failed standard efficiency motors
- To replace oversized and underloaded motors
- As part of an energy management or preventative maintenance program
- When utility rebates are offered that make high-efficiency motor retrofits even more cost effective

This Energy Efficient Electric Motor Selection Handbook (Handbook) shows you how to assess energy savings and cost effectiveness when making motor purchase decisions. The Handbook also discusses field data acquisition techniques, high-efficiency motor speed/load characteristics, performance under part-load conditions, and operation with an abnormal power supply.

Additionally, the Handbook tells you where further information is available. You can obtain performance and price data for both standard and energy efficient motors through the Motor Challenge Information Clearinghouse (800) 862-2086. Finally, the Handbook contains a motor test data sheet (Appendix B) and a list of motor manufacturers' representatives (Appendix C).

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Appendix A: Efficiency as a Function of Load for 900, 1200, 1800 and 3600 RPM Standard Efficiency Motors

Appendix B: Motor Nameplate and Field Test Data Form

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Chapter 1 Introduction

Industrial Motor Population, Energy Consumption and Uses

The population of electric motors 1/6 horsepower (hp) and larger grew from approximately 720 million in 1977 to over 1.1 billion in 1991.[1,2] The total annual energy consumption due to motor-driven processes was estimated at 1574 million megawatt-hours (MWh) in 1988—equivalent to 57 percent of our nations total electrical energy use. Forty-seven percent of this motor energy use occurred within the industrial sector.[2]

In the industrial sector, motors are used to drive pumps, fan and compressors, as well as materials handling and materials processing equipment. Commercial sector end use applications include cooling, space heating and ventilation; refrigeration units and water circulation and supply. Motors are used within residences to drive appliances, air conditioning and air handling units. Motor energy use by sector is summarized in Table 1.[2]

Almost 70 percent of the electrical energy used by manufacturing industries is dedicated to motor drives. The chemicals industry is the largest process user of motor-driven electricity, with pulp and paper a close second.[1] Petroleum, food processing, primary metals, metals fabrication and rubber/plastics industries are also substantial consumers of electricity for motor driven processes.

Over 90 percent of the U.S. inventory of roughly 1.1 billion motors lie within the fractional horsepower range (1/6 to 1 hp). With higher average annual hours of use, however, motors in the higher horsepower classes consume disproportionately much more electricity than the smaller motors. For example, the 2.3 percent of all motors exceeding 5 horsepower account for over 75 percent of all motor electrical energy consumption. Motor populations and annual energy usage by size category are given in Table 2.[2]

In 1987, industrial sector use of electricity in the Northwest amounted to 6,062 average megawatts (MWa). This is equivalent to 38.8 percent of the region's 15,618 MWa of total electricity sales to final consumers. Food, chemical, paper, lumber, and metal industries account for more than 90 percent of the region's industrial use of electricity.[3] A 1988 study of possible industrial sector energy conservation measures revealed the potential for approximately 345 MWa of energy savings, with changeouts of standard to energy efficient motors accounting for 52.7 MWa or 15.2 percent of the total savings.[4] Replacing standard with energy efficient motors can save Northwest industrial customers $13.8 million annually, given an electricity price of only $.03/kWh.

Table 1
Motor Energy Use by Sector, 1988

Sector	Annual Motor Energy Use, MWh, millions	Percentage of Sector Use by Motors	Percentage of Total Motor Energy Use
Residential	333	37	21
Commercial	304	43	19
Industrial	742	78	47
Other (utilities, public authorities, railways)	195		13

Total Annual Motor Energy Use, MWh, millions	1574
Total U.S. Electrical Energy Consumption	2783
Percentage of Consumption by Motor-Driven Systems	57%

Table 2
Motor Population and Energy Consumption by Size Class, 1988

Motor Rating, hp	Population, thousands	Percentage of Total Motor Inventory	Annual Energy Consumption, MWh, millions	Percentage of Motor-Drive Energy Use
1/6-<1	900,000	90.2	224	14.3
1-5	75,000	7.5	160	10.2
7.5-20	15,000	1.5	93	5.9
25-50	5,000	0.5	160	10.2
60-125	3,000	0.3	345	22.0
>125	200	0.02	587	37.4
Total	**998,200**		**1,569**	

Annual Electric Motor Sales Volume and Energy Savings Potential

Since 1977, sales of polyphase AC motors in the 1 to over 500 horsepower size have ranged from 1.38 to 2.13 million units annually. Motor purchases for both new application and replacement purposes are sensitive to both business cycle conditions and investment incentives. Annual sales volumes are given in Table 3.[1]

Historically, only 15 percent of motor sales involved premium or high-efficiency motors, as the highest priorities of motor buyers have been availability, quick delivery, reliability, and price. A survey of motor manufacturers conducted by the Washington State Energy Office in 1990 found that energy-efficiency was ranked only 5th out of 11 purchaser concerns.

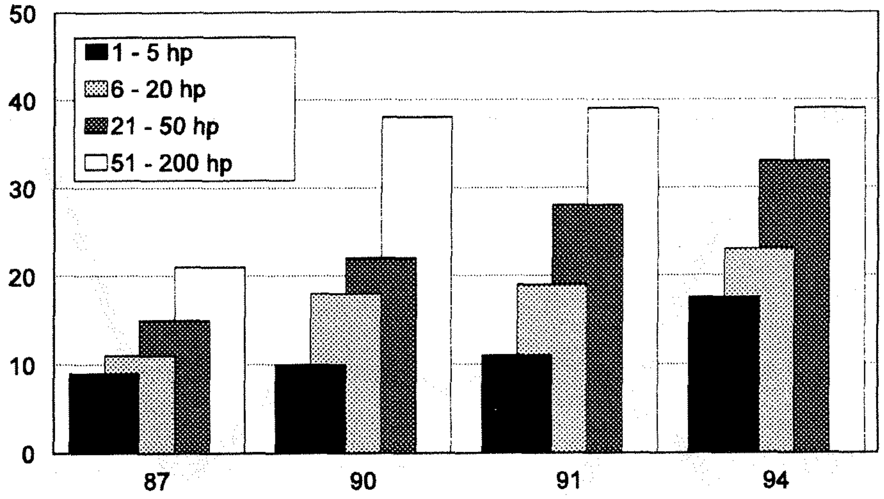
Electrical utility conservation acquisition, motor rebate and educational programs have resulted in a change in motor purchasing patterns, particularly for the higher horsepower units. Between 1987 and 1994, the market share for energy efficient motors in the 50 to 200 horsepower size range increased from just over 20 to nearly 40 percent. Energy efficient motor sales trends are depicted in Figure 1.[5] Original equipment manufacturers (OEMs) still represent a major market segment that is relatively unaffected by utility-sponsored motor market transformation efforts.

Several studies have been completed which attempt to determine the national savings potential associated with replacing existing standard-efficiency motors with energy efficient units. The American Council for an Energy-Efficient Economy estimates a nationwide annual energy savings of 58.6 million MWh-equivalent to the output of almost twelve 1,000 MW power stations (with a 65 percent capacity factor and 8 percent grid

Table 3
Sales of Motors by Horsepower Range and Year (1000 Units)

	1977	1979	1981	1983	1985	1987	1989	1991
Polyphase AC								
1-5hp	1,325	1,417	1,193	881	957	1,287	1,052	1,240
7.5-20hp	397	473	435	331	352	451	539	482
25-50	139	155	157	105	120	127	154	133
60-125hp	55	59	66	40	47	38	60	40
150-200hp	8	19	21	14	14	26	20	30
250-500hp	8	8	8	6	6	8	17	16
Over 500hp	4	4	4	2	3	2	12	2
Total	**1,937**	**2,136**	**1,882**	**1,380**	**1,498**	**1,938**	**1,854**	**1,943**

Figure 1
Energy Efficient Motor Sales
Percentage of Total Units



loss)-given that all existing standard-efficiency motors were to be upgraded.[2] Interestingly, over 55 percent of the estimated available savings occurs from replacing motors with rated outputs less than 5 horsepower. These disproportionate savings occur due to the tremendous efficiency improvements obtainable and lower penetration of energy efficient motors in the small horsepower classes. As larger motors have always been relatively efficient, gains are more modest and are typically associated with replacing motors that have been rewound. Energy savings estimates by motor size range are given in Table 4.[2]

Easton Consultants recently examined various strategies to introduce 1 hp to 200 hp energy efficient motors into North America's OEM market. Based on 1992 motors sales data, an energy savings of 395 *million* kWh annually is attainable each year through the preferential purchase of energy efficient motors. Easton's findings are illustrated in Figure 2.[5,6]

When to Buy Energy Efficient Motors

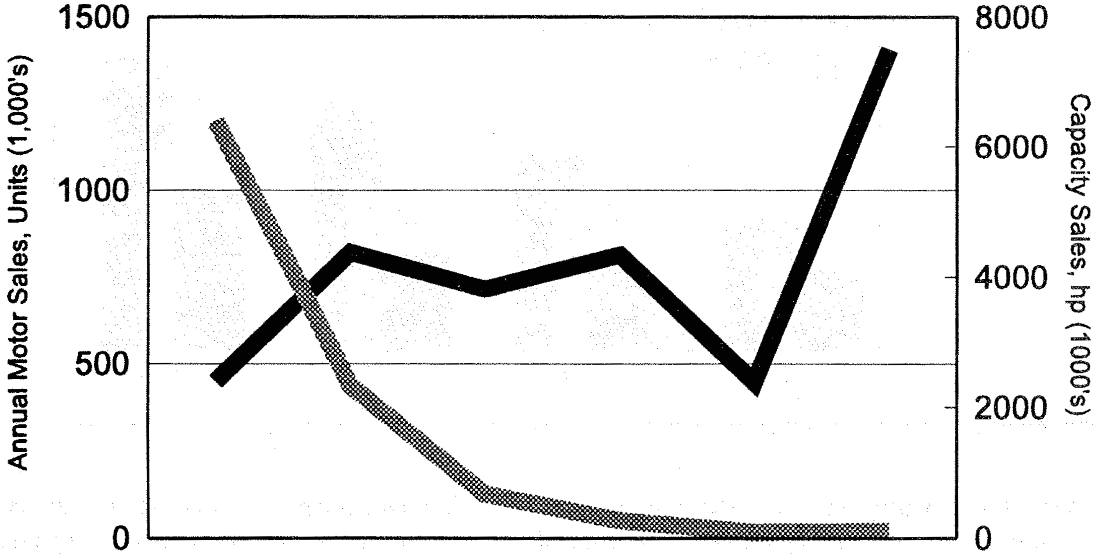
The energy savings from replacing standard with energy efficient motors can be substantial. This Handbook contains guidelines to help you identify motors that are candidates for replacement with energy efficient electric motors. Using readily available

Table 4
Replacement of Existing Standard with Energy-Efficient Motors
National Savings Estimates by Motor Size Range

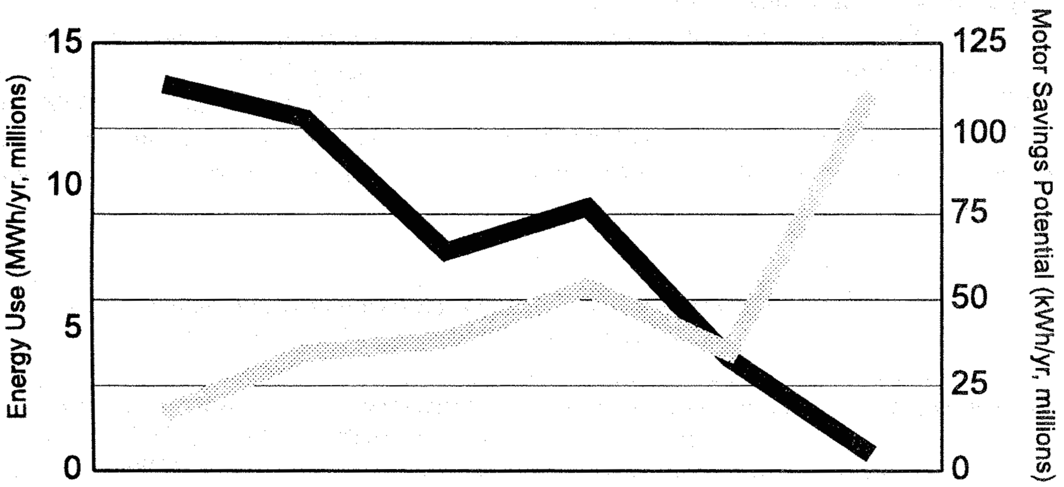
Size Range (hp)	Weighted Average Size (hp)	Efficiency Improvement (%)	National Annual Energy Savings, MWh Millions	Percentage of Total Savings
1/6-<1	1/4	15	24.2	41.3
1-5	2.1	7.1	8.2	14.0
7.5-20	11.9	6.1	4.1	7.0
25-50	32.5	4.5	5.2	8.9
60-125	86.7	3.6	8.9	15.2
>125	212	1.9	8.0	13.6
Total			**58.6**	

Figure 2

Induction Motors Sales, Energy Use and Conservation Savings Potential, 1992



	1 to 5	7.5 to 20	25 to 50	60 to 125	150 to 200	>200
Average HP in Class:	2	10	30	85	140	375
1992 unit sales (x 1,000): ▨	1200	438	127	51	17	20
Capacity sales (x 1,000 hp): ■	2400	4380	3810	4335	2380	7500



	1 to 5	7.5 to 20	25 to 50	60 to 125	150 to 200	>200
Capacity Sales (hp, thou.):	2400	4380	3810	4335	2380	7500
Avg Hours/Yr:	1200	1500	2000	2500	3000	3000
Annual Energy Use (MWh/yr, mill.): ▨	1.99	4.14	4.61	6.45	4.19	13.23
Current Avg. Market Eff. (%):	81	88.9	92.4	94	95.1	N/A
Future Avg. Market Eff. (%):	85.6	91.1	93.7	95.1	95.9	N/A
Avg. Savings (%):	5.7	2.5	1.4	1.2	0.8	~.04
Savings Potential (kWh/yr, mill.): ■	113	103	64	77	33	5

information such as motor nameplate capacity, operating hours, and electricity price you can quickly determine the simple payback that would result from selecting and operating an energy efficient motor.

Using energy efficient motors can reduce your operating costs in several ways. Not only does saving energy reduce your monthly electrical bill, it can postpone or eliminate the need to expand the electrical supply system capacity within your facility. On a larger scale, installing energy conservation devices allows your electrical utility to defer building expensive new generating plants, resulting in lower costs for you, the consumer.

Saving this energy and money requires the proper selection and use of energy efficient motors.[7] There are three general opportunities for choosing energy efficiency motors: 1) when purchasing a new motor, 2) in place of rewinding failed motors, and 3) to retrofit an operable but inefficient motor for energy conservation savings. Energy efficient motors should be considered in the following instances:[8]

- For all new installations.
- When major modifications are made to existing facilities or processes.
- For all new purchases of equipment packages that contain electric motors, such as air conditioners, compressors, and filtration systems.
- When purchasing spares or replacing failed motors.
- Instead of rewinding old, standard-efficiency motors.
- To replace grossly oversized and underloaded motors.
- As part of an energy management or preventative maintenance program.
- When utility conservation programs, rebates, or incentives are offered that make energy efficient motor retrofits cost-effective.

Motors are the largest single use of electricity in most industrial plants. A study conducted for Seattle City Light indicates that 42 percent of that utility's industrial customer electrical consumption goes to motor driven end uses.[9] The dominance of motor loads can be even greater in some industries. For instance, energy audits conducted by the Washington State Energy Office revealed over 78,000 hp of motor-driven loads at 24 small and mid-sized industrial facilities.[10] Loads at various manufacturing plants include: A saw and planer mill with 65 motors and 6,215 hp of connected load. Approximately 94 percent of the 13.8 million kWh of that facility's annual electrical energy consumption goes to motors driving boiler feedwater pumps, forced draft fans, hydraulic systems, air compressors, planer drives, blowers, feeders, chippers, edgers, hoggers, debarkers, radial saws, and slabbers.

A small cedar mill similarly has 37 motors with 2,672 total hp. A Northwest plywood drying facility uses 72 motors with 3,275 hp of nameplate capacity. These motors drive combustion air fans, scrubbers, circulating air fans, condensate pumps, charging pumps, hoggers, fines and chip blowers, bag house blowers, and glue mixers. Forty-seven percent of the electrical consumption at a controlled-atmosphere cold storage facility is due to refrigeration system compressor, evaporator fan, and condenser fan motors while a potato processing plant has 17 motors with 1,115 hp driving ammonia compressors, hydraulic pumps, and air compressors.

Chapter 2
Energy Efficient Motor Performance and Price

The efficiency of a motor is the ratio of the mechanical power output to the electrical power input. This may be expressed as:

$$Efficiency = \frac{Output}{Input} = \frac{Input - Losses}{Input} = \frac{Output}{Output + Losses}$$

Design changes and better materials reduce motor losses, making energy efficient motors more efficient than standard motors. Reduced losses mean that an energy efficient motor produces a given amount of work with less energy input than a standard motor.[8]

In 1989, the National Electric Manufacturers Association (NEMA) developed a standard definition for energy efficient motors. The definition, designed to help users identify and compare electric motor efficiencies on an equal basis, includes a table of threshold nominal full-load efficiency values.[11] This energy efficient definition was originally presented as Table 12-6b of the NEMA MG1-1989 standards for motors and generators. For each unique combination of horsepower, enclosure, and synchronous speed, the table provided a nominal threshold efficiency to be met before a motor could be identified as "energy efficient". A revision to MG1 maintained the Table 12-6b standard, but presented a new Table 12-6c as a suggested standard for "future design". The first transformation of Table 12-6c from "suggested....future design" to a current standard occurred, not as a NEMA standard revision, but when it was adopted into the Energy Policy Act of 1992, discussed below.

An element of confusion was introduced when NEMA revised its MG1 document in 1993 and both tables (often cited by number rather than name) were renumbered. Table 12-6b was renumbered Table 12-9 and Table 12-6c was renumbered Table 12-10. The efficiency values and titles remained unchanged. In October, 1994, NEMA issued Revision 1 to its MG1-1993, which eliminated Table 12-9 entirely and re-titled Table 12-10, promoting it to be the official current definition of "energy efficient". With this re-christening, NEMA also extended Table 12-10's coverage beyond its prior 200 hp limit to 500 hp for most motors. The efficiencies for motors up through 200 hp remained the same as those which first appeared in Table 12-6c. A motor's performance must equal or exceed the efficiency levels given in Table 5 of this handbook (reprinted from Table 12-10 of NEMA MG-1-1993, Rev. 1) for it to be classified as "energy efficient".

The Energy Policy Act of 1992 (EPACT) requires that most general purpose motors manufactured for sale in the United States after October 24, 1997, meet new minimum efficiency standards. These standards are identical to the shaded area of Table 5. The Act applies to 1 to 200 horsepower general purpose, T-frame, single-speed, foot mounted, continuous rated, polyphase squirrel cage induction motors conforming to NEMA Designs A and B. Covered motors are designed to operate with 230 or 460 volt power supplies, have open or "closed" (totally enclosed) enclosures, and operate at speeds of 1200, 1800 or 3600 RPM. Such motors dominate industrial and commercial applications of one horsepower and above.[12] While the Act applies to both imported motors and motors purchased as components of other pieces of equipment, it does not apply to definite-purpose or special-purpose motors (those designed with specific mechanical construction features, with specific operating characteristics, or for use on a particular type of application). Examples of motors which are excluded from the new-federal minimum efficiency standards include:

- Non-NEMA frame motors,
- Definite-purpose motors and special-purpose motors, as defined by NEMA,
- All motors less than 1 horsepower or greater than 200 horsepower,
- NEMA design C and D polyphase induction motors,
- All synchronous, direct-current, permanent magnet, reluctance, shaded-pole, and wound rotor motors,
- Motors that are not foot-mounted (e.g., vertical-mounted),

- Motors manufactured in the United States for export,
- Multi-speed motors, and,
- Rebuilt, repaired or rewound motors.

Nominal full-load efficiencies for currently available energy efficient and standard motors are shown in Figure 3.[13] Figure 3 clearly indicates that the NEMA and Energy Policy Act mandated standards are easy for motor manufacturers to exceed. In fact, many motors on the market qualify as energy efficient machines. It is also apparent that you can improve efficiency by several points through simply buying one whose performance lies near the top of the range of available efficiencies, rather than one that just meets the NEMA minimum standard.

Frequently, an energy efficient motor model might barely perform above the efficiency of another manufacturers' standard unit. Of course, after October 24, 1997, all general purpose T-frame motors manufactured must exceed the EPACT mandated standards. Average nominal full-load efficiencies and 1995 list prices for standard and energy efficient motors are summarized in Table 6.

Table 5

NEMA Threshold Full-Load Nominal Efficiency Values for Energy Efficient Motors (From NEMA MG1 Table 12-10)[1]

Open Motors

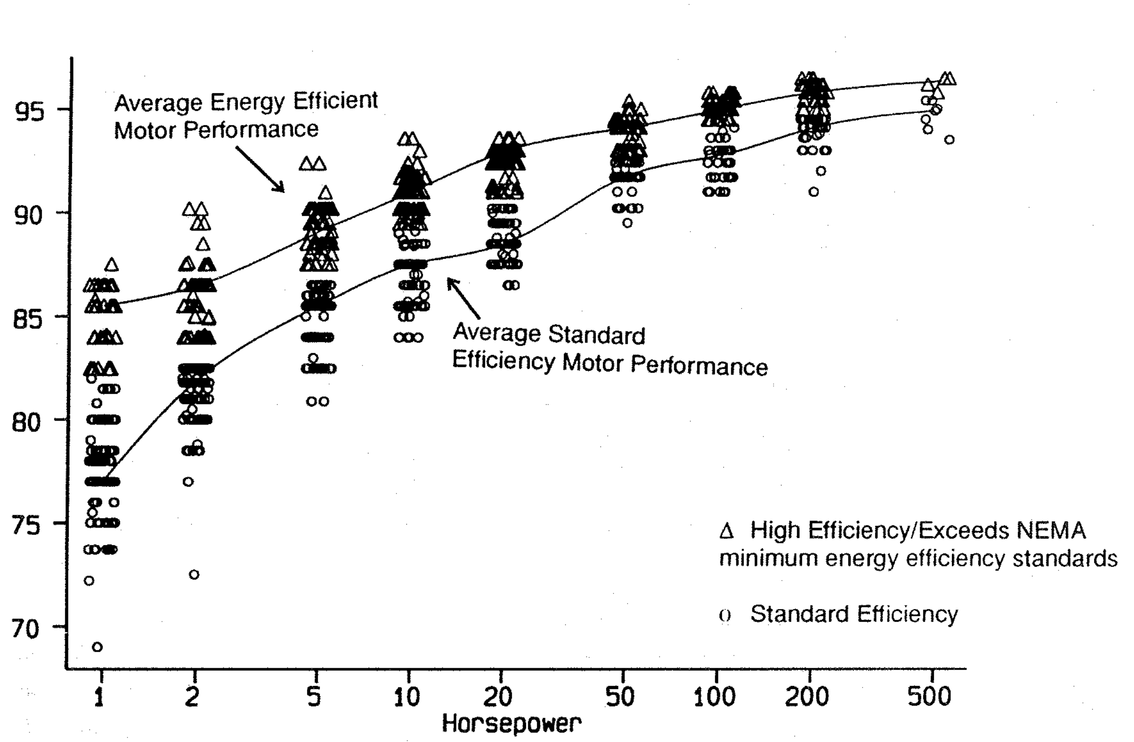
hp	3600	1800	1200	900
1	–	82.5	80.0	74.0
1.5	82.5	84.0	84.0	75.5
2	84.0	84.0	85.5	85.5
3	84.0	86.5	86.5	86.5
5	85.5	87.5	87.5	87.5
7.5	87.5	88.5	88.5	88.5
10	88.5	89.5	90.2	89.5
15	89.5	91.0	90.2	89.5
20	90.2	91.0	91.0	90.2
25	91.0	91.7	91.7	90.2
30	91.0	92.4	92.4	91.0
40	91.7	93.0	93.0	91.0
50	92.4	93.0	93.0	91.7
60	93.0	93.6	93.6	92.4
75	93.0	94.1	93.6	93.6
100	93.0	94.1	94.1	93.6
125	93.6	94.5	94.1	93.6
150	93.6	95.0	94.5	93.6
200	94.5	95.0	94.5	93.6
250	94.5	95.4	95.4	94.5
300	95.0	95.4	95.4	–
350	95.0	95.4	95.4	–
400	95.4	95.4	–	–
450	95.8	95.8	–	–
500	95.8	95.8	–	–

Enclosed Motors

hp	3600	1800	1200	900
1	75.5	82.5	80.0	74.0
1.5	72.5	84.0	85.5	77.0
2	84.0	84.0	86.5	82.5
3	85.5	87.5	87.5	84.0
5	87.5	87.5	87.5	85.5
7.5	88.5	89.5	89.5	85.5
10	89.5	89.5	89.5	88.5
15	90.2	91.0	90.2	88.5
20	90.2	91.0	90.2	89.5
25	91.0	92.4	91.7	89.5
30	91.0	92.4	91.7	91.0
40	91.7	93.0	93.0	91.0
50	92.4	93.0	93.0	91.7
60	93.0	93.6	93.6	91.7
75	93.0	94.1	93.6	93.0
100	93.6	94.5	94.1	93.0
125	94.5	94.5	94.1	93.6
150	94.5	95.0	95.0	93.6
200	95.0	95.0	95.0	94.1
250	95.4	95.0	95.0	94.5
300	95.4	95.4	95.0	–
350	95.4	95.4	95.0	–
400	95.4	95.4	–	–
450	95.4	95.4	–	–
500	95.4	95.8	–	–

[1] The shaded area indicates motor classes covered by the efficiency standards contained within the Energy Policy Act of 1992.

Figure 3
Standard and Energy Efficient Motor Performance Ranges



Motor Losses and Loss Reduction Techniques

A motor's function is to convert electrical energy to mechanical energy to perform useful work. The only way to improve motor efficiency is to reduce motor losses. Even though standard motors operate efficiently, with typical efficiencies ranging between 83 and 92 percent, energy efficient motors perform significantly better. An efficiency gain from only 92 to 94 percent results in a 25 percent reduction in losses. Since motor losses result in heat rejected into the atmosphere, reducing losses can significantly reduce cooling loads on an industrial facility's air conditioning system.

Motor energy losses can be segregated into five major areas, each of which is influenced by design and construction decisions.[14] One design consideration, for example, is the size of the air gap between the rotor and stator.[15,16] Large air gaps minimize manufacturing costs. Smaller air gaps improve efficiency and power factor. Even smaller air gaps further improve power factor, but can reduce efficiency and risk vibration problems. Motor losses may be categorized as those which are fixed, occurring whenever the motor is energized, and remaining constant for a given voltage and speed, and those which are variable and increase with motor load.[17] These losses are described as follows:

Fixed Losses

1. Core loss represents energy required to overcome opposition to changing magnetic fields within the core material (hysteresis) and includes losses due to creation of eddy currents that flow in the core. Core losses are decreased through the use of improved permeability electromagnetic (silicon) steel and by lengthening the core to reduce magnetic flux densities. Eddy current losses are decreased by using thinner steel laminations with better interlaminar insulation.

2. Windage and friction losses occur due to bearing friction and air resistance. Improved bearing and seal selection, air-flow, and fan design are employed to reduce these losses. In an energy efficient motor, loss minimization results in reduced cooling requirements so a smaller fan can be used. Both core losses and windage and friction losses are essentially independent of motor load.

Table 6
Average Efficiencies and Typical List Prices for Standard and Energy Efficient Four-Pole (1800 RPM) Motors

hp	Average Standard Motor Efficiency, % [1]	Average Energy-Efficient Motor Efficiency, % [2]	Energy Savings, % [3]	Typical Standard TEFC Motor List Price [4]	Typical Energy-Efficient TEFC Motor List Price [4]	List Price Premium
1	77.4 (58)	83.7 (24)	7.5	$203 (55)	$211 (19)	$8
1.5	79.6 (58)	85.2 (22)	6.6	$217 (55)	$262 (17)	$45
2	80.7 (55)	85.3 (21)	5.4	$226 (52)	$259 (16)	$33
3	82.3 (73)	88.8 (25)	7.3	$252 (67)	$325 (17)	$73
5	83.9 (56)	89.1 (21)	5.8	$310 (51)	$379 (18)	$69
7.5	85.0 (51)	90.1 (31)	5.7	$408 (50)	$538 (26)	$130
10	86.0 (50)	90.9 (27)	5.4	$516 (49)	$650 (24)	$134
15	87.7 (43)	92.2 (37)	4.9	$677 (42)	$864 (24)	$187
20	88.2 (39)	92.4 (32)	4.5	$843 (38)	$1,055 (27)	$212
25	88.9 (60)	93.1 (24)	4.5	$993 (41)	$1,226 (13)	$233
30	88.8 (50)	93.3 (23)	4.8	$1,160 (32)	$1,425 (15)	$265
40	90.0 (34)	94.0 (24)	4.3	$1,446 (33)	$1,772 (14)	$326
50	90.6 (32)	94.1 (24)	3.7	$1,688 (29)	$2,066 (14)	$378
60	91.3 (22)	94.8 (26)	3.7	$2,125 (19)	$2,532 (18)	$407
75	91.9 (21)	94.9 (26)	3.2	$2,703 (18)	$3,084 (14)	$381
100	92.3 (18)	95.3 (30)	3.1	$3,483 (15)	$3,933 (15)	$450
125	92.1 (10)	95.2 (18)	3.3	$4,006 (09)	$4,709 (13)	$703
150	92.8 (16)	95.6 (13)	2.9	$5,760 (12)	$6,801 (10)	$1,041
200	93.1 (15)	95.6 (12)	2.6	$7,022 (12)	$8,592 (09)	$1,570
250	94.1 (18) [5]	96.0 (10)	2.0	$8,863 (15)	$12,701 (09)	$3,838
300	94.1 (13)	95.9 (05)	1.9	$10,871 (11)	$14,479 (04)	$3,608
350	93.6 (07)	95.7 (07)	2.2	$13,262 (07)	$15,800 (06)	$2,538
400	94.1 (08)	95.9 (08)	1.9	$14,938 (08)	$16,731 (07)	$1,793
450	94.2 (10)	96.0 (05)	1.9	$14,890 (10)	$19,333 (04)	$4,443
500	94.2 (07)	96.0 (04)	1.9	$18,190 (07)	$18,271 (02)	$82

hp	Average Standard Motor Efficiency, % [1]	Average Energy-Efficient Motor Efficiency, % [2]	Energy Savings, % [3]	Typical Standard TEFC Motor List Price [4]	Typical Energy-Efficient TEFC Motor List Price [4]	List Price Premium
1	76.9 (50)	85.2 (29)	9.7	$234 (47)	$362 (24)	$128
1.5	78.9 (48)	85.9 (35)	8.1	$241 (45)	$402 (30)	$161
2	80.4 (42)	85.8 (38)	6.3	$306 (39)	$442 (33)	$136
3	81.6 (38)	88.7 (46)	8.0	$308 (37)	$488 (41)	$180
5	83.6 (30)	89.1 (47)	6.2	$344 (29)	$544 (42)	$200
7.5	85.6 (46)	90.8 (47)	5.7	$494 (45)	$743 (42)	$249
10	85.8 (23)	90.9 (49)	5.6	$614 (23)	$888 (44)	$274
15	86.7 (20)	92.2 (46)	6.0	$879 (20)	$1,194 (41)	$315
20	88.6 (40)	92.5 (51)	4.2	$1,102 (40)	$1,441 (46)	$339
25	89.3 (36)	93.3 (44)	4.3	$1,321 (35)	$1,778 (39)	$457
30	89.5 (23)	93.5 (45)	4.3	$1,628 (22)	$2,111 (40)	$483
40	90.1 (23)	94.0 (44)	4.1	$2,056 (22)	$2,746 (39)	$690
50	91.2 (25)	94.0 (48)	3.0	$2,567 (24)	$3,399 (43)	$832
60	91.6 (26)	94.8 (43)	3.4	$3,897 (25)	$4,970 (37)	$1,073
75	91.6 (18)	94.9 (43)	3.5	$4,891 (18)	$6,080 (38)	$1,189
100	92.2 (29)	95.2 (43)	3.2	$5,793 (28)	$7,790 (38)	$1.997
125	92.2 (21)	95.5 (38)	3.5	$7,584 (21)	$10,000 (33)	$2,416
150	93.0 (28)	95.7 (38)	2.8	$9,167 (27)	$11,667 (33)	$2,500
200	93.5 (22)	95.8 (39)	2.4	$11,318 (21)	$14,500 (33)	$3,182
250	93.7 (24) [5]	95.8 (35)	2.2	$14,246 (23)	$17,741 (33)	$3,495
300	94.2 (12)	95.9 (21)	1.8	$16,715 (11)	$18,813 (17)	$2,098
350	94.4 (10)	96.0 (14)	1.7	$21,525 (10)	$24,271 (12)	$2,746
400	94.4 (10)	95.9 (08)	1.6	$27,391 (10)	$27,920 (07)	$529
450	94.5 (08)	95.8 (03)	1.4	$28,775 (07)	$29,731 (02)	$956
500	94.8 (06)	96.3 (04)	1.6	$33,300 (06)	$37,800 (03)	$4,470

Notes for Table 6: Full-load efficiencies are given. The numbers in parenthesis indicate the number of motors examined. List prices are extracted from the MotorMaster Version 2.2 (1994) motor price and performance database.

1. Indicates the performance of "typical" standard-efficiency motors as defined by Table 12-9 of NEMA MG 1-1993 (unrevised). Note: Table 6-B was renamed 12-9.
2. Indicates the performance of curently available energy efficient motors as defined by Table 12-10 of the October 1994, revision of NEMA MG 1-1993.
3. Energy savings are defined as the percentage reduction in energy consumption of the standard-efficiency motor or

$$\frac{\left(\frac{1}{\eta_{std}}-\frac{1}{\eta_{EE}}\right)x100}{\frac{1}{\eta_{std}}}$$

4. Indicates the median for motors within this class.
5. For motors exceeding 200 hp, the standard-efficiency motor performance is derived for all motors with full-load efficiencies below the criteria established by Table 12-10 of the October 1994, revision of NEMA MG 1 - 1993.

Variable Losses

3. Stator losses appear as heating due to current flow (I) through the resistance of the stator winding. This is commonly referred to as an I^2R loss. I^2R losses can be decreased by modifying the stator slot design or by decreasing insulation thickness to increase the volume of wire in the stator.

4. Rotor losses appear as I^2R heating in the rotor winding. Rotor losses can be reduced by increasing the size of the conductive bars and end rings to produce a lower resistance.

5. Stray load losses are the result of leakage fluxes induced by load currents. Both stray load losses and stator and rotor I^2R losses increase with motor load. Motor loss components are summarized in Table 7. Loss distributions as a function of motor horsepower are given in Table 8 while variations in losses due to motor loading are shown in Figure 4.[18,19]

Determining and Comparing Motor Efficiencies

Efficiency Definitions Vary

When evaluating motors on the basis of efficiency improvements or energy savings, it is essential that a uniform efficiency definition be used. It is often difficult to accurately compare manufacturers' published, quoted, or tested efficiencies, as various values are used in catalogues and vendor literature. Common definitions include:[17]

- Nominal or Average Efficiency. NEMA specifies that efficiency be expressed as the average full load efficiency of a large population of motors of the same design. NEMA defines efficiency based on the average of a large population because they acknowledge that motor-to-motor variations in efficiency are inevitable within a single line. NEMA also specifies testing standards for the determination of the average efficiency. For most motors this is IEEE Standard 112, Method B. "Nominal" literally means "pertaining to name" and refers to the efficiency value appearing on the nameplate, which is based upon the average efficiency. This is described further in the section on nameplate labeling standards at the end of this chapter. NEMA advocates that *nominal efficiency* be used to compute energy consumption of a motor or group of motors.
- Minimum or Guaranteed Efficiency. Because of the inevitable motor-to-motor efficiency variation NEMA has defined a minimum efficiency that all individual motors must meet or exceed. The minimum is set at a level associated with approximately 20% greater losses than the losses associated with the nominal efficiency. Minimum efficiency is a standard to be met or exceeded by manufacturers; it is not appropriate for computing the most probable energy consumption. The NEMA-defined minimum efficiency usually appears on the nameplate labeled, "Guaranteed Efficiency".

Purchase Price Versus Running Cost - A Comparison

Let's compare the fuel cost savings of an efficient automobile over a less efficient automobile with savings obtained from purchase of an energy efficient over a standard-efficiency motor. Based upon 15,000 miles per year at a fuel economy of 25 miles per gallon with gasoline priced at $1.20 per gallon, the fuel cost of a typical car is $720 per year or about eight percent of the $9,000 purchase price. A five-mile-per-gallon improvement in fuel economy saves 100 gallons of gasoline valued at $120 annually.

In contrast, a 15-hp standard efficiency motor, continuously operating at 75 percent of its full rated load, would consume 85,189 kWh/year of electrical energy. At an electricity rate of only $.03/kWh, this energy is valued at $2,555 or 315 percent of the motor's list price. A typical 15-hp continuously operating energy efficient motor conserves 3,863 kWh of electricity valued at $116 annually. Vehicle and motor purchase alternatives are summarized below.

Vehicle Versus Motor Purchase—Comparison Base Case

New Car (25 MPG)		New 15-hp Standard-Efficiency Motor	
Purchase Price:	$9,000	List Price:	$811
Drive:	15,000 miles/yr	Use:	Continuous
MPG:	25	Load Factor:	75%
Gal/Yr:	600	kWh/Yr:	85,189
Fuel Cost Value @ $1.20/gal:	$720	Electricity Cost @ .03/kWh:	$2,555
Ratio of Annual Fuel Cost To Initial Cost:	8.0%		315%

Alternatives

Fuel-Efficient Car (30 MPG)		New 15-hp Energy Efficient Motor	
Efficiency Improvement:	5 MPG	Efficiency Improvement: 86.3 to 90.4%	4.1%
Annual Fuel Savings:	100 Gal.	Annual kWh Savings:	3,863
Value of Savings:	$120/year	Value of Savings:	$116/year
Savings over 150,000 mile operating life: 1,000 gallons, $1,200		Savings over 20-year service life: 77,260 kWh and $2,320	

Over a 20-year operating period, the standard motor would consume approximately 1.7 million kWh of electrical energy. This energy is valued at $51,100 or more than 6,300 percent of the initial motor purchase price.

- Apparent Efficiency. Apparent efficiency is the product of motor power factor and minimum efficiency. With this definition, energy consumption can vary considerably as the power factor can be high while the efficiency is low. Specifications should not be based on "apparent" efficiency values.
- Calculated Efficiency. This term refers to an average expected efficiency based upon a relationship between design parameters and test results. Specifications should not be based on "calculated" efficiency values.

Motor Efficiency Testing Standards

It is critical that motor efficiency comparisons be made using a uniform product testing methodology. There is no single standard-efficiency testing method that is used throughout the world.[8,15] The most common standards are:

- IEEE 112-1991 (United States)
- IEC 34-2 (International Electrotechnical Commission)
- JEC-37 (Japanese Electrotechnical Committee)
- BS-269 (British)
- C-390-93 (Canadian Standards Association)
- ANSI C50.20 same as IEEE 112 (United States)

IEEE Standard 112-1991, Standard Test Procedure for Polyphase Induction Motors and Generators, is the common method for testing induction motors in the United States. Five methods for determining motor efficiency are recognized. The common practice for motors in the 1 to 125-hp size range is to measure the motor power output directly with a dynamometer while the motor is operating under load. Motor efficiency is then determined by carefully measuring the electrical input and the mechanical power output.[15]

The five motor efficiency testing standards differ primarily in their treatment of stray load losses. The Canadian Standards Association (CSA) C-390 methodology and IEEE 112-Test Method B are considered identical

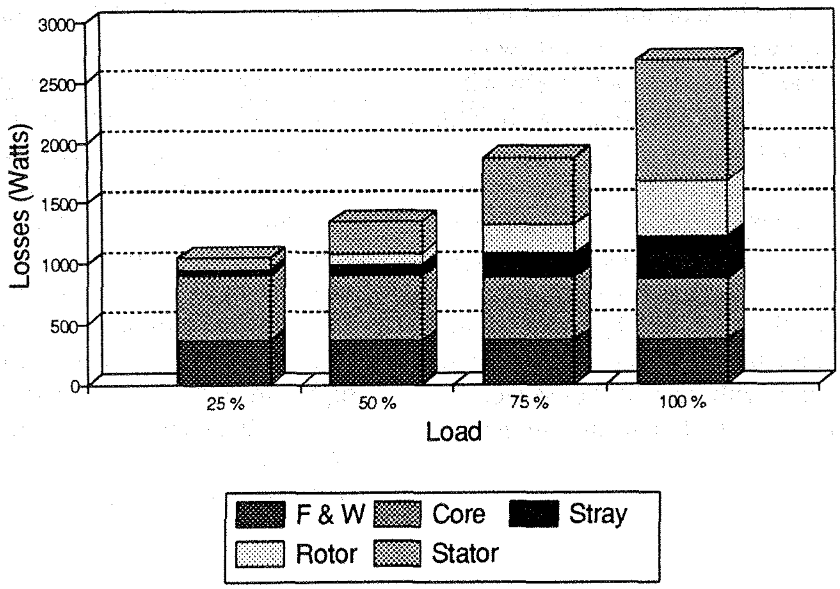
Table 7
Motor Loss Categories

No Load Losses	Typical Losses (%)	Factors Affecting these Losses
Core Losses	15-25	Type and quantity of magnetic material
Friction and Windage Losses	5-15	Selection and design of fans, bearings, and seals
Motor Operating Under Load		
Stator I^2R Losses	25-40	Stator conductor size
Rotor I^2R Losses	15-25	Rotor conductor size and material
Stray Load Losses	10-20	Manufacturing and design methods

Table 8
Typical Distributions of Motor Losses, Percent
(1800 RPM Open Drip-Proof Enclosure)

Types of Loss	Motor Horsepower		
	25	50	100
Stator I^2R	42	38	28
Rotor I^2R	21	22	18
Core Losses	15	20	13
Windage and Friction	7	8	14
Stray Load	15	12	27

Figure 4
Motor Losses versus Load



and determine the stray load loss through an indirect process. The IEC standard assumes stray load losses to be fixed at 0.5 percent of input, while the JEC Standard assumes there are no stray load losses.[8] As indicated in Table 9, the apparent efficiency of a motor, when tested under the different standard conventions, can vary by several percentage points.[8,20]

Table 9
Efficiency Results From Various Motor Testing Standards

	Full-Load Efficiency (%)	
Standard	**7.5 hp**	**20 hp**
Canadian (CSA C-390)	80.3	86.9
United States (IEEE-112, Test Method B)	80.3	86.9
International (IEC-34-2)	82.3	89.4
British (BS-269)	82.3	89.4
Japanese (JEC-37)	85.0	90.4

Testing Equipment Accuracy Limitations

Each motor manufacturer has its own motor test facility. The accuracy of this equipment varies. Three types of dynamometers are commonly used for testing medium and large scale motors: eddy current clutches, water brakes, and direct current generators. These units have different speed and accuracy limitations.[15] Instrumentation used during the motor test can also affect accuracy.

The variation in testing ability was illustrated by a round robin test sponsored by NEMA in 1978 and repeated in 1992 and 1993. Three motors of different sizes (5, 25, and 100 hp) were shipped to 11 different motor manufacturers and 5 independent test labs with the request that they be tested in accordance with IEEE 112-Method B. A second test examined efficiency change due to variations in materials and manufacturing tolerances. This exercise involved testing motors of a common design that were manufactured over a period of months. These tests show that variation in measured losses frequently exceed ±10 percent for specific motor designs while the combined variation from manufacturing and testing with state-of-the-art techniques can exceed ±19 percent. Test results are given in Table 10.[14,21]

What does an efficiency uncertainty mean to motor purchasers? It means that a motor rated at 92.5 percent efficiency is essentially comparable to one with a 92.0 percent value. Purchasers of energy efficient motors should select a unit that has a measured efficiency close to the maximum value available within a given size, enclosure, and speed class. Motors that barely exceed the NEMA threshold energy efficient qualifying standards are not recommended.

Table 10
Uncertainty in Full-Load Efficiency Measurements

Motor hp	Manufacturing Variations	IEEE 112-Method B Testing of Identical Motors
5	± 2.6%	1.1%
25	± 2.1%	0.9%
100	± 1.6%	0.9%

NEMA Motor Nameplate Labeling Standards

NEMA provides a standard for labeling efficiency on nameplates (MG1-1993, Rev. 1, Sec. 12.58.2) for NEMA designs A, B, and E polyphase induction motors in the 1 to 500 HP size range. The full-load motor nameplate efficiency is selected from a table of nominal efficiencies (shown here as Table 11) and represents a value that is "not greater than the average efficiency of a large population of motors of the same design," tested in accordance with IEEE 112. It must appear on the nameplate labeled, "NEMA Nominal Efficiency" or "NEMA Nom. Eff.".

Variations in materials, manufacturing processes, and tests result in motor-to-motor efficiency variations for a given motor design. Because of this, NEMA characterizes full load efficiency as, "not a unique efficiency but rather a band of efficiency". To translate this concept into a standard, NEMA created the bands shown in Table 11 based upon a "logical series" of efficiencies and the "minimum associated with each nominal". Each minimum represents full load losses roughly 20% higher than those associated with the nominal efficiency. Bands have been sized such that the nominal efficiency of a band is exactly equal to the minimum efficiency two bands above.

Based upon NEMA's nameplate labeling standard, one should expect a new motor's efficiency to exceed the Table 11 minimum and have the greatest probability of lying between the nameplate nominal and the nominal of the next higher band.

NEMA nominal efficiency bands are used to "avoid the inference of undue accuracy that might be assumed from using an infinite number of nominal efficiency values."[14] The efficiency bands vary between 0.4 to 1.5 percent between the 84 and 95.5 percent nominal efficiency range. Motors with efficiencies falling within a given band may be treated as having essentially equivalent operating efficiencies. The nameplate nominal efficiency thus represents a value that may be used to compare the relative energy consumption of a motor or group of motors.[15]

Table 11
NEMA Motor Nameplate Efficiency Marking Standard

Nominal Efficiency (%)	Minimum Efficiency (%)	Nominal Efficiency (%)	Minimum Efficiency (%)
98.2	97.8	87.5	85.5
98.0	97.6	86.5	84.0
97.8	97.4	85.5	82.5
97.6	97.1	84.0	81.5
97.4	96.8	82.5	80.0
97.1	96.5	81.5	78.5
96.8	96.2	80.0	77.0
96.5	95.8	78.5	75.5
96.2	95.4	77.0	74.0
95.8	95.0	75.5	72.0
95.4	94.5	74.0	70.0
95.0	94.1	72.0	68.0
94.5	93.6	71.0	66.0
94.1	93.0	68.0	64.0
93.6	92.4	66.0	62.0
93.0	91.7	64.0	59.5
92.4	91.0	62.0	57.5
91.7	90.2	59.5	55.0
91.0	89.5	57.5	52.5
90.2	88.5	55.0	50.5
89.5	87.5	52.5	48.0
88.5	86.5	50.5	46.0

MotorMaster Database

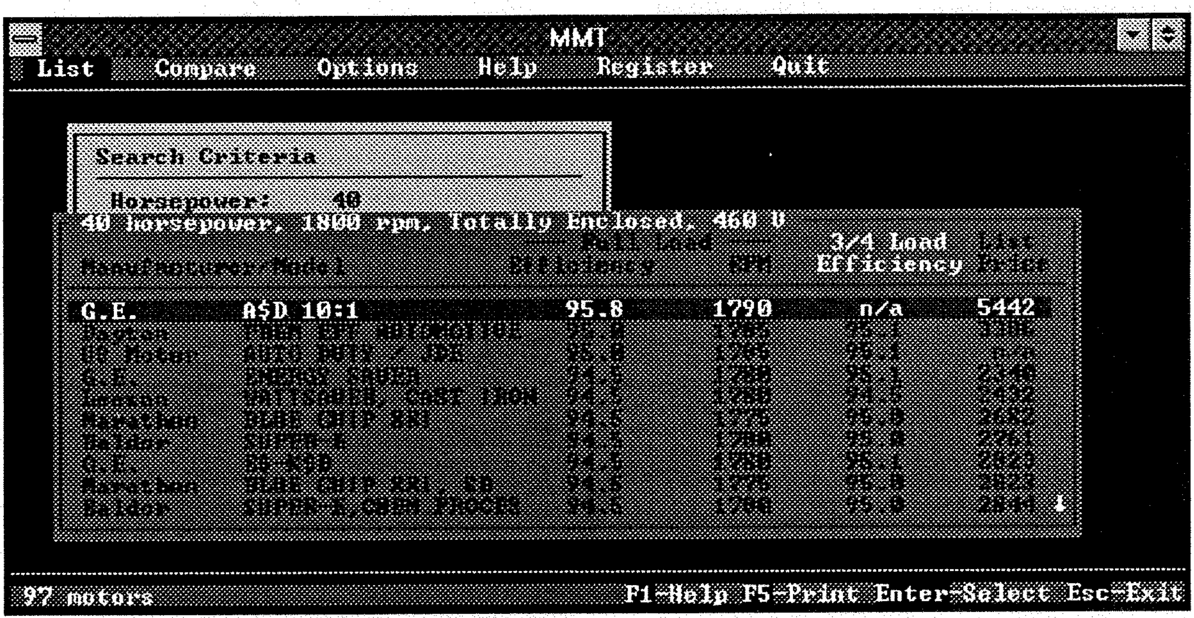
In order to help you identify, evaluate, and procure energy efficient motors, the Motor Challenge Program maintains the *MotorMaster* motor performance software. More than 11,000 NEMA Design A and B three-phase motors are included in *MotorMaster*, ranging from 1 to 600 horsepower, with speeds of 900, 1200, 1800, and 3,600 RPM, and open drip-proof (ODP), totally enclosed fan-cooled (TEFC), totally enclosed, non-ventilated (TENV), and explosion-proof (EXPL) enclosures. Motors rated to operate at 200, 208, 230, 460, 575, 220/440, 2,300, and 4,160 volts are included. All full and part-load efficiency data is measured in accordance with the IEEE 112 Test Method B protocol to guarantee consistency. The information is supplied by manufacturers, and the database is updated annually. Users can query the database to produce a listing, ranked in order of descending *full-load efficiency*, for all motors within a stated size, speed, voltage, and enclosure classification.

A sample database listing is shown in Table 12. The database also contains the manufacturer's name, motor model, catalog number, frame size, full-load, locked rotor and breakdown torque; full-load, locked rotor and idle amperage draw; full-load RPM, service factor, warranty period, part-load efficiency and power factor values; and list price. Note that the nominal full-load motor efficiencies vary from 95.8 to 88.5 percent for the 97 motors identified. Prices also vary. In many cases, motors with identical list prices exhibit very different efficiency ratings.

MotorMaster can also be used to determine the energy and demand savings, value of savings, and simple payback on investment due to selecting and operating an energy efficient over a standard efficiency motor. *MotorMaster* is designed to accommodate New Motor Purchase, Repair/Rewind, and Replacement of Operable Motor scenarios.

Table 12

Typical *MotorMaster* Database Report

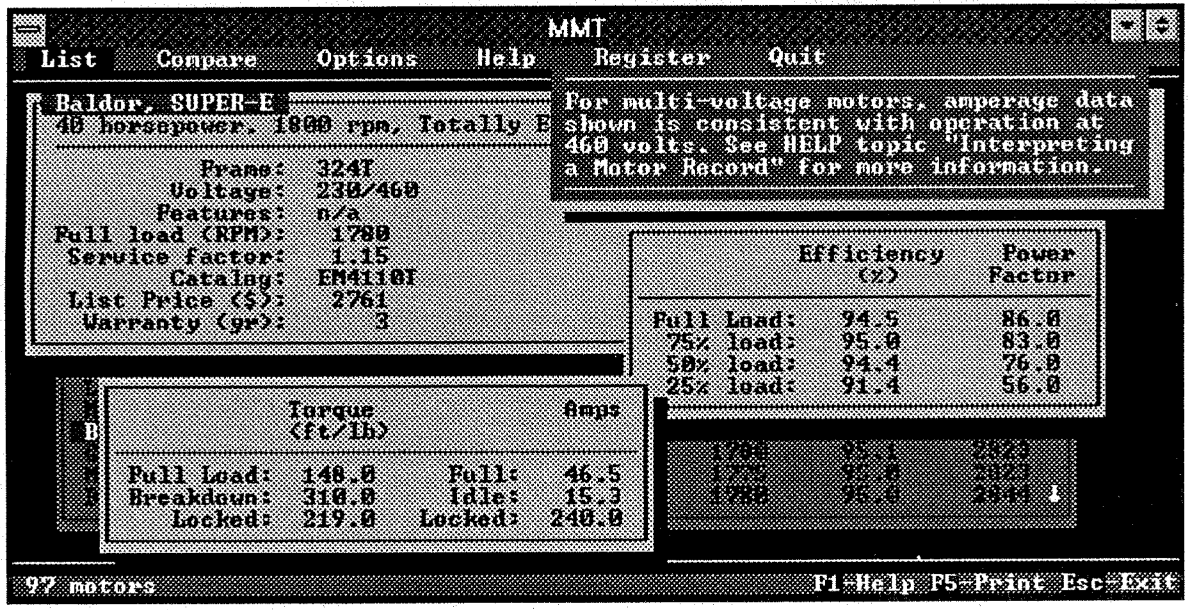


```
Search Criteria

 Horsepower:    40
40 horsepower, 1800 rpm, Totally Enclosed, 460 V
                          ---- Full Load ----   3/4 Load  List
Manufacturer/Model         Efficiency    RPM   Efficiency Price

G.E.      A$D 10:1           95.8        1790     n/a      5442
```

```
97 motors                         F1-Help F5-Print Enter-Select Esc-Exit
```



```
Baldor, SUPER-E
40 horsepower, 1800 rpm, Totally E

           Frame:  324T
         Voltage:  230/460
        Features:  n/a
Full load (RPM):    1780
 Service factor:    1.15
         Catalog:  EM4110T
 List Price ($):    2761
  Warranty (yr):       3
```

```
For multi-voltage motors, amperage data
shown is consistent with operation at
460 volts. See HELP topic "Interpreting
a Motor Record" for more information.
```

```
             Efficiency    Power
                (%)        Factor

Full Load:     94.5         86.0
 75% load:     95.0         83.0
 50% load:     94.4         76.0
 25% load:     91.4         56.0
```

```
            Torque              Amps
           (ft/lb)

Full Load:  140.0      Full:    46.5
Breakdown:  310.0      Idle:    15.3
   Locked:  219.0    Locked:   240.0
```

```
97 motors                                    F1-Help F5-Print Esc-Exit
```

Chapter 3
How Much Can You Save?

The amount of money you can save by purchasing an energy efficient motor instead of a standard motor depends on motor size, annual hours of use, load factor, efficiency improvement, and the serving utility's charges for electrical demand and energy consumed.

Four pieces of information are required prior to evaluating the economic feasibility of procuring an energy efficient instead of a standard motor. First, obtain a copy of your utility's rate schedule. Then determine load factor or actual motor output divided by full rated output. Obtain the number of motor operating hours at this load point. With this information you can readily estimate the efficiency of the existing motor at its load point and then determine annual energy and cost savings.

Understanding Your Utility's Rate Schedule

The cost of electricity for commercial or industrial facilities is typically comprised of four components:

1. **Basic or Hookup Charge**. A fixed amount per billing period that is independent of the quantity of electricity used. This charge covers the cost of reading the meter and servicing your account.

2. **Energy Charges**. A fixed rate ($/kWh) or rates, times the electrical consumption (kWh) for the billing period. Energy charges are frequently seasonally differentiated and may also vary with respect to the quantity of electricity consumed. Utility tariffs may feature declining block or inverted rate schedules. With a declining block rate schedule, illustrated in Table 13, energy unit prices decrease as consumption increases.

3. **Demand Charge**. A fixed rate ($/kW) times the billable demand (kW) for the billing period. Demand charges are often based upon the highest power draw for any 15-minute time increment within the billing period. Some utilities feature ratcheted demand charges where the applicable monthly demand charge is the highest value incurred during the preceding year.

4. **Power Factor Penalty or Reactive Power Charge**. A penalty is frequently levied if power factor falls below an established value (typically 90 or 95 percent). A low power factor indicates that a facility is consuming a proportionally larger share of reactive power. While reactive power (VAR) does not produce work and is stored and discharged in the inductive and capacitive elements of the circuit, distribution system or I^2R losses occur. The utility requires compensation for these losses.

Table 13
Utility Rate Schedule Showing Seasonal Pricing and Declining Block Rates

Monthly Rate:	
Basic Charge:	$23.50, plus:
Demand Charge:	No charge for the first 50 kW of Billing Demand
October-March:	$7.73 per kW for all over 50 kW of Billing Demand
April-September:	$5.15 per kW for all over 50 kW of Billing Demand
Energy Charge:	
October-March:	6.2377 cents per kWh for the first 20,000 kWh 4.8059 cents per kWh for all over 20,000 kWh
April-September:	5.6888 cents per kWh for the first 20,000 kWh 4.3690 cents per kWh for all over 20,000 kWh

Determining Load Factor

The load factor or average percentage of full-rated output provided by your motor must be known before energy efficient motor changeout energy savings can be determined. To calculate the load factor, multiply the power draw (obtained through three-phase wattmeter or from voltage, amperage, and power factor measurements) times the expected motor efficiency. Then divide by 0.746 times the nameplate horsepower rating of the motor. For a three-phase system, wattage draw equals the product of average power factor, voltage and current (amps) times 1.732. Motor field load estimation techniques are discussed in more detail in Chapter 4.

Determining Operating Hours

The number of motor operating hours at its load point must also be known as electrical energy savings are directly proportional to the number of hours a motor is in use. All things being equal, a high-efficiency motor operated 8,000 hours per year will conserve four time the quantity of energy of an equivalent motor that is used 2,000 hours per year.

A recent evaluation conducted by Portland General Electric (PGE) indicates that customer-provided operating hour estimates for individual motors can be erroneous.[22] PGE recommends that run-time or time-of-use loggers be used to calculate total motor operating hours, as well as hourly operating profiles for estimating peak impacts. The time-of-use loggers record motor start and stop times by sensing the magnetic fields generated when the motor is operating.

Calculating Annual Energy Savings

Before you can determine annual dollar savings, you need to estimate the annual energy savings. Energy efficient motors require fewer input kilowatts to provide the same output as a standard-efficiency motor. The difference in efficiency between the high-efficiency motor and a comparable standard motor determines the demand or kilowatt savings. For two similar motors operating at the same load, but having different efficiencies, the following equation is used to calculate the kW reduction.[8,15]

Equation 1

$$kW_{saved} = hp \times L \times 0.746 \times \left(\frac{100}{E_{std}} - \frac{100}{E_{HE}}\right)$$

where:

hp = *Motor nameplate rating*

L = *Load factor or fraction of full operating load*

E_{std} = *Standard motor efficiency under actual l conditions, %*

E_{HE} = *Energy efficient motor efficiency under actual load conditions, %*

The kW savings are the demand savings. The annual energy savings are calculated as follows:[8]

Equation 2

$$kWh_{savings} = kW_{saved} \times \text{Annual Operating Hours}$$

You can now use the demand savings and annual energy savings with utility rate schedule information to estimate your annual reduction in operating costs. Be sure to apply the appropriate seasonal and declining block energy charges.

The total annual cost savings is equal to:

Equation 3

$$\text{Total savings} = (kW_{saved} \times 12 \times \text{Monthly demand charge}) + (kWh_{savings} \times \text{Energy charge})$$

Equations 1-3 apply to motors operating at a specified constant load. For varying loads, you can apply the energy savings equation to each portion of the cycle where the load is relatively constant for an appreciable period of time. The total energy savings is then the sum of the savings for each load period. Determine the demand savings at the peak load point. The equations are not applicable to motors operating with pulsating loads or for loads that cycle at rapidly repeating intervals.[15]

Savings also depend on motor size and the gain in efficiency between a new energy efficient motor and a new or existing standard-efficiency unit. Energy efficient motor savings, based upon an average energy charge of $0.04/kWh, are shown in Figure 5. The performance gain for the energy efficient motor is based on the difference between the average nominal full-load efficiencies for all energy efficient motors on the market as compared to the average efficiency for typical standard-efficiency units.

Motor Purchase Prices

Motor dealers rarely sell motors at the manufacturer's full list price. Even a customer walking in "off the street" is offered a list price discount. Motor prices continuously vary, and rather than reprint catalogs and brochures, manufacturers advertise high list prices and authorize their dealers to provide discounts. Several major manufacturers tend to use common list prices for both their lines of standard and energy efficient motors. Each motor manufacturer, however, has a unique discounting policy, which typically varies with respect to dealer sales volume.

The discounting practice of one motor manufacturer is given in Table 14. The dealer's wholesale price is the list price times the appropriate multiplier for the dealer sales volume. The dealer makes its profit through "marking up" the manufacturer's discounted list price. Typical dealer markups range from 10 to 25 percent and depend on dealership practices and the size of the purchase order or number of motors a customer buys. There is no difference in the discount for energy efficient and standard motors. Thus, you can buy a standard or energy efficient motor for 55 to 87 percent of the manufacturers stated list price. Be sure to get quotes from vendors and use discounted motor prices or price premiums when determining the cost effectiveness of energy efficient motor investments.

Table 14
Typical Motor Wholesale Pricing Practices

Annual Dealer Sales Volume	List Price Multiplier (%)
0 - $35,000/year	70
$35,001-100,000/year	57
$100,000/year or more	50

Assessing Economic Feasibility

Because of better design and use of higher quality materials, energy efficient motors cost 15 to 30 percent more than their standard-efficiency counterparts. In many cases, however, this price premium is quickly recovered through energy cost savings. To determine the economic feasibility of installing energy efficient motors, examine the total annual energy savings in relation to the price premium.

Common methods of assessing the economic feasibility of investment alternatives include:

- Simple payback
- Life cycle costing methodologies
    - Net Present Value (NPV)
    - Benefit to Cost Ratio
    - Internal Rate of Return (IRR)

Most industrial plant managers require that investments be recovered through energy savings within one to

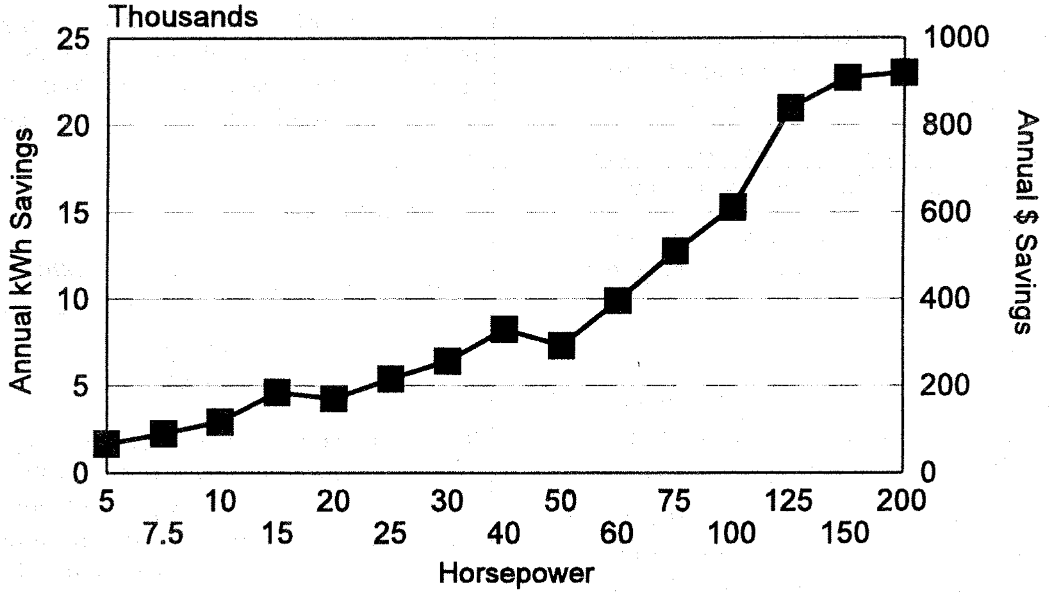


Figure 5
Annual Energy Savings versus Motor Size
for TEFC, 1800 RPM, 8000 hrs/yr, $0.04/kWh, 75% load

three years based on a simple payback analysis. The simple payback is defined as the period of time required for the savings from an investment to equal the initial or incremental cost of the investment. For initial motor purchases or the replacement of burned-out and unrewindable motors, the simple payback period for the extra investment associated with an energy efficient motor purchase is the ratio of the price premium less any available utility rebate, to the value of the total annual electrical savings.

Equation 4

$$\textit{Simple payback years} = \frac{\textit{Price premium} - \textit{utility rebate}}{\textit{Total annual cost savings}}$$

For replacements of operational motors, the simple payback is the ratio of the full cost of purchasing and installing a new energy efficient motor relative to the total annual electrical savings.

Equation 5

$$\textit{Simple payback years} = \frac{\textit{New motor cost} + \textit{installation charge} - \textit{utility rebate}}{\textit{Total annual cost savings}}$$

Recommendations for Motor Purchasers

As a motor purchaser you should be familiar with and use consistent sets of nomenclature. You should also refer to standard testing procedures. Be sure to:[15]

- Insist that all guaranteed quotations are made on the same basis (i.e., nominal or guaranteed minimum efficiency).
- Prepare specifications that identify the test standard to be used to determine motor performance.
- Recognize the variance in manufacturing and testing accuracy and establish a tolerance range for acceptable performance.
- Comparison shop.
- Obtain an energy efficient motor with a nominal efficiency within 1.5 percent of the maximum value available within an enclosure, speed and size class.
- For pumps and fans, select an energy efficient motor with a full-load speed which is comparable to that of the standard-efficiency motor to be replaced.

The following analysis for a 75 hp TEFC motor operating at 75 percent of full rated load illustrates how to use Equations 1-5 to determine the cost-effectiveness of purchasing an energy efficient over a standard-efficiency motor for the initial purchase case.

Kilowatts saved:

$$kW_{saved} = hp\ x\ Load\ x\ 0.746\ x \left(\frac{100}{E_{std}} - \frac{100}{E_{HE}}\right)$$
$$= 75\ x\ .75\ x\ 0.746\ x \left(\frac{100}{91.6} - \frac{100}{94.9}\right)$$
$$= 1.59$$

This is the amount of power conserved by the energy efficient motor during each hour of use. Annual energy savings are obtained by multiplying by the number of operating hours at the indicated load.

Energy saved:

$$kWh_{savings} = \textit{Hours of operation}\ x\ kW_{saved}$$
$$= 8{,}000\ \textit{hours}\ x\ 1.59$$
$$= 12{,}743\ kWh/year$$

Annual cost savings:

$$\textit{Total cost savings} =$$
$$(kW_{saved}\ x\ 12\ x\ \textit{Monthly demand charge}) +$$
$$(kWh_{savings}\ x\ \textit{Energy charge})$$
$$= 1.59\ x\ 12\ x\ \$5.35/kW + 12{,}743\ x\ \$0.03/kWh$$
$$= \$484$$

For the assumed hours of operation and energy and demand charges, installing an energy efficient motor reduces your utility billing by $484 per year. The simple payback for the incremental cost associated with an energy efficient motor purchase is the ratio of the discounted list price premium (from Table 6) or incremental cost to the total annual cost savings. A list price discount of 25 percent is used in this analysis.

Cost Effectiveness:

$$\textit{Simple payback} = \frac{\textit{List price premium x Discount factor}}{\textit{Total annual cost savings}}$$
$$= \frac{\$1189 x 0.75}{\$484} = 1.8\ \textit{years}$$

The additional investment required to buy an energy efficient motor would be recovered within 1.8 years. Energy efficient motors can rapidly pay for themselves through reduced energy consumption. After this initial payback period, the annual savings will continue to be reflected in lower operating costs and will add to your firm's profits.[8]

Energy consumption and dollar savings estimates should be based upon a comparison of nominal efficiencies as determined by IEEE 112 - Method B for motors operating under appropriate loading conditions. When available, use efficiencies from the manufacturer's catalog or *MotorMaster*. Nameplate efficiencies are rounded down from their actual test values to certain standard values prescribed by NEMA. NEMA's intent in creating these finite efficiency "bands" is to emphasize that actual efficiency varies somewhat by individual motors within a single design. Though these bands are more narrow than the true uncertainty, their use adds a small degradation of accuracy.

Making the Right Choice

Comparison shop when purchasing a motor, just as you would when buying other goods and services. Other things being equal, seek to maximize efficiency while minimizing the purchase price. Frequently, substantial efficiency gains can be obtained without paying a price premium. Figure 6 illustrates the list price versus full-load efficiency for 10 hp/1800 RPM standard and energy efficient motors. It is readily apparent that you can obtain an efficiency improvement of as much as 6 points without paying any price penalty.

With the right information, you can quickly identify a motor that produces substantial energy and cost savings for little or no extra investment. The value of a 1 point efficiency improvement is shown with respect to motor horsepower in Figure 7. At an electricity price of $.04/kWh, a single point of efficiency gain for a 50 hp motor can result in an annual savings of approximately 2,600 kWh, worth $104.

Because so many motors exceed the minimum NEMA energy-efficiency standards, it is not enough to simply specify an energy efficient motor. Be certain to purchase an energy efficient motor with the highest available efficiency characteristics.

The value associated with "making the right choice" is graphically characterized by the minimum/maximum savings analysis illustrated in Figure 8. You can often double the available savings by choosing a motor with the top performance in its class instead of a motor that barely satisfies NEMA minimum energy-efficiency standards.

Sensitivity of Load to Motor Speed

For centrifugal loads such as fans or pumps, even a minor change in a motor's full-load speed translates into a significant change in load and annual energy consumption. Fan or "affinity" laws indicate that the horsepower loading imposed on a motor by a centrifugal load varies as the third power or cube of its rotational speed. In contrast, the quantity of air or flow of water delivered varies linearly with speed.

Some energy efficient motors tend to operate with reduced "slip" or at a slightly higher speed than their standard-efficiency counterparts. This small difference - an average of only 5 to 10 RPM for 1800-RPM synchronous speed motors - is significant. A seemingly minor 20 RPM increase in a motor's full-load rotational speed from 1740 to 1760 RPM can result in a 3.5 percent increase in the load placed upon the motor by the rotating equipment. A 40 RPM speed increase can boost energy consumption by 7 percent, completely offsetting the energy and dollar savings typically expected from the purchase of a high-efficiency motor. (This topic is discussed in more detail in Chapter 6).

Figure 6

List Price versus Efficiency for Standard and Energy Efficient Motors

10 hp, 1800 RPM, TEFC

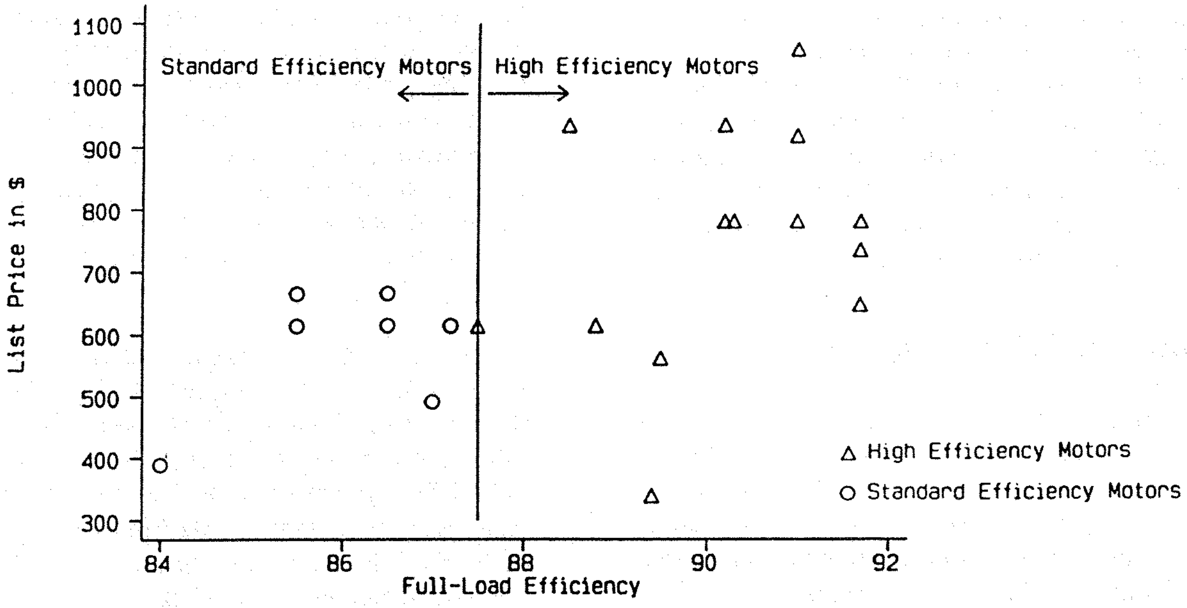


Figure 7

Value of 1 Percent Efficiency Gain by Motor Size

3/4 Load, 8000 Hours, $0.04/kWh

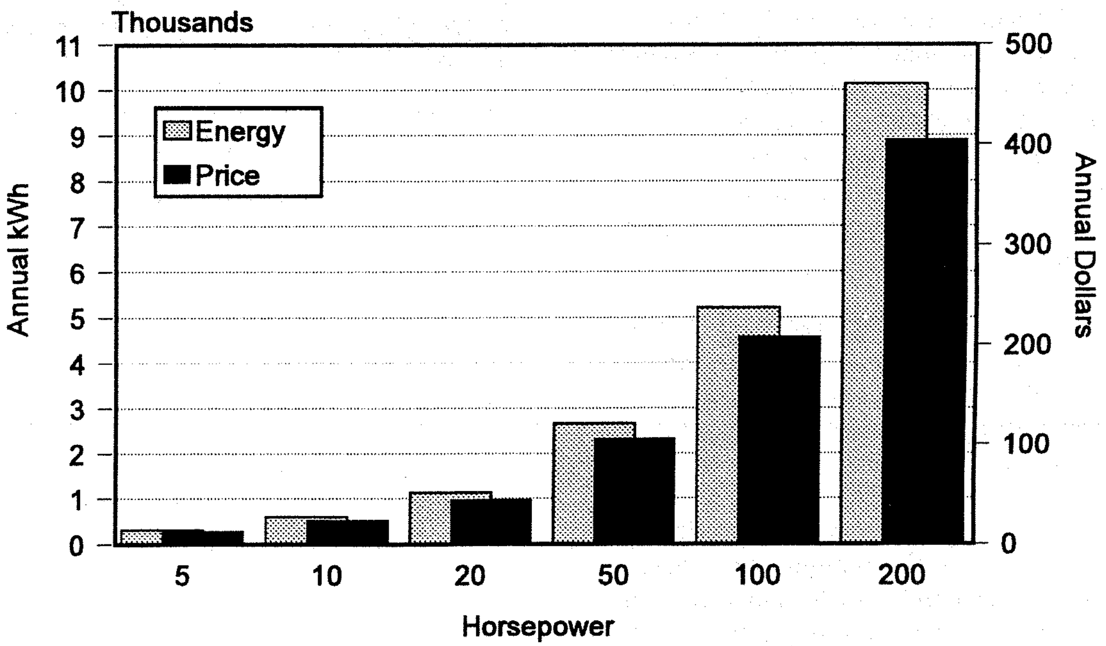
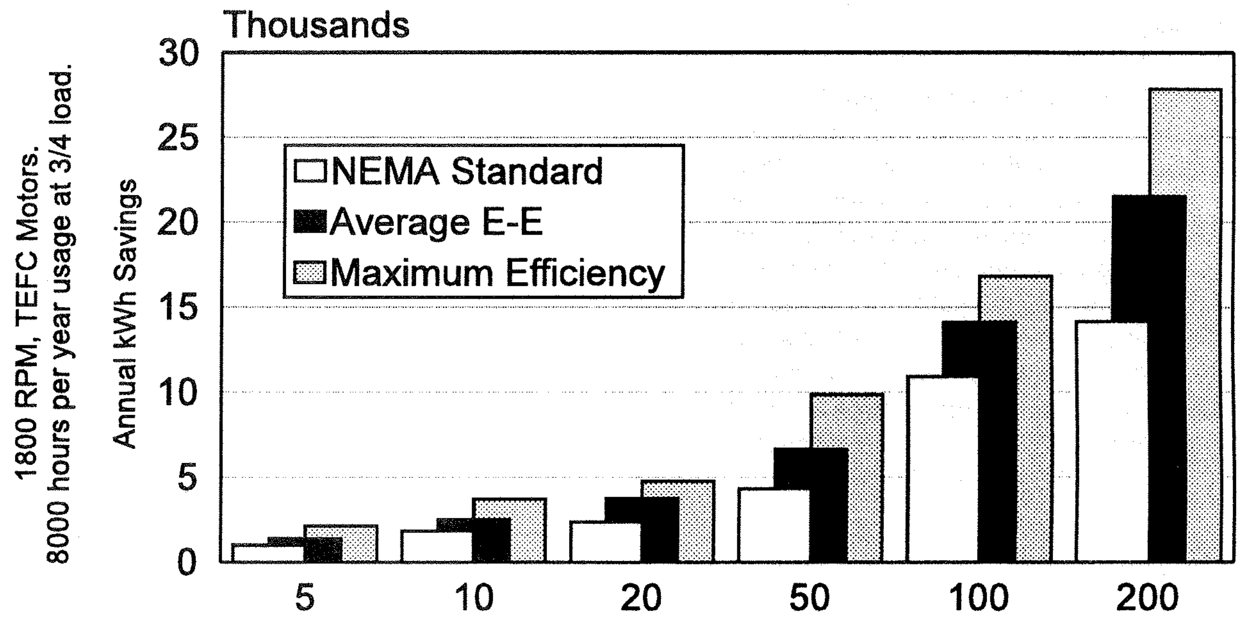


Figure 8
Energy Savings by Using Energy Efficient Over Standard Motors



Note: Figure 8 illustrates the annual energy savings available through selection of an energy-efficient TEFC motor that just satisfies the NEMA Table 12-10 energy efficient motor standards; for a motor that exhibits average high-efficiency performance; and for a motor with superior performance for a given speed, enclosure, and size class. The base case is the purchase of a "typical" 1994 standard-efficiency motor. Base case and average energy efficient motor efficiencies are taken from Table 6.

Additional Benefits of Energy Efficient Motors

Energy efficient motors are longer than standard-efficiency motors as the rotor and stator cores are lengthened to reduce losses associated with the magnetic flux density. However, they are mounted in the same frame as corresponding standard-efficiency T-frame motors. They fully conform with NEMA inrush current, starting, and breakdown torque standards. Conventional NEMA controls and protection can be applied.[17]

Many manufacturers claim that their energy efficient motors operate cooler than their standard efficiency counterparts.[20] Lower operating temperatures translate into increased motor, insulation, and bearing life. The result is fewer winding failures, increased bearing life, longer periods between scheduled maintenance actions, and fewer forced outages.

Accelerated life testing, by subjecting the motor to repeated stalls and other abuse, indicates that energy efficient motors should have a longer life expectancy than standard-efficiency designs.[23] Besides this increased capacity to withstand stalling and overloads, energy efficient motors should operate with lower no-load losses.

Besides reducing operating costs and extending winding and bearing service lives, additional benefits typically associated with using energy efficient motors include:[2, 17]

- An extended warranty
- Extended lubrication cycles due to cooler operation
- Better tolerance to thermal stresses resulting from stalls or frequent starting
- Increased ability to handle overload conditions due to cooler operation and a 1.15 service factor
- Fewer failures under conditions of impaired ventilation
- More resistance to abnormal operating conditions, such as under and over voltage or phase unbalance

- More tolerance to poorer voltage and current waveshapes
- A slightly higher power factor in the 100 HP and lower size range, which reduces distribution system losses and utility power factor penalty changes

These benefits however, depend on many factors. Based on manufacturer design practices, energy efficient motors may have higher or lower power factors than their standard-efficiency counterparts. The same manufacturing tools and methods are used for energy efficient and standard motors and both should be derated the same amount under conditions of voltage unbalance. Generally, the perception exists that standard and energy efficient motors operate at different temperatures and there is more temperature margin available in the energy efficient motor before reaching NEMA operating temperature limits.

Chapter 4
Motor Field Load and Efficiency Estimation Techniques

Field evaluation of motors is essential for the industrial plant operator, engineer or electrician to make informed decisions regarding saving energy through proper motor selection and use.[24,25] The determination of energy savings from the use of energy efficient motors is greatly influenced by assumptions regarding motor operating hours and efficiency and by the techniques used to estimate motor load.[22]

Load, operating hours and efficiency improvement values provide the basis for the operating cost comparisons that could support replacing an existing motor with a more efficient unit.[26] Unfortunately, industrial plant personnel are faced with the use of field measurement techniques that are either simple and inaccurate or more detailed and accurate, but also expensive and intrusive as the motor must be decoupled from the driven equipment. This last requirement can impose unacceptable constraints in an industrial environment.[24]

The remainder of this chapter discusses the need to "tune" the in-plant electrical distribution system prior to obtaining measurements at the motor starting terminals and discusses the advantages and limitations of several commonly used field load and efficiency estimation techniques.

Evaluate the Plant Electrical System

Before reliable field load measurement can be taken, the electrical distribution system must be examined. The system voltage and the phase-to-phase voltage balance must be within allowable limits for reliable and meaningful motor performance measurements to be taken.[27] Acceptable system delivery voltage values are defined by state electrical codes. Allowable ranges are summarized within Table 15.[25]

Table 15
Acceptable System Voltage Ranges

Nominal System Voltage	Allowable Limits %	Allowable Voltage Range
120 V (L-N)	±5%	114 V - 126 V
240 V (L-L)	±5%	228 V - 252 V
480 V (L-L)	±5%	456 V - 504 V

As daily and weekly voltage variations can exceed acceptable ranges, measurements taken at one point in time can be misleading. When the long-term average of the three-phase voltages exceeds the range values in Table 15, the system is out of compliance. System over or under voltage correction should be undertaken prior to conducting motor field tests.[25] Correction usually begins through contacting the servicing electrical utility.

Voltage unbalance occurs when unequal voltages exist on the motor leads. Voltage unbalance is defined as 100 times the maximum deviation of the line voltage from the average voltage divided by the average voltage (See Chapter 7). NEMA warns against operating any motor with an unbalance exceeding 1-percent. With a well designed in-plant electrical distribution system, the amount of unbalance at the service entrance should be about the same as at the Motor Control Centers. Differences in voltage balance are caused by differential voltage drops between the service entrance and the load centers, by single-phase loads which are not uniformly allocated among the phases, and by open-delta or open-wye transformation.[24]

Obtaining Motor Load Values

The Slip Method

The synchronous speed of an induction motor depends on the frequency of the power supply and on the number of poles for which the motor is wound. The higher the frequency, the faster a motor runs. The more poles the motor has, the slower it runs.[28] The synchronous speed (Ns) for a squirrel-cage induction motor is given by Equation 6. Typical synchronous speeds are indicated in Table 16.

Equation 6

$$Ns = \frac{120 \, x \, f}{p}$$

where:

f = frequency of the power supply

p = poles for which the motor is wound

Table 16

Induction Motor Synchronous Speeds

	Motor Synchronous Speed, RPM	
Poles	**60 Hertz**	**50 Hertz**
2	3,600	3,000
4	1,800	1,500
6	1,200	1,000
8	900	750
10	720	600
12	600	500

The actual speed of the motor is less than its synchronous speed with the difference between the synchronous and actual speed referred to as slip. The amount of slip present is proportional to the load imposed upon the motor by the driven equipment. Slip is typically expressed as a percentage where:[28]

$$Percent\ slip = \frac{(synchronous\ speed - actual\ speed)}{synchronous\ speed} x\ 100$$

The motor load can be estimated with slip measurements as follows:[29]

Equation 7

$$Slip = RPM_{sync} - RPM_{measured}$$

$$Motor\ load = \frac{Slip}{RPM_{sync} - RPM_{full\ load\ (nameplate)}}$$

For example:

Given: $RPM_{sync} = 1{,}800$ $\quad RPM_{measured} = 1{,}770$

$RPM_{nameplate} = 1{,}750$ $\quad Nameplate\ hp = 25$

Then: $Slip = 1{,}800 - 1{,}770 = 30$

$$Motor\ load = \frac{30}{1800 - 1750} = \frac{30}{50} = 0.6$$

Some analysts use load estimates obtained from speed/slip relationships and power draw measurements to estimate the motor efficiency at its load point. This "input/output" method makes use of the direct ratio of the difference between two very uncertain numbers. This relationship magnifies possible errors which, in turn, can lead to gross variations in the efficiency estimate.[26] The input/output formula uses the motor load as obtained from the slip method as follows:

$$Approximate\ output\ hp = Motor\ load\ x\ Nameplate\ hp$$

$$Motor\ efficiency = \frac{(.746\ x\ Output\ hp)}{Measured\ Input\ kW} x\,100\ percent$$

Annual energy savings are determined by inserting both the estimated existing motor load and operating efficiency into Equations 1 and 2 in Chapter 3.

The speed/slip technique for determining motor load has been favored due to its simplicity and safety advantages. The two most easily measured motor operating parameters are temperature and speed. Most motors are constructed such that the shaft is accessible to a tachometer or a strobe light.

The accuracy of the slip method is, however limited by multiple factors. First, there is a broad tolerance with respect to reporting nameplate full-load speed. Secondly, at any load, slip varies inversely as the square of the motor terminal voltage. Third, slip is affected by the rotor cage resistance which, in turn, is dependent upon operating temperature.[26] The remaining issue is that of operator error. Tachometers are sensitive instruments and tests made by multiple operators on a constantly loaded motor indicate speed readings can vary by ±2 rpm.[30]

The largest source of uncertainty related to use of the slip method is related to the allowable tolerance with respect to the manufacturers reporting of the nameplate full-load speed. NEMA Standard MG1-12.46 states that the nameplate speed for a polyphase motor shall not exceed 20 percent of the difference between synchronous speed and rated speed when measured at rated voltage, frequency, and load when at an ambient temperature of 25°C. The range for a "correct" slip of 40 rpm is thus 40±20 percent or 32 to 48 rpm. The nameplate full-load speed, reported in accordance with

NEMA Standards, could legitimately vary from 1752 to 1768 rpm.[26]

Given this broad allowable slip tolerance, manufacturers generally round their reported full-load speed values to some multiple of 5 rpm.[26,30] While 5 rpm is but a small percent of the full-load speed and may be thought of as insignificant, the slip method relies on the *difference* between full-load nameplate and synchronous speeds. Given a 40 rpm "correct" slip, a seemingly minor 5 rpm disparity causes a 12 percent change in calculated load.

Slip also varies inversely with respect to the motor terminal voltage squared - and voltage is subject to a separate NEMA tolerance of ±10 percent at the motor terminals. Given only a 5 percent voltage variation, the full-load rpm for a motor with a "correct" slip of 40 rpm could range from 1,756 to 1,764 rpm.[26] A voltage correction factor can, of course, be inserted into the slip load equation. The revised slip load, assuming the motor is rated at 460 volts (nameplate), with a measured voltage of 482 volts is:[30]

Equation 8

$$Motor\ load = \frac{Slip}{(RPM_{sync} - RPM_{full\ load\ (nameplate)})\ x \left(\frac{460\ volts}{482\ volts}\right)^2}$$

Another issue is that of motor temperature. Dynamometer and field tests confirm as motor temperature increases, the full-load speed decreases. It is typical to find a 4 rpm difference in full-load speed for a cold (room temperature) versus a warm motor.[30] While the slip method is attractive for its simplicity, it's precision should not be overestimated. **The slip method is generally not recommended for determining motor loads in the field.**

Use of Line Current Measurements

The amperage draw of a motor varies approximately linearly with respect to load down to about 50 percent of full-load.[30] (See Figure 9). Below the 50 percent load point, due to reactive magnetizing current requirements, power factor degrades, and the amperage curve becomes increasingly non -linear and is no longer a useful indicator of load. The no load or "idle" amperage for most motors is typically on the order of 25 to 40 percent of the nameplate full-load current while the power draw or no-load loss is only 4 to 8 percent of the nameplate horsepower.

Advantages of using the current-based load estimation technique are that NEMA MG1-12.47 allows a tolerance of only 10 percent when reporting nameplate full-load current. In addition, motor terminal voltages only affect current to the first power, while slip varies with the square of the voltage. Finally, a motor's current draw is not directly related to operating temperature.[26]

Both nameplate full-load and no-load current values apply only at the rated motor voltage. Thus, root mean square current measurements should always be corrected for voltage. If the supply voltage is below that indicated on the motor nameplate, the measured amperage value is correspondingly higher than expected under rated conditions and must be ratioed downwards.[26] The converse holds true if the supply voltage at the motor terminals is above the motor rating. The equation that relates motor load to measured current values is:

Equation 9

$$Motor\ load = \frac{Amps_{measured}}{Amps_{full\ load,\ nameplate}}\ x \left(\frac{Volts_{measured}}{Volts_{nameplate}}\right)$$

While the line current is approximately linear with respect to motor load down to 50 percent load, the relationship is not directly proportional; i.e. at 50 percent load the amperage measured is generally higher than 50 percent of the full-load current. If the current at 50 percent load is known, the motor load can be obtained by linearly interpolating between two known values, the full-load and half load currents. A modified equation, which is useful for motors in the 50% to full load range is:[31]

Equation 10

$$\text{Motor load(\%)} = 50 + 50\ \text{x}\ \frac{\left(Amps_{measured}\ x \left(\frac{Volts_{measured}}{Volts_{nameplate}}\right) - Amps_{50\%\ load}\right)}{Amps_{full\ load,\ nameplate} - Amps_{50\%\ load}}$$

Line currents at 50 percent load are given in Figure 10 for motors of different sizes and synchronous speeds. This Figure can be used to approximate current values at the 50 percent load point when specific motor data is not available.[30]

Figure 9
Motor Amperage Draw as a Function of Load

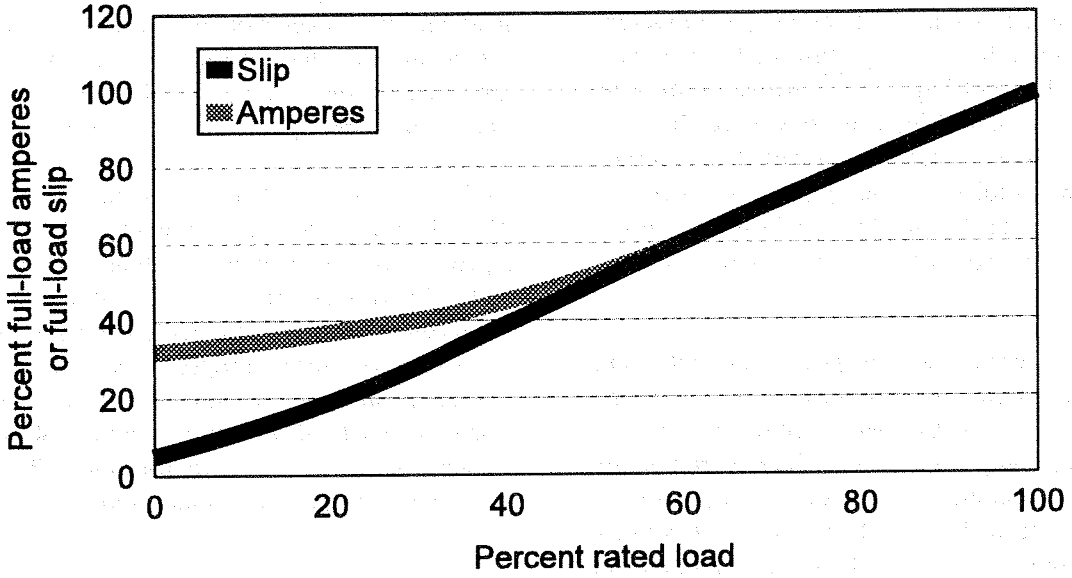
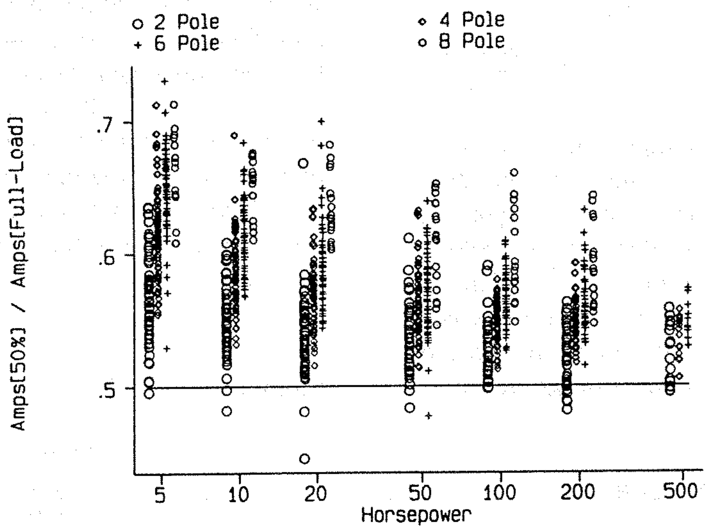


Figure 10
Line currents at 50 Percent Load for Motors of Different Sizes and Speeds



Obtaining Standard Motor Efficiency Values

It is difficult to conduct field tests which provide an accurate indication of motor efficiency. An approximation method is described in this section, which makes use of basic motor performance measurements.

Most analyses of motor energy conservation savings assume that the existing motor is operating at its nameplate efficiency. This assumption is reasonable above the 50 percent load point as motor efficiencies generally peak at about 3/4 load with performance at 50 percent load almost identical to that at full-load. Larger horsepower motors exhibit a relatively flat efficiency curve down to 25 percent of full-load.[30] (Motor efficiency versus load relationships are discussed in more detail in Chapter 5.)

When an efficiency value is not stamped on a motor nameplate, motor efficiency estimates may be extracted from Appendix A. Appendix A contains nominal efficiency values at full, 75 and 50 percent load for typical standard-efficiency motors of various sizes and with synchronous speeds of 900, 1200, 1800 and 3600 rpm. Appendix A is derived from the *MotorMaster* database and indicates "industry average" full and part-load performance for all standard-efficiency motors currently on the market.[25]

Using this efficiency and load estimation technique involves three steps. First, amperage measurements are used to identify the load imposed on the operating motor. Then a motor part-load efficiency value which is consistent with the approximated load is obtained by interpolating from the data supplied in Appendix A. A revised load estimate is then derived from both the power measurement at the motor terminals and the part-load efficiency value as follows:

Equation 11

$$Load = \frac{kW_{measured} \ x \ Motor\ Efficiency\ at\ Load\ Point}{hp_{nameplate} \ x \ 0.746}$$

Both the derived load and efficiency values and operating hour assumptions are inserted into Equations 1 and 2 to obtain the annual energy and demand savings associated with replacing a standard-efficiency motor with an energy efficient unit.

The validity of using nameplate full or part-load standard motor performance values to determine existing motor efficiency and load is based upon two motor characteristics. First, the efficiency curve for most motors is relatively flat down to loads of 40 to 50 percent of rated load. Secondly, while the efficiency of premium-efficiency motors has improved dramatically since the 1980's as energy costs increased and a demand for energy-conserving motors developed, the performance of standard-efficiency motors has remained relatively constant. Table 17 indicates the performance of standard and energy efficient motors over time.[17,32]

During the decade of the sixties through the early 1970's (a period of inexpensive energy), manufacturers built inexpensive and relatively inefficient motors by minimizing use of copper, aluminum and steel. While these motors had lower initial costs than earlier designs, they used more energy due to their inefficiency.[2]

These less efficient and more compact motors were made possible through the development of insulating materials that could withstand high temperatures. Motors with higher losses could thus be designed, as the temperature rise due to the losses could be accommodated without damaging the insulation or reducing the expected motor operating lifetime.[2]

Some analysts have attempted to correct for improvements in standard motor performance over time by reducing the existing motor efficiency by 0.1 percent for each year of age up to ten years. The efficiency is reduced by 2.0 percent if the motor has been rewound. These values are arbitrary and are based upon unconfirmed field experience.[25]

Table 17
History of Motor Efficiency Improvements

hp	1944 Design (%)	1955 U Frame (%)	1965 Standard-Efficiency (%)	1980[1] Standard-Efficiency (%)	1994[2] Standard-Efficiency (%)	1994[3] Energy-Efficient (%)
7.5	84.5	87.0	84.0	-	85.1	90.2
15	87.0	89.5	88.0	86.5	87.8	92.0
25	89.5	90.5	89.0	88.0	88.9	93.3
50	90.5	91.0	91.5	90.4	90.4	94.1
75	91.0	90.5	91.5	90.8	91.8	94.8
100	91.5	92.0	92.0	91.6	92.1	94.9

1. Average from five manufactures.
2. Average for 1800 RPM, ODP, 460 V standard-efficiency motors.
3. Average for all 1800 RPM, ODP, 460 V energy efficient motors (i.e., above the former NEMA 12-9 standard) from *MotorMaster* database.

Segregated Loss Techniques

The Oak Ridge National Laboratory is in the process of assessing various motor field efficiency measurement techniques. Unfortunately, the techniques yielding the highest quality estimations of motor changeout energy savings are also the most intrusive and/or require sophisticated and expensive equipment.[33] The IEEE Standard 112 measurement methods were not specifically written for field efficiency measurement applications and involve bench testing with a dynamometer, a duplicate machine or the use of equivalent circuit methods.[34] The equivalent circuit methodology involves uncoupling the motor to conduct a no load test, a locked rotor test, and measurements of stator winding resistance. An air-gap torque method does not require extra downtime, but requires relatively expensive equipment to capture and analyze line voltage and line current wave forms.

The "Stanford Method" consists of inserting measured values into a set of empirical equations which were developed through conducting tests on a population of motors.[35] While a detailed discussion of these "high level" testing methodologies is beyond the scope of this Handbook, selected references are provided for the interested user.

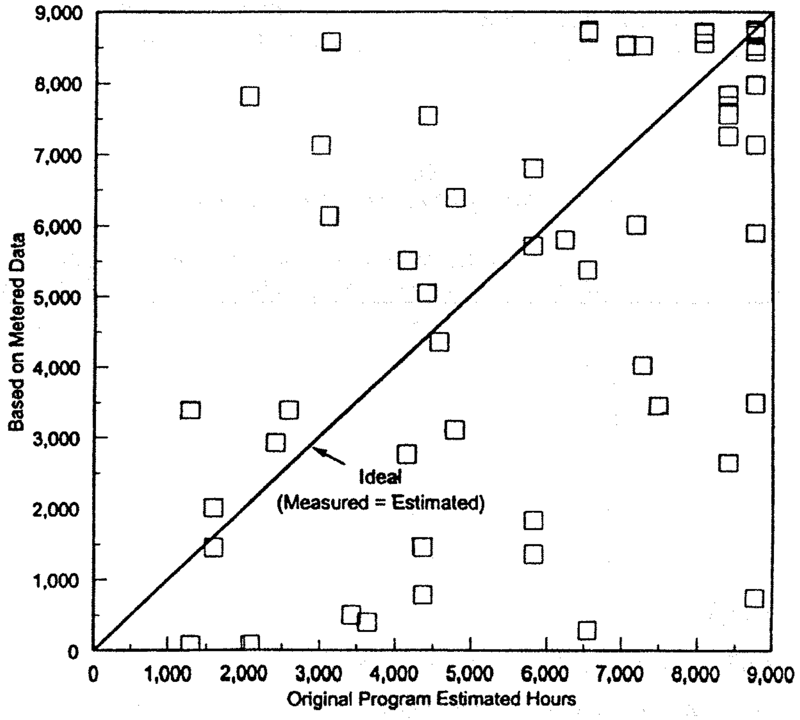
Estimating Operating Hours

Estimates of energy savings from the use of energy efficient motors are significantly influenced by assumptions regarding motor operating hours. Ideally, time-of-use meters are used to record motor start and stop times over a test interval through sensing the magnetic field generated when the motor is operating. A detailed operating history is useful for calculating total annual operating hours as well as examining hourly operating profiles which affect peak demand charges.[22]

Operating hour estimates are generally, however, based upon information supplied by plant electricians, engineers or management. An evaluation conducted by Portland General Electric indicates that on the average, motors operate at 93 percent of the estimated hours of operation reported on motor rebate forms. Wide variations do exist, however, in the customer provided and field-measured estimates of operating hours, suggesting users have a difficult time accurately estimating annual motor run times.[22] In fact, a scatter plot, reproduced as Figure 11, indicates that some motors with operator estimates of 2,000 hours exceeded 7,500 hours of annual use. Conversely, some motors with user estimates exceeding 6,000 hours annually were

Figure 11

Comparison of Metered versus Estimated Annual Hours of Motor Operation



metered and found to operate less than 1,000 hours per year.

Operating hours errors can be reduced by constructing an operating time profile. Such a profile, depicted in Table 18, requires the user to provide input regarding motor use on various shifts during work days, normal weekends and holidays.[25]

The nature of the load being served by the motor is also important. Motors which are coupled to variable speed drives and operate with low load factors or which serve intermittent, cyclic or randomly acting loads, may not be good candidates for cost-effective replacement with energy efficient units.

Table 18
Motor Operating Profile

	Work-Day Schedule	**Wknd/ Holiday Schedule**	
1st Shift			
2nd Shift			
3rd Shift			
Operating Period			Wks/Yr.

Chapter 5
Energy Efficient Motor Selection Guidelines

Initial Motor Purchases

When considering a new motor purchase, there are two choices: a less expensive standard-efficiency motor or a more costly energy efficient motor. For this case, the cost premium of buying an energy efficient motor over a standard motor is equal to the difference in prices. Installation costs are the same for both motors.

Consider a 50 hp standard-efficiency motor, purchased for $1,700 and operated 8,000 hours per year at 75 percent of full rated load. At an efficiency of 91.1 percent and with an electrical rate of $0.03 per kilowatt hour, the motor will consume $7,369 worth of electricity each year. During a typical 10-year motor operating life with an average 5 percent escalation in energy prices, the total electrical bill for operating this motor would exceed $92,600, over 50 times the purchase price of the motor.

While the improvement in efficiency associated with the purchase of an energy efficient motor is typically only 2 to 5 percent, the incremental cost of the energy efficient motor can often be rapidly recovered. This occurs because the price premium may be less than anticipated while the ratio of the motor's annual operating cost to its initial purchase price is quite high.

Although the energy and dollar savings associated with buying an energy efficient motor can be impressive, selecting the energy efficient unit is not always appropriate. Motors that are lightly loaded or infrequently used, such as motor driving control valves or door openers, may not consume enough electricity to make the energy efficient alternative cost-effective. Remember, for a motor operating under a constant load, the electricity savings associated with efficiency improvement are directly proportional to the hours of operation.

The simple payback is defined as the period of time required for the profit or savings from an investment decision to equal the incremental cost of the investment. This investment repayment period is directly dependent upon electricity costs—for example, the simple payback for a motor operating in a utility territory where electrical rates are $.02/kWh will be twice that for a similar motor used where electricity is priced at $.04/kWh.

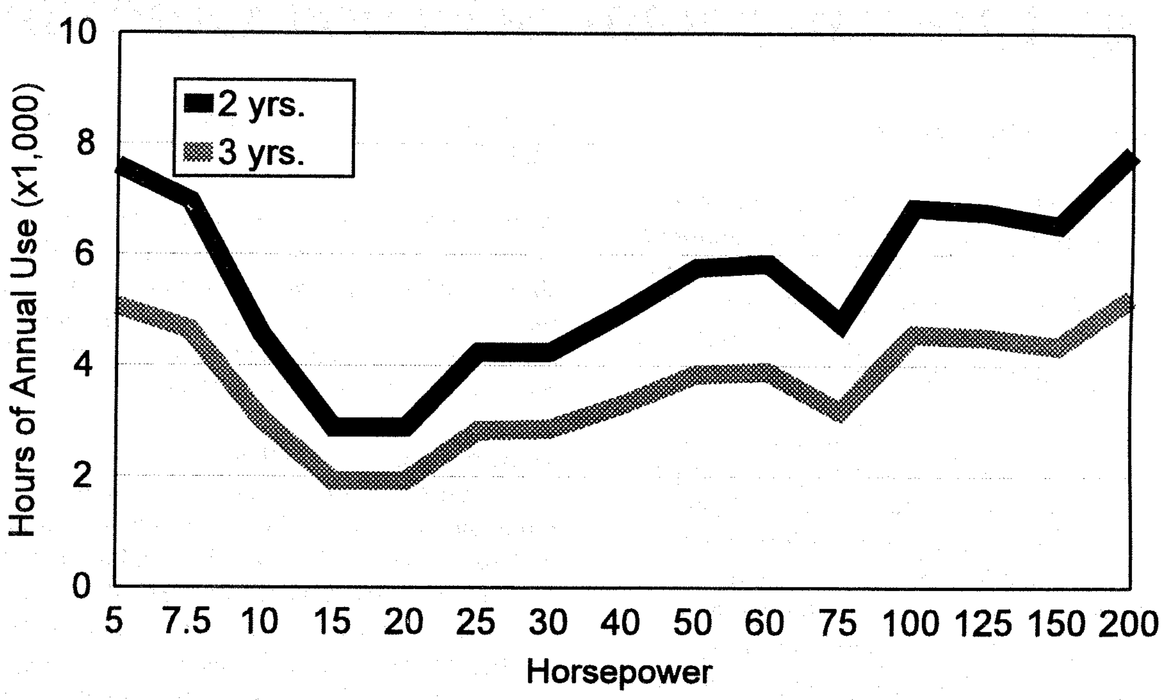
A short payback period indicates a worthwhile investment. Different industries or facilities use different simple payback criteria or investment "hurdle rates." Industrial sector energy conservation measures typically must have simple paybacks within the 3 year range to be considered cost effective.

To help you decide whether or not to purchase a new energy efficient motor, Figure 12 presents the minimum annual operating hours required to achieve two and three year simple paybacks as a function of motor size given an electrical rate of $.04/kWh. (Operating hour requirements can readily be prorated for other electrical rates.) This analysis uses the average standard and energy efficient motor performance data presented in Table 6 and assumes a 75 percent motor loading with a list price discount factor of 35 percent.

Several conclusions can be drawn from Figure 12. An energy efficient motor is warranted given the following:

- for 10 - 75 hp motors, operation exceeding 5,000 and 2,000 to 3,000 hours per year, respectively for two and three year simple paybacks.
- for very small and larger motors, operation exceeding 6,500 and 4,500 hours per year, respectively, for two and three year simple paybacks.

Figure 12
Annual Operating Hours for Payback, New Motor Purchase



Motor Failure and Repair

Unlike an initial motor purchase where your decision is limited to procuring a standard versus a premium efficiency motor, a motor failure or burnout produces three alternatives. Your options are to repair the failed motor, purchase a new standard-efficiency motor, or purchase an energy efficient replacement motor. For this scenario, motor installation labor costs are again not included, as the failed motor must be removed and reinstalled anyway.

Assuming the failed motor can be repaired, the baseline or lowest initial cost approach may be to rewind the motor to its original specifications. As some older U-Frame motors were built with oversized slots, it is sometimes possible to perform a rewind that slightly increases the efficiency of the motor by adding more copper to reduce I^2R losses.[17] If the original unit was wound with aluminum wire, current practice is to replace it with copper, which also reduces I^2R losses.[32] The reduction in I^2R loss increases the inrush current which may cause nuisance tripping and necessitate a change to protection equipment.

A motor should be rewound with the same (or larger) winding wire size and configuration. If a repair shop does not have the correct wire size in stock and uses a smaller diameter wire, stator I^2R losses will increase, resulting in decreased efficiency.

While a decrease in the number of turns in a stator winding reduces the winding resistance, it also shifts the point at which the motor's peak efficiency occurs toward higher loads and increases the motor's magnetic field, starting current, locked rotor, and maximum torque. A change from ten to nine turns will increase the starting current by 23 percent, which can cause problems in the electrical distribution and motor protection systems.[36]

In a typical rewind, the stator is heated to a temperature high enough to burn out its winding insulation. The windings are then removed and replaced.[23] In the past, many rewind shops emphasized speed. High temperatures were used to shorten repair times and get the motor back in service quickly. Hand-held torches were sometimes used to burn away varnish for easier coil removal.[17,32] The resulting higher temperatures increased losses by changing the electrical characteristics of the motor's core.

For both standard and energy efficient motors, the rewind shop should follow the motor manufacturers' recommended burnout temperature specifications. When stripping out the old windings, it is essential to keep the stator core below 700 degrees Fahrenheit. If the stator core gets too hot, the insulation between the stator laminations will break down, increasing eddy current losses and lowering the motor's operating efficiency. After being damaged, the lamination insulation cannot be repaired nor the efficiency loss restored without undergoing a major repair, such as restacking the iron. The motor also becomes less reliable.[23,32]

Insulation removal techniques vary between rewind shops and should be investigated prior to deciding where to have the motor rewound. Always choose a shop with a controlled temperature winding burnout oven or which uses low temperature mechanical stripping to minimize core loss. Some shops have core loss testers and can screen motors to determine if they are repairable prior to stripping.[37]

The repair shop should also determine and report the cause for a motor's failure. Apart from proper stripping procedures, the motor owner should ensure the rewind shop does the following.[32]

- Uses proper methods of cleaning.
- Installs class F or better insulation.
- Uses phase insulation between all phase junctions.
- Uses tie and blocking methods to ensure mechanical stability.
- Brazes rather than crimps connections.
- Uses proper lead wire and connection lugs.
- Applies a proper varnish treatment.

As motor design characteristics (such as slot geometry and configuration), failure modes, rewind practices, materials specifications and treatments vary, it is impossible to identify a "typical" rewind cost for a motor with a given horsepower, speed, and enclosure. Costs also vary regionally. A pricing guide used by the shops themselves is Vaughen's ® price guide (Available from Vaughen's Price Publishing, 800-828-4436).

Motor efficiency losses after rewinds also vary considerably. While dynamometer tests conducted by independent testing laboratories indicate that new motors, when properly stripped and rewound, can be restored to their original efficiency, laboratory tests on motors from a variety of repair shops indicate losses are typically higher in motors that have been rewound. This has been caused by various factors including core damage at failure or during stripping, downsizing wire gage, errors or modifications of winding pattern, and use of higher friction bearing seals.

An analysis of core loss tests taken over a 1 year period at General Electric repair facilities indicates average *core* losses are 32 percent higher than normal for motors that had been previously rewound.[36] General Electric also conducted a test of 27 rewound motors in the 3 to 150-hp size range. The test results indicate total losses increased by 18 percent for motors that have been rewound compared to those that have not been rewound.[23] An 18 percent increase in losses corresponds to an approximate 1.5 to 2.5 percent decrease in full-load efficiency.

Rewound motors can exhibit severe efficiency losses, especially if they were rewound more than 15 years ago or have accumulated unrepaired core and rotor damage over several rewinds. Rewind losses of 5 percent or more are possible. Losses of this magnitude are likely to cause early failure from overheating.

When should an energy efficient motor be purchased in lieu of repairing a failed standard-efficiency motor? This decision is quite complicated as it depends on such variables as the rewind cost, expected rewind loss, energy efficient motor purchase price, motor size and original efficiency, load factor, annual operating hours, electricity price, the availability of a utility rebate, and simple payback criteria.

At least some of the time, rewinding *will* be the best decision. The prospects for a good rewind are greatly improved if you keep good records on your motor and provide them to the repair shop. Repair shops often cannot get complete specifications from manufacturers. They must "reverse engineer" motors, counting winding turns, noting slot patterns, and measuring wire size before removing old windings. Sometimes a motor has failed repeatedly in the past because of a previous nonstandard rewind. The same error can be repeated unless the shop knows the motor is a "repeat offender" diagnoses the problem, and rewinds the motor to original specifications. Sometimes a motor is subjected to unusual service requirements, such as frequent starts, a dirty environment, or low voltage. Most shops know how to modify original specifications to adjust to such conditions.

Here are several rewind "rules of thumb":

- Always use a qualified rewind shop. Look for an ISO 9000 or Electrical Apparatus Service Association EASA-Q based quality assurance program, cleanliness, good record keeping, and evidence of frequent equipment calibration. A quality rewind can maintain the original motor efficiency. However, if a motor core has been damaged or the rewind shop is careless, significant losses can occur.
- Motors less than 40 hp in size and more than 15 years old (especially previously rewound motors) often have efficiencies significantly lower than currently available energy efficient models. It is usually best to replace them. It is nearly always best to replace non-specialty motors under 15 hp.
- If the rewind cost exceeds 50 to 65 percent of a new energy efficient motor price, buy the new motor. Increased reliability and efficiency should quickly recover the price premium.

For further reading see the Industrial Electrotechnology Laboratory Horsepower Bulletin and "How to Determine When to Repair and When to Replace a Failed Electric Motor" and "Evaluating Motor Repair Shops" of the EPRI and BPA publication, "Quality Electric Motor Repair: A Guidebook for Electric Utilities".[37, 38, 39]

Table 19 indicates when new energy efficient motors should be purchased versus rewinding an existing motor as a function of motor operating hours and simple payback criteria. A new energy efficient motor should be purchased if the operating hours exceed the stated value. Table 19 may be used for National Electrical Manufacturers Association (NEMA) Design A or B motors, in the 5 to 125-hp size range. Assumptions used in the preparation of this table include an expected 2 point loss in an average standard motor efficiency due to rewinding for motors below 40 hp with a single point deducted for larger motors. Rewind costs are extracted from *MotorMaster* default tables. The rewound motor is assumed to be replaced with an average energy efficient motor operated at a 75 percent load factor, and a list price discount of 35 percent.

You can easily complete a cost-effectiveness analysis for a rewind. If you can be assured that the past and prospective rewinds comply with *all* the foregoing recommended practices, the original efficiency could be maintained. Otherwise, two points should be subtracted from your standard motor efficiency to reflect expected rewind losses on smaller motors (<40 hp) with one point subtracted for large motors. Annual energy and cost savings are determined by accessing *MotorMaster's* compare/rewind scenario or inputting the appropriate energy efficient motor performance, operating hours, electricity price, and load factor into Equations 1 through 3. The incremental cost of procuring the energy efficient unit is the quoted price for the new motor less the rewind price and any utility rebate. The simple payback for the energy efficient motor is simply the incremental cost divided by the total annual energy conservation benefits.

Replacement of Operable Standard Efficiency Motors

This motor retrofit scenario occurs when you consider replacing an existing, operable standard-efficiency motor with an energy efficient unit solely to conserve energy. In this instance, the cost of replacement is the full purchase price for the new motor minus any utility rebate and the salvage value for the motor to be replaced. An installation cost is also levied. No downtime or loss of production costs are incurred as it is assumed the retrofit can be scheduled during a periodic maintenance shutdown. For this scenario, the entire cost of purchasing and installing the energy efficient motor must be returned through the energy savings achieved by the increased motor efficiency.

Table 19

Annual Hours for Payback

New Energy Efficient Motor Versus Rewind for TEFC, 1,800 RPM, 75 Percent Load

Simple Payback Criteria, Years[1]	Annual Operating Hours						
hp	5	10	25	50	75	100	125
3	1,280	1,520	4,106	7,786	7,920	-	7,866
2	1,920	2,280	6,106	-	-	-	-

[1] For an electrical rate of $0.04/kWh

Considering average standard and premium-efficiency motor efficiencies, simple paybacks are determined for 5, 20, and 100 hp, 1800 RPM TEFC motors, operating 8,000 hours per year at 75 percent load, with electricity prices of \$.03 and \$.04/kWh. A 35 percent new motor list price discount factor is assumed. As indicated in Figure 13, simple paybacks typically exceed five years. Based solely on energy savings, industrial users would typically find it not cost-effective to retrofit operable standard-efficiency motors with energy efficient units. Such an action may, however, make sense if:

- Funding is available through a utility energy conservation program to partially offset the purchase price of the new energy efficient motor.
- The standard-efficiency motor is known to be degraded.
- The standard-efficiency motor is oversized and underloaded.

Oversized and Underloaded Motors

Motors rarely operate at their full-load point. Field tests of motors at four industrial plants indicate that, on the average, they operate at 60 percent of their rated load.[24] Motors driving supply or return air fans in Heating Ventilation and Air Conditioning (HVAC) systems generally operate at 70 to 75 percent of rated load.[30]

A persistent myth is that oversized motors, especially motors operating below 50 percent of rated load, are never efficient and should immediately be replaced with appropriately sized energy efficient units. In actuality, many motors are even more efficient at 50 percent load than they are at full-load. Several pieces of information are required to complete an accurate assessment of energy savings from re-sizing. They are the load on the motor; the operating efficiency of the motor at that load point; the full-load speed of the motor to be replaced; and the full-load speed of the downsized replacement motor. With this information, *MotorMaster* or Equations 1 through 3 can be used to determine the simple payback for changeout alternatives.

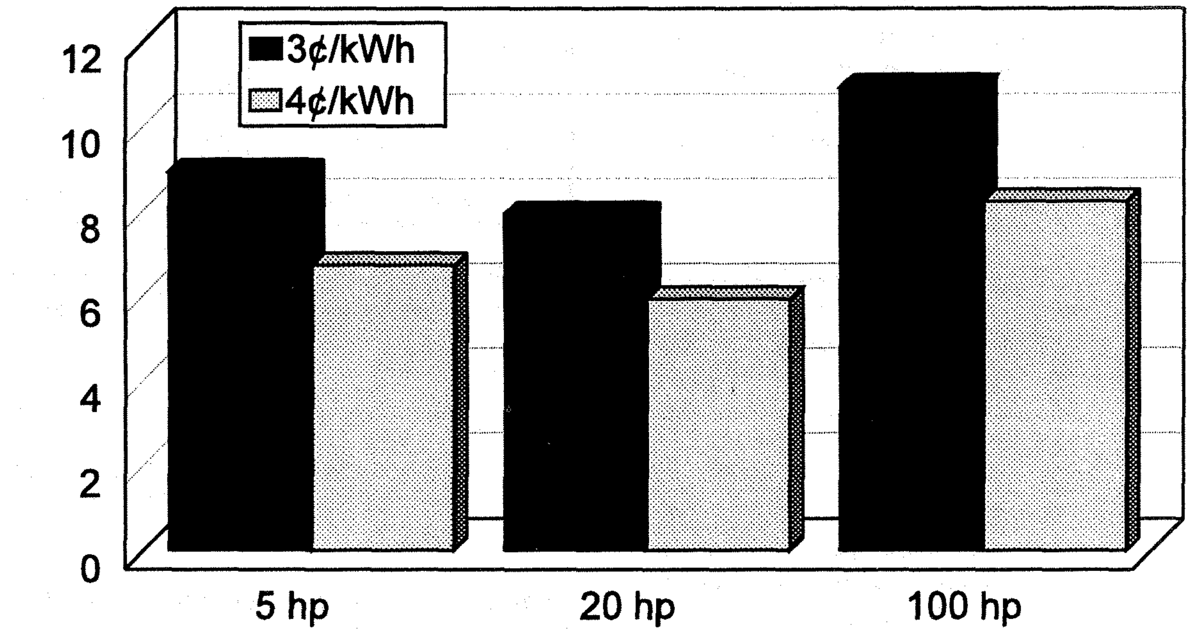
Industries procure oversized motors for a number of reasons:[7,8]

- To ensure against motor failure in critical processes.
- When plant personnel do not know the actual load and thus select a larger motor than necessary.

Figure 13

Replacement of an Operable Standard Efficiency Motor

Years for SImple Payback



	5 hp	20 hp	100 hp
3¢/kWh	8.9	7.9	10.9
4¢/kWh	6.7	5.9	8.2

- To build in capability to accommodate future increases in production.
- To conservatively ensure the unit has ample power to handle load fluctuations.
- When maintenance staff replace a failed motor with the next larger unit, if one of the correct size is not available.
- When an oversized motor has been selected for equipment loads that have not materialized.
- When process requirements have been reduced.
- To operate under adverse conditions such as voltage unbalance.
- To eliminate the requirement to stock motors of multiple sizes.

As a general rule, motors that are undersized and overloaded have a reduced life expectancy with a greater probability of unanticipated downtime and loss of production. On the other hand, motors that are oversized and thus lightly loaded have an extended expected operating life, but may suffer both efficiency and power factor reduction penalties.

Efficiency and Motor Load/Speed Relationships

The efficiency of both standard and energy efficient motors typically peaks near 75 percent of full-load and is relatively flat down to the 50 percent load point. Motors in the larger size ranges can operate with reasonable energy efficiency at loads down to 25 percent of rated load. Efficiency values at partial-load points are given for energy efficient and standard motor models of various sizes in Table 20.[31]

An inspection of Table 20 indicates two additional trends. Larger motors exhibit higher full and partial-load efficiency values; with the efficiency decline below the 50 percent load point occurring more rapidly for the smaller size motors. A 100 hp standard motor operating at 40 percent of rated load may operate as efficiently as an energy efficient 40 hp motor operating at its rated load point. On the other hand, an energy efficient 5 hp replacement motor could operate with an efficiency as much as five points above that of a standard 10 hp motor operating at its 40 percent load point.

As long as a motor is operating above 40 percent of rated load, the efficiency does not vary significantly.

Table 20
Efficiency at Full and Partial-loads for 1800 RPM, ODP Motors

	Full-Load	75% Load	50% Load	25% Load
100 hp				
U.S. Motors - Premium	95.8	96.1	96.1	94.3
Reliance XE	95.4	95.7	95.4	93.2
Magnetek Standard	93.0	94.0	94.0	89.3
U.S. Motors - Standard	92.4	93.8	93.9	91.6
40 hp				
U.S. Motors - Premium	94.5	94.9	94.6	92.0
Reliance XE	94.1	94.1	94.0	91.4
Magnetek Standard	91.0	89.5	92.4	86.5
U.S. Motors - Standard	90.2	88.0	90.8	86.9
20 hp				
U.S. Motors - Premium	93.0	92.7	92.5	89.5
Reliance XE	92.0	93.0	92.0	84.8
Magnetek Standard	88.5	89.5	89.5	84.0
U.S. Motors - Standard	88.0	88.0	86.3	79.9
10 hp				
U.S. Motors - Premium	91.7	90.4	89.8	85.3
Reliance XE	91.7	92.2	91.8	87.8
Magnetek Standard	87.7	89.5	88.5	82.5
U.S. Motors - Standard	86.0	88.0	86.0	80.6
5 hp				
U.S. Motors - Premium	89.5	90.4	89.5	84.3
Reliance XE	89.5	89.7	87.5	82.6
Magnetek Standard	85.5	86.5	85.5	75.5
U.S. Motors - Standard	84.0	84.0	82.0	74.0

Consider downsizing motors that are less than 40 - 50 percent loaded.[35] Power factor declines sharply when the motor is operated below 65 percent of full-load amperage, especially in the smaller horsepower

Figure 14

Motor Part Load Efficiency as a Function of % Full-Load Efficiency

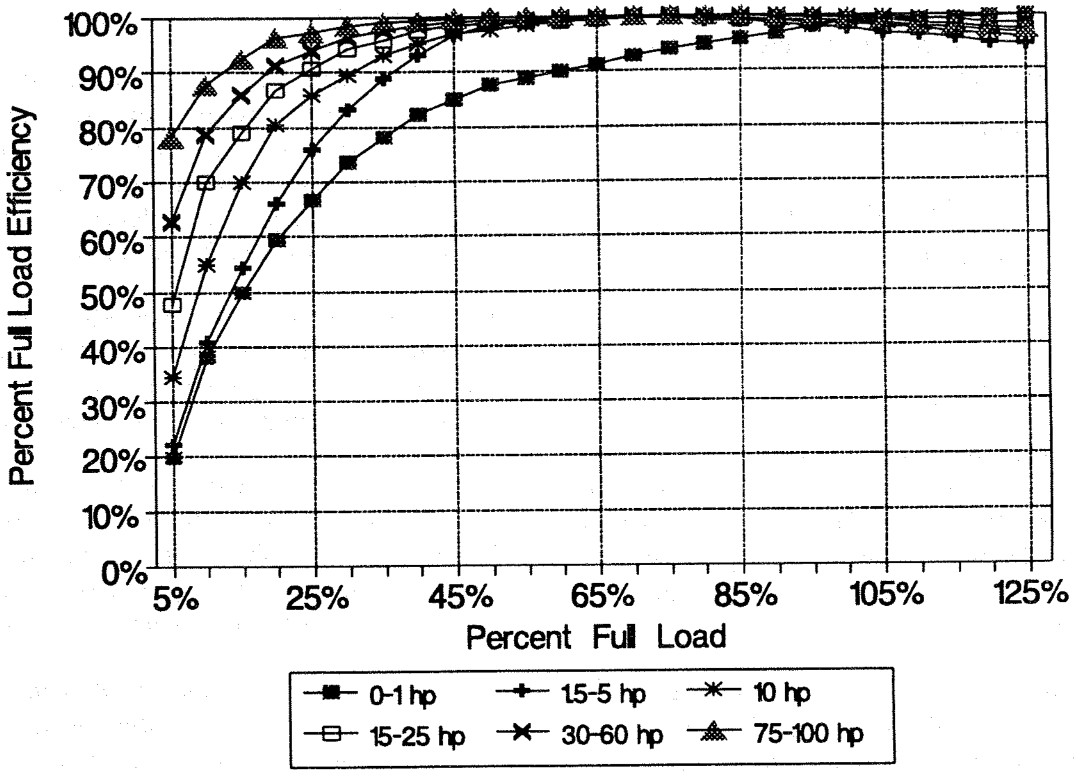
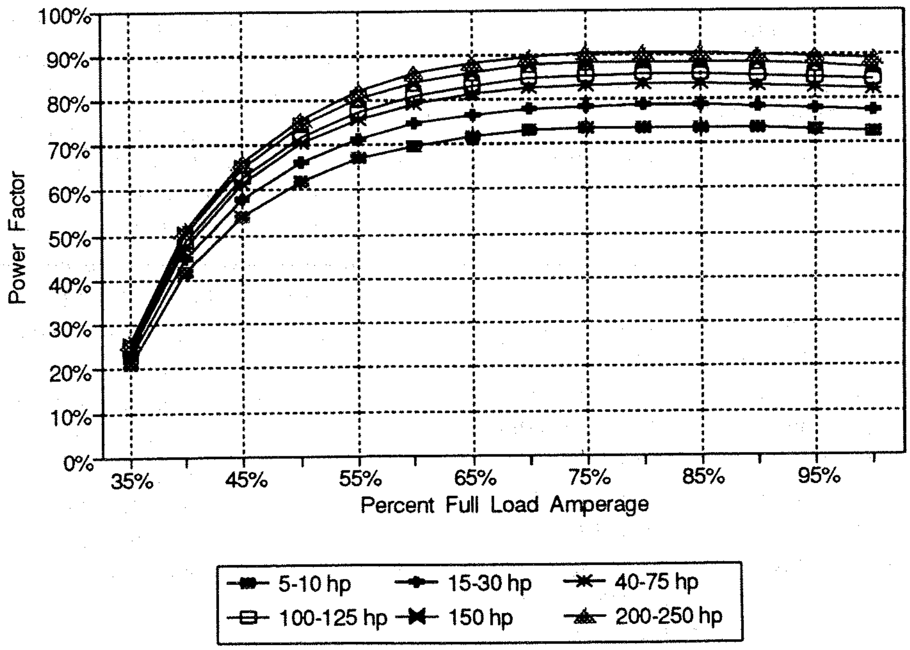


Figure 15

Motor Power Factor as a Function of Percent Full-load Amperage



size ranges. Typical part-load motor efficiency and power factor characteristics are indicated in Figures 14 and 15.

The cost penalties associated with using a substantially oversized motor can include:[8]

- A higher motor purchase price.
- Increased electrical supply equipment cost due to increased KVA and KVAR requirements.
- Increased energy costs due to decreased part-load efficiency.
- Power factor penalties.
- Larger motor starter and contactor sizes.

Replacing significantly underloaded motors with smaller energy efficient or even standard motors often improves system efficiency.[7] Care must be taken, however, to fully understand the characteristics of the driven load and alternative motors before changing out existing motors.

For instance, with a variable load, such as a variable air volume HVAC system, the motor must be sized to operate under fully loaded conditions. Inlet vanes, or other throttling devices must be set at "full open" so efficiency and load factor measurements can be taken at maximum load. Worn belts and pulleys can result in a reduced load being applied to the motor, giving the impression that it is underloaded. To eliminate this problem, worn belts or pulleys should be replaced before load and efficiency tests are made.[35] Load types include:[36]

- Continuous-running steady loads.
- Continuous-running with intermittent loading.
- Variable loads.
- Cyclic loads.

It is easiest to take measurements and properly size a motor driving a continuously running steady load. Be sure to take torque characteristics into consideration for intermittent or cyclic loading patterns. Also, consider purchase of an inverter duty motor and be sure to provide adequate fan circulation and cooling for motors coupled to adjustable-speed drives. Overheating is a particular concern at either reduced speed or high torque loading because of the non-ideal voltage and current waveforms encountered with electronic variable-frequency drives.[40,41]

It is best to operate an induction motor at 65 to 95 percent of full-rated load. You can save the most when the motor is properly matched with respect to the work that must be performed.

The replacement of an operable standard-efficiency motor with an energy efficient unit may be justified if the existing motor is operating inefficiently due to improper oversizing. In this instance, the cost effectiveness is bolstered due to the reduced cost of the smaller replacement motor and the substantial efficiency gain.

Though the initial cost of the smaller motor is less, additional costs will likely be incurred due to changing frame sizes, replacing couplings or half couplings, and modifying or changing controls, breakers and heaters.[30]

Operating efficiency and motor load values must be assumed or based on field measurements (see Chapter 4). Full-load speed for the existing motor may be extracted from the nameplate while speed characteristics for new motors are obtained from manufacturer's catalogs.

Many energy efficient motors tend to operate with a reduced full-load slip, i.e., at a slightly higher speed than their standard-efficiency counterparts. For centrifugal fans and pumps, even a minor change in the motor's operating speed translates into a significant change in imposed load and annual energy consumption. This rotating equipment speed/slip relationship is discussed in detail in Chapter 6.

Slip and operating speed are dependent upon applied load, and the percentage load imposed upon a motor is in turn dependent upon its size. For example, a 25 percent loaded 100 hp motor could be replaced by a 50 hp motor loaded to approximately 50 percent; a 62.5 percent loaded 40 hp motor; an 83 percent loaded 30 hp motor or a fully loaded 25 hp motor. As loads on a motor are progressively increased, it begins to rotate slower until, at the full-load point, operation occurs at the full-load speed. Thus, oversized and lightly loaded motors tend to operate at speeds which approach synchronous. An appropriately sized smaller or fully loaded energy efficient motor, with a higher full-load RPM than the motor to be replaced, may actually operate at a slower speed than the original oversized motor. This speed and load shift can be significant and must be taken into account when computing both energy and demand savings.[31]

For centrifugal loads, the replacement motor selected should be the next nameplate size above the motor output when operating under fully loaded conditions. It is recommended that load be metered for a variety of motor operating conditions such that the maximum load point is known with confidence. See Chapter 4 for a discussion of motor field load and efficiency estimation techniques.

Motors are selected based on startup, or locked rotor, pull up, breakdown and full load torque and load characteristics. This approach for examining the benefits of changing out oversized and underloaded motors works best for continuously operating motors under steady load conditions and for motors driving loads with low startup torque requirements, such as centrifugal fans and pumps where torque is a linear function of speed. The approach should not be used for motors driving conveyors or crushers—where oversizing may be required to account for high startup torque, transient loads, or abnormal operating conditions.

NEMA (in MG1-1993, Revision 1, Sections 12.38.1 through 12.38.4) establishes minimum locked rotor torque values for Design A through E induction motors. Energy efficient and standard efficiency motors are subject to the same torque standards. **Most energy efficient motors exhibit approximately the same locked rotor, breakdown, and rated load torque characteristics as their standard-efficiency counterparts.** Startup or locked rotor torque values for both standard and energy efficient, 1800 RPM TEFC motors are indicated in Figure 16.

Using *MotorMaster* to Conduct Analyses of Motor Repair or Oversized Motor Replacement Opportunities

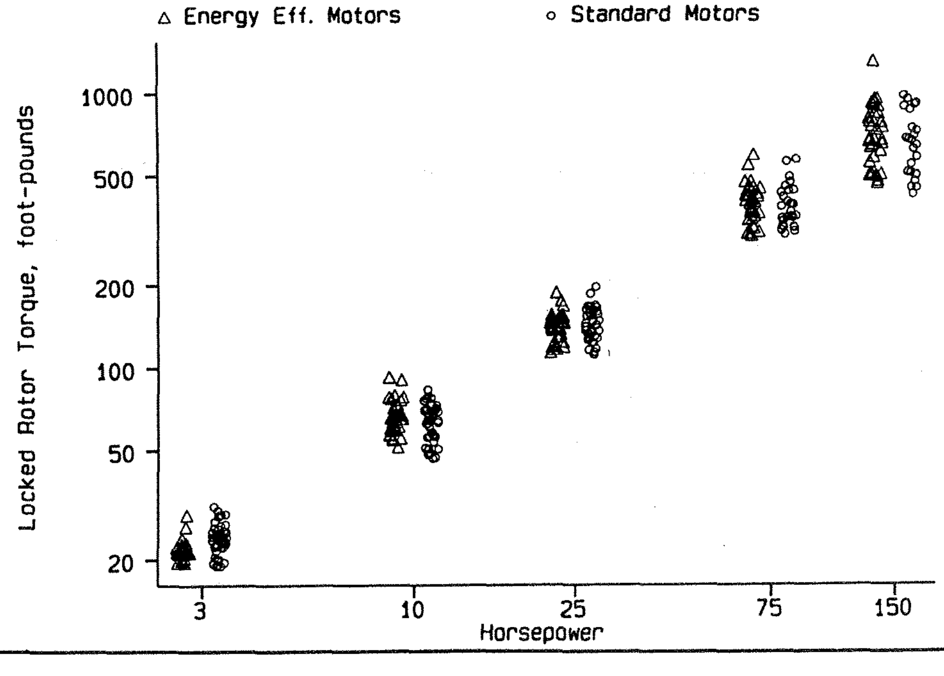
MotorMaster's Compare section was specifically created to effectively and correctly conduct analyses of new motor purchase, motor rewind or oversized and underloaded motor replacement actions. *MotorMaster* contains full 75, 50, and 25 percent load and power factor data for most currently available motors. An oversized motor replacement analysis can readily be made, with *MotorMaster* interpolating to determine the efficiency at the appropriate internally computed load point for the new downsized motor. Default rewind costs or equipment and installation cost data for the replacement motor are automatically entered into the analysis.

MotorMaster software contains a speed/correction algorithm such that when the nameplate full-load speed of the motor to be replaced is entered, any increase or decrease in load due to load/slip relationships is automatically calculated. Speed change effects are thus used when determining annual energy and dollar savings and the simple payback from investing in a new, energy efficient motor.

Figure 16

Locked Rotor Torque Values for Standard and Energy Efficient Motors

1800 RPM, TEFC Motors



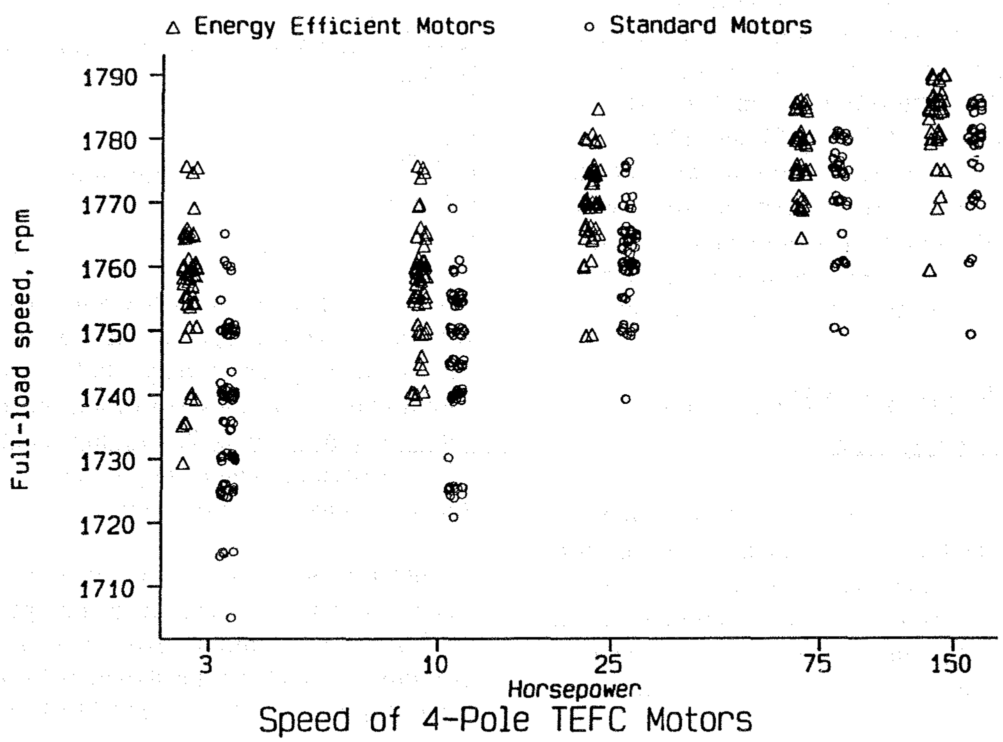
Chapter 6
Motor Speed, Design Voltage, Enclosure, and Power Factor Considerations

Sensitivity of Efficiency Gains to Motor Operating Speed

A motor's rotor must turn slower than the rotating magnetic field in the stator to induce an electrical current in the rotor conductor bars and thus produce torque. When the load on the motor increases, the rotor speed decreases. As the rotating magnetic field cuts the conductor bars at a higher rate, the current in the bars increases, which makes it possible for the motor to withstand the higher loading. Motors with slip greater than 5 percent are specified for high inertia and high torque applications.[40]

NEMA Design B motors deliver a starting torque that is 150 percent of full-load or rated torque and run with a slip of 3 to 5 percent at rated load.[40] Energy efficient motors, however, are usually "stiffer" than equivalently sized standard motors and tend to operate at a slightly higher full-load speed. This characteristic is illustrated in Figure 17, which shows the full-load speed for 1,800 RPM standard and energy efficient motors of various sizes. On the average, energy efficient motors rotate only 5 to 10 RPM faster than standard models. The speed range for available motors, however, exceeds 40 to 60 RPM.

Figure 17
Full-Load Speed Characteristics of Standard and Energy Efficient Motors



For centrifugal loads, even a minor change in the motor's full-load speed translates into a significant change in the magnitude of the load and energy consumption. The "Fan" or "Affinity Laws," indicated in Table 21, show that the horsepower loading on a motor varies as the third power (cube) of its rotational speed. In contrast, the quantity of air delivered varies linearly with speed.[42]

As summarized in Table 22, a relatively minor 20-RPM increase in a motor's rotational speed, from 1,740 to 1,760 RPM, results in a 3.5 percent increase in the load placed upon the motor by the rotating equipment. A 40-RPM speed increase will increase air or fluid flow by only 2.3 percent, but can boost energy consumption by 7 percent, far exceeding any efficiency advantages expected from purchase of a higher efficiency motor. Predicted energy savings will not materialize, in fact, energy consumption will substantially increase. This increase in energy consumption is troublesome when the additional air or liquid flow is not needed or useful, but can be beneficial if original flow was marginal.

Be aware of the sensitivity of load and energy requirements to rated motor speed. Replacing a standard motor with an energy efficient motor in a centrifugal pump or fan application can result in reduced energy savings if the energy efficient motor operates at a higher RPM. **A standard-efficiency motor with a rated full-load speed of 1,750 RPM should be replaced with an energy efficient unit of like speed in order to capture the full energy conservation benefits associated with a high-efficiency motor retrofit.** Alternatively, you can use sheaves or trim pump impellers so equipment operates at its design conditions.

Operating Voltage Affects on Motor Performance

Generally, high-voltage motors have a lower efficiency range than equivalent medium-voltage motors because increased winding insulation is required for the higher voltage machines. This increase in insulation results in a proportional decrease in available space for copper in the motor slot.[43] Consequently, I^2R losses increase.

Table 21

Fan Laws/Affinity Laws

Law #1: $$\frac{CFM_2}{CFM_1} = \frac{RPM_2}{RPM_1}$$

Quantity (CFM) varies as fan speed (RPM)

Law #2: $$\frac{P_2}{P_1} = \frac{(RPM_2)^2}{(RPM_1)^2}$$

Pressure (P) varies as the ***square*** *of fan speed*

Law #3: $$\frac{hp_2}{hp_1} = \frac{(RPM_2)^3}{(RPM_1)^3}$$

Horsepower (hp) varies as the ***cube*** *of fan speed*

Table 22

Sensitivity of Load to Motor Speed

$$\frac{(1{,}760)^3}{(1{,}740)^3} = 3.5 \textit{ percent horsepower increase}$$

$$\frac{(1{,}780)^3}{(1{,}740)^3} = 7.0 \textit{ percent horsepower increase}$$

Losses are also incurred when a motor designed to operate at 230 volts is operated at 208 volts or with a reduced voltage power supply. Under this condition, the motor will exhibit a lower full-load efficiency, run hotter, slip more, produce less torque, and have a shorter life.[44] Efficiency can be improved by switching to a higher voltage transformer tap.

If operation at 208 Volts is required, an efficiency gain can be procured by installing an energy efficient NEMA Design A motor. Efficiency, power factor, temperature rise, and slip are shown in Table 23 for typical open-drip proof 10 hp - 1800 RPM Design B and Design A motors operated at both 230 and 208 volts.[15,44]

Table 23
Performance Comparison for 10 hp NEMA Design B versus Design A Motors at 230 and 208 Volts

	Design B		Design A	
Volts	208	230	208	230
Efficiency, %	80.6	84.4	83.7	85.3
Power Factor, %	85.0	82.7	84.1	78.5
Temp. Rise, deg. C	91.0	72.0	73.0	66.0
Slip, %	5.9	4.1	4.6	3.5

Motor Speed and Enclosure Considerations

Energy efficient motors are a worthwhile investment in all size, speed, and enclosure classifications. In general, higher speed motors and motors with open enclosures tend to have slightly higher efficiencies than low-speed or totally-enclosed fan-cooled units. In all cases, however, the energy efficient motors offer significant efficiency improvements, and hence energy and dollar savings, when compared with the standard-efficiency models.

Typical motor efficiency gains are illustrated in Figures 18 through 20. Figure 18 shows the efficiency improvement expected from the selection of energy efficient over standard-efficiency motors with varying nominal speeds. The efficiency gain, and hence the energy and dollar savings benefits, are generally largest for the 3,600-RPM motors. Similarly, Figure 19 indicates that the energy savings associated with 1,800-RPM energy efficient over standard open motors slightly exceed those available from the high-efficiency over the standard enclosed model. Figure 20 indicates that energy efficient motors provide even greater efficiency improvements when operating under part load conditions.

Figure 18
Motor Speed Versus Efficiency Gain

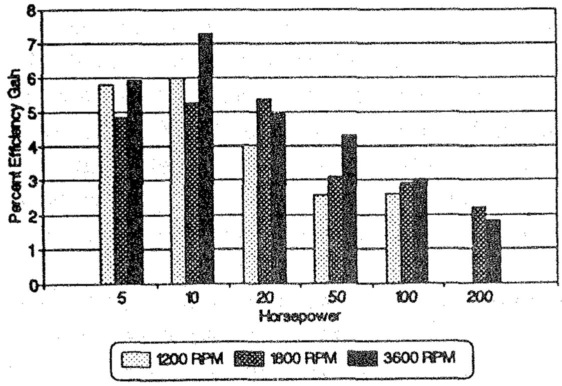


Figure 19
Motor Enclsure Versus Efficiency Gain
3/4 Load, 1800 RPM Motor

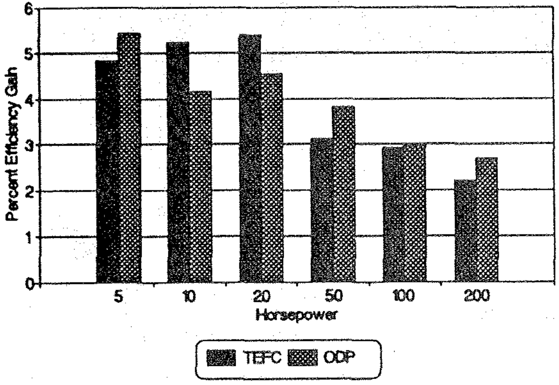
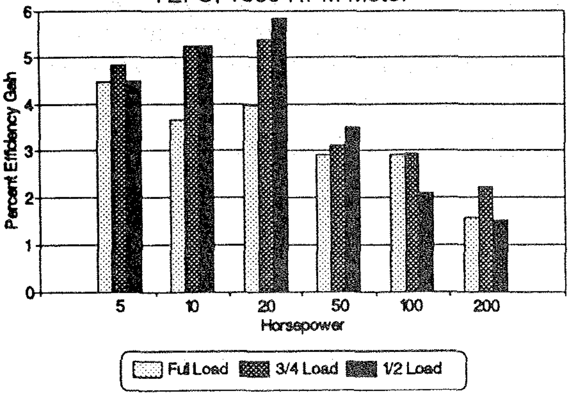


Figure 20
Efficiency Improvements Versus Motor Load
TEFC, 1800 RPM Motor



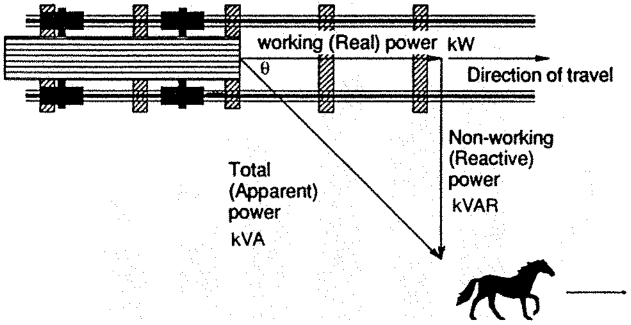
Efficiency Improvements at Part-Load Conditions

Energy efficient motors perform better than their standard-efficiency counterparts at both full and partially loaded conditions. Typical efficiency gains for 5-, 20-, and 100-hp motors when operating at full; 3/4-; and 1/2-load are given in Figure 20. Efficiency improvements from use of an energy efficient motor actually increase slightly under half-loaded conditions. While the overall energy conservation benefits are less for partially versus fully-loaded motors, the percentage of savings remains relatively constant. To obtain full-, 3/4-, and 1/2-load efficiencies and power factor information, consult the *MotorMaster* Database.

Power Factor Improvement

An induction motor requires both active and reactive power to operate. The active or true power, measured in kW, is consumed and produces work or heat. The reactive power, expressed in kVARs, is stored and discharged in the inductive or capacitive elements of the circuit, and establishes the magnetic field within the motor that causes it to rotate.[8,15] The apparent power is the product of the total voltage and total current in an AC circuit and is expressed in kilovolt-amperes (kVA). The total or apparent power is also the vector sum of the active and reactive power components. Power factor is the ratio of the active to the total power, (Figure 21).[45]

Figure 21
Power Definitions



$$\text{where: power factor} = \frac{\text{true power}}{\text{apparent power}} = \frac{kW}{kVA} = Cos\theta$$

The electric utility must supply both active and reactive power loads. A low or "unsatisfactory" power factor is caused by the use of inductive (magnetic) devices and can indicate a possible low system electrical operating efficiency. Induction motors are generally the principal cause of low power factor because many are in use which are not fully loaded.[46]

When motors operate near their rated load, the power factor is high, but for lightly loaded motors the power factor drops significantly. This effect is partially offset as the total current is less at reduced load. Thus, the lower power factor does not necessarily increase the peak kVA demand because of the reduction in load. Many utilities, however, levy a penalty or surcharge if a facility's power factor drops below 95 or 90 percent.

In addition to increased electrical billings, a low power factor may lower your plant's voltage, increase electrical distribution system line losses, and reduce the system's capacity to deliver electrical energy. While motor full- and part-load power factor characteristics are important, they are not as significant as nominal efficiency. When selecting a motor, conventional wisdom is to purchase efficiency and correct for power factor.[15]

Low power factors can be corrected by installing external capacitors at the main plant service or at individual pieces of equipment. Power factor can also be improved and the cost of external correction reduced by minimizing operation of idling or lightly loaded motors and by avoiding operation of equipment above its rated voltage.

Power factors can be improved through replacement of standard- with energy efficient motors which are appropriately matched to their driven loads. Power factors vary tremendously, based on motor design and load conditions. While some energy efficient motor models offer power factor improvements of 2 to 5 percent, others have lower power factors than typical equivalent standard motors. Even high power factor motors are affected significantly by variations in load. A motor must be operated near its rated loading in order to realize the benefits of a high power factor design.

Chapter 7
Motor Operation Under Abnormal Conditions

Motors must be properly selected according to known service conditions. Usual service conditions, defined in NEMA Standards Publication MG1-1993, Rev. 1, *Motors and Generators,* include:[47]

1. Exposure to an ambient temperature between 0°C and 40°C
2. Installation in areas or enclosures that do not seriously interfere with the ventilation of the machine
3. Operation within a tolerance of ± 10 percent of rated voltage
4. Altitude not above 3,300 feet.
5. Operation within a tolerance of ± 5 percent of rated frequency
6. Operation with a voltage unbalance of 1 percent or less

Operation under unusual service conditions may result in efficiency losses and the consumption of additional energy. Both standard and energy efficient motors can have their efficiency and useful life reduced by a poorly maintained electrical system.[8] Monitoring voltage is important for maintaining high-efficiency operation and correcting potential problems before failures occur. Preventative maintenance personnel should periodically measure and log the voltage at a motor's terminals while the machine is fully loaded.

Over Voltage

As the voltage is increased, the magnetizing current increases by an exponential function. At some point, depending upon design of the motor, saturation of the core iron will increase and overheating will occur.[43] At about 10 to 15 percent over voltage both efficiency and power factor significantly decrease for standard efficiency motors while the full-load slip decreases[8]. The starting current, starting torque, and breakdown torque all significantly increase with over voltage conditions.[20]

A voltage that is at the high end of tolerance limits frequently indicates that a transformer tap has been moved in the wrong direction. An overload relay will not recognize this over-voltage situation and, if the voltage is more than 10 percent high, the motor can overheat. Over voltage operation with VAR currents above acceptable limits for extended periods of time may accelerate deterioration of a motor's insulation.[40]

Under Voltage

If a motor is operated at reduced voltage, even within the allowable 10 percent limit, the motor will draw increased current to produce the torque requirements imposed by the load.[32] This causes an increase in both stator and rotor I^2R losses. Low voltages can also prevent the motor from developing an adequate starting torque. The effects on motor efficiency, power factor, RPM, and current from operating outside nominal design voltage are indicated in Figure 22.[48]

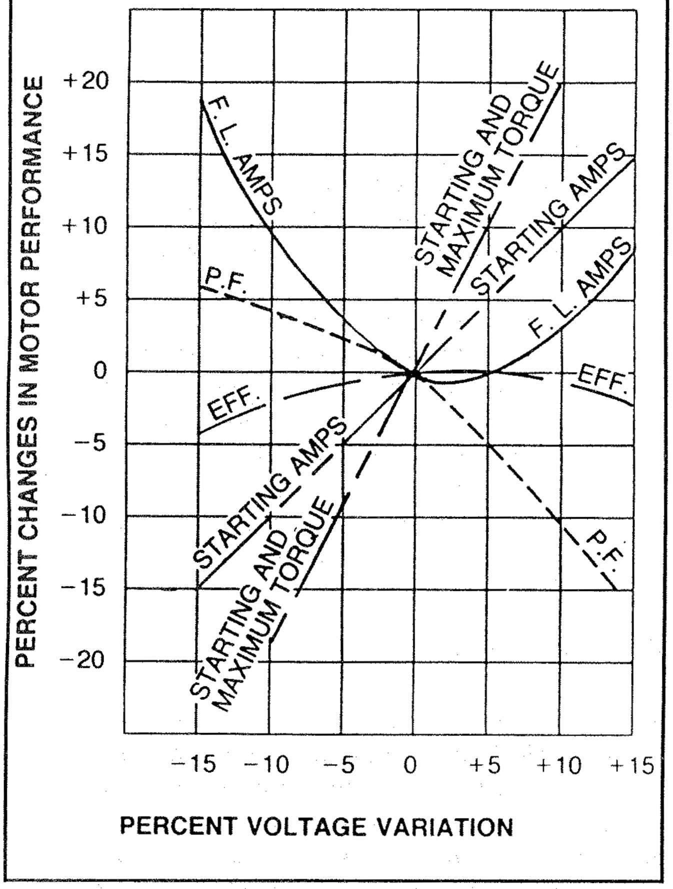
Reduced operating efficiency because of low voltages at the motor terminals is generally due to excessive voltage drops in the supply system.[8] If the motor is at the end of a long feeder, reconfiguration may be necessary. The system voltage can also be modified by:

- Adjusting the transformer tap settings
- Installing automatic tap-changing equipment if system loads vary considerably over the course of a day
- Installing power factor correction capacitors that raise the system voltage while correcting for power factor

Since motor efficiency and operating life are degraded by voltage variations, only motors with compatible voltage nameplate ratings should be specified for a system.

Figure 22

Voltage Variation
Effect on Motor Performance



For example, three phase motors are usually rated at 460 volts for 480 volt nominal service. Some (particularly older) motors are rated at 440 volts. Service voltage can vary by 5% from nominal and it is not unusual for voltage to exceed 485 volts at the motor leads. This would exceed the 10% range for which a NEMA designed motor is supposed to operate "successfully". Efficiency would be degraded by up to 3% and power factor would be dramatically reduced by about 10%. Although NEMA stipulates that motors operate successfully over a ± 10% range from nameplate voltage, they caution that motors will not necessarily meet performance standards when they deviate from exact nameplate voltage.

Phase Voltage Unbalance

A voltage unbalance occurs when there are unequal voltages on the lines to a polyphase induction motor. This unbalance in phase voltages also causes the line currents to be out of balance. The unbalanced currents cause torque pulsations, vibrations, increased mechanical stress on the motor, and overheating of one and possibly two of the phase windings. This results in a dramatic increase in motor losses and heat generation, which both decrease the efficiency of the motor and shorten its life.[40]

Voltage unbalance is defined by NEMA as 100 times the maximum deviation of the line voltage from the average voltage on a three-phase system divided by the average voltage.[49] For example, if the measured line voltages are 462, 463, and 455 volts, the average is 460 volts. The voltage unbalance is:

$$\left(\frac{460-455}{460}\right)\times 100\% = 1.1\%.$$

A voltage unbalance of only 3.5 percent can increase motor losses by approximately 20 percent.[47] Unbalances over 5 percent indicate a serious problem. Unbalances over 1 percent require derating of the motor, and will void most manufacturers' warranties. Per NEMA MG1-14.35, a voltage unbalance of 2.5 percent would require a derate factor of 0.925 to be applied to the motor rating. Derating factors due to unbalanced voltage for integral horsepower motors are given in Figure 23[2]. The NEMA derating factors apply to all motors. There is no distinction between standard and energy efficient motors when selecting a derate factor for operation under voltage unbalance conditions.

Common causes of voltage unbalance include:[8,40,49]

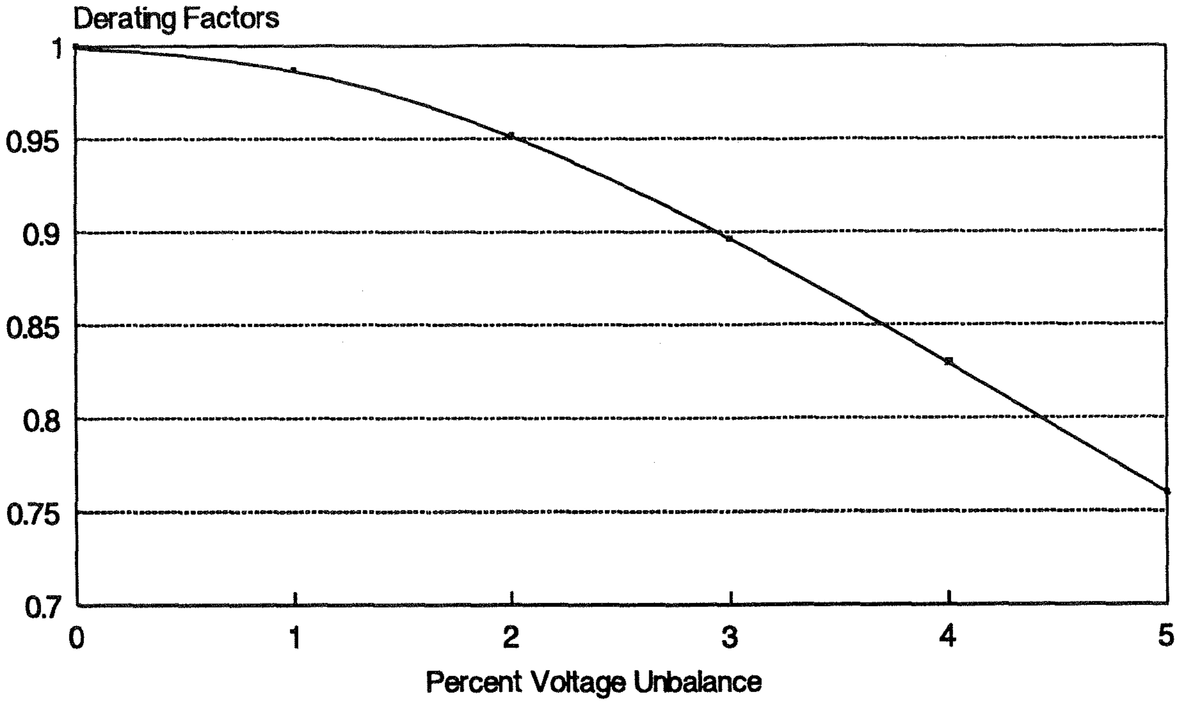
- Faulty operation of automatic power factor connection equipment
- Unbalanced or unstable utility supply
- Unbalanced transformer bank supplying a three-phase load that is too large for the bank
- Unevenly distributed single-phase loads on the same power system
- Unidentified single-phase to ground faults
- An open circuit on the distribution system primary

The following steps will ensure proper system balancing.[8]

- Check your electrical system single-line diagram to verify that single-phase loads are uniformly distributed

Figure 23

Motor Derating Factors due to Voltage Unbalance



- Regularly monitor voltages on all phases to verify that a minimum variation exists.
- Install required ground fault indicators
- Perform annual thermographic inspections

Load Shedding

Energy and power savings can be obtained directly by shutting off idling motors to eliminate no-load losses.[7] This action also greatly improves the overall system power factor, which in turn improves system efficiency. Typical no-load or idling power factors are in the 10 to 20 percent range. Load shedding is most effective for slower speed (1,800 RPM and less) motors used in low-inertia applications.[15] While it is possible to save energy by de-energizing the motor and restarting it when required, excessive starting, especially without soft-starting capability, can cause overheating and increased motor failures.

Consideration must be given to thermal starting capability and the life expectancy of both motor and starting equipment.[15] Motors 200 hp and below can only tolerate about 20 seconds of maximum acceleration time with each start. Motors should not exceed more than 150 start seconds per day.[8] Starting limitations for motors over 200 hp should be obtained from the manufacturer. Maximum number of starts per hour and minimum off-time guidelines for 1800 RPM Design B motors of various sizes are given in Table 24.[47]

Table 24

Allowable Number of Motor Starts and Minimum Time Between Starts

(For 1800 RPM Design B Motors)

Motor Size, hp	Maximum Number of Starts per Hour[1]	Minimum Off Time (Seconds)
5	16.3	42
10	12.5	46
25	8.8	58
50	6.8	72
100	5.2	110

[1] This table is extracted from NEMA Standards Publications No. MG10 *Energy Management Guide for Selection and Use of Polyphase Motors*. NEMA has prepared a comprehensive load shedding table for 3600, 1800, and 1200 RPM motors in the 1- to 250-hp size range. NEMA also presents a methodology for minimizing winding stresses by adjusting the number of allowable starts per hour to account for load inertia.

Chapter 8
Motor Selection Considerations

Overall motor performance is related to the following parameters:[15]

- Acceleration capabilities
- Breakdown torque
- Efficiency
- Enclosure type
- Heating
- Inrush current
- Insulation class
- Power factor
- Service factor
- Sound level
- Speed
- Start torque

A good motor specification should define performance requirements and describe the environment within which the motor operates. As the purchaser, you should avoid writing design-based specifications that would require modification of standard components such as the frame, bearing, rotor design, or insulation class.[8]

Specification contents should include:

- Motor horsepower and service factors
- Temperature rise and insulation class
- Maximum starting current
- Minimum stall time
- Power factor range
- Efficiency requirement and test standard to be used
- Load inertia and expected number of starts

Environmental information should include:

- Abrasive or non-abrasive
- Altitude
- Ambient temperature
- Hazardous or non-hazardous
- Humidity level

You should specify special equipment requirements such as thermal protection, space heaters (to prevent moisture condensation), and whether standard or non-standard conduit boxes are required.

Motor Enclosures

Many types of motor enclosures are available, including:[28]

Open. An enclosure with ventilating openings that permit passage of external cooling air over and around the motor windings. This design is now seldom used.

Open Dripproof (ODP). An open motor in which ventilation openings prevent liquid or solids from entering the machine at any angle less than 15 degrees from the vertical.

Guarded. An open motor in which all ventilating openings are limited to specified size and shape. This protects fingers or rods from accidental contact with rotating or electrical parts.

Splash-Proof. An open motor in which ventilation openings prevent liquid or solids from entering the machine at any angle less than 100 degrees from the vertical.

Totally Enclosed. A motor enclosed to prevent the free exchange of air between the inside and outside of the case, but not airtight.

Totally Enclosed Nonventilated (TENV). A totally-enclosed motor that is not equipped for cooling by means external to the enclosed parts.

Totally Enclosed Fan-Cooled (TEFC). A totally-enclosed motor with a fan to blow cooling air across the external frame. They are commonly used in dusty, dirty, and corrosive atmospheres.

Encapsulated. An open motor in which the windings are covered with a heavy coating of material to provide protection from moisture, dirt, and abrasion.

Explosion-Proof. A totally-enclosed motor designed and built to withstand an explosion of gas or vapor within it, and to prevent ignition of gas or vapor surrounding the machine by sparks, flashes, or explosions that may occur within the machine casing.

Inverter duty. Motor manufacturers make certain design changes to optimize products offered for use in adjustable speed drive applications. All electronic variable speed drives have an inverter to create the variable frequency necessary for speed control. Not only is the frequency variable, but the AC output is neither a perfect sine wave nor a constant RMS voltage. Motors designed for 60 Hz sinusoidal power vary in their tolerance to the kind of power provided by inverters. Most manufactures produce lines of variable or constant torque definite purpose motors especially designed for "inverter duty". Others produce motors with fix-speed fans or external cooling ducts.

Motor Insulation Systems

The ultimate cause of winding or insulation failure is frequently internal heat production and increased operating temperatures due to high currents or contamination. An insulation system is comprised of insulating materials for conductors and the structural parts of a motor.[28] Since motor failure often occurs due to oxidation and thermal degradation of insulating materials, motors that run hotter tend to have shorter operating lives. The relationship between operating temperature and motor insulation life is shown in Figure 24.[44] A typical rule of thumb is that the service life expectancy of winding insulation is reduced by one-half for each 10°C increase in operating temperature.

Grease life also varies with temperature. As the bearing temperature increases, a motor must be regreased more frequently to prevent premature bearing failures.[36]

All insulation systems are not the same. NEMA has established standards for insulation design, temperature rating, and motor thermal capacity.[47] Four classes of insulation have been designated, each with an allowable operating temperature. These insulation systems, designated classes A, B, F, and H, vary with respect to design and selection of material and bonding agent thermal range. A Class A insulation system is one which is shown by experience or test to have a suitable operating life when operated at 105°C. A Class B system shows acceptable thermal endurance when operated at 130°C; a Class F insulation system can be operated at 155°C, while a Class H system can be operated at a limiting temperature of 180° C.[28] Class B and F systems are most commonly used.

Service Factor

Motors are designed with an allowable increase in temperature above ambient during operation. This is referred to as temperature rise. The maximum allowable temperature rise during operation for a motor varies with respect to insulation class and the motor's service factor. The service factor is essentially a safety margin and refers to the motor's ability to continuously deliver horsepower beyond its nameplate rating under specified conditions. Most motors are rated with a 1.0 or 1.15 service factor. A 10-hp motor operating under rated conditions with a 1.15 service factor should be able to continuously deliver 11.5 horsepower without exceeding the NEMA allowable temperature rise for its insulation system.[47] NEMA allows an ambient

Table 25
Temperature Limitations for Insulation Classes

Service Factor	Enclosure	Insulation Temperature	Class B	Class F	Class H
Any	All	Ambient Temperature	40°C/104°F	40°C/104°F	40°C/104°F
1.0	Open	Allowable Rise	80°C/144°F	105°C/189°F	125°C/225°F
1.0	Open	Operating Limitation	120°C/248°F	145°C/293°F	165°C/329°F
>=1.15	Open	Allowable Rise	90°C/162°F	115°C/207°F	N/A
>=1.15	Open	Operating Limitation	130°C/266°F	155°C/198°F	N/A
Any	TEFC	Allowable Rise	85°C/153°F	110°C/198°F	135°C/243°F
Any	TEFC	Operating Limitation	125°C/257°F	150°C/302°F	175°C/347°F

temperature of 40°C (104°F) when specifying "usual service conditions."

If the ambient temperature exceeds 40° C or at elevations above 3,300 feet, the motor service factor must be reduced or a higher horsepower motor is required. As the oversized motor will be underloaded, the operating temperature rise is less and overheating will be reduced.[28]

NEMA temperature standards for motors with Class B, F, and H insulation and a 1.0 or 1.15 service factor are given in Table 25.[8] Note that a motor equipped with Class F insulation, but operating within Class B temperature limitations, is operating far below its maximum operating limitations. It is thus running "cooler" relative to its thermal capability.[47] Premium- or energy efficient motors are typically equipped with Class F insulation and rated with a 1.15 service factor.

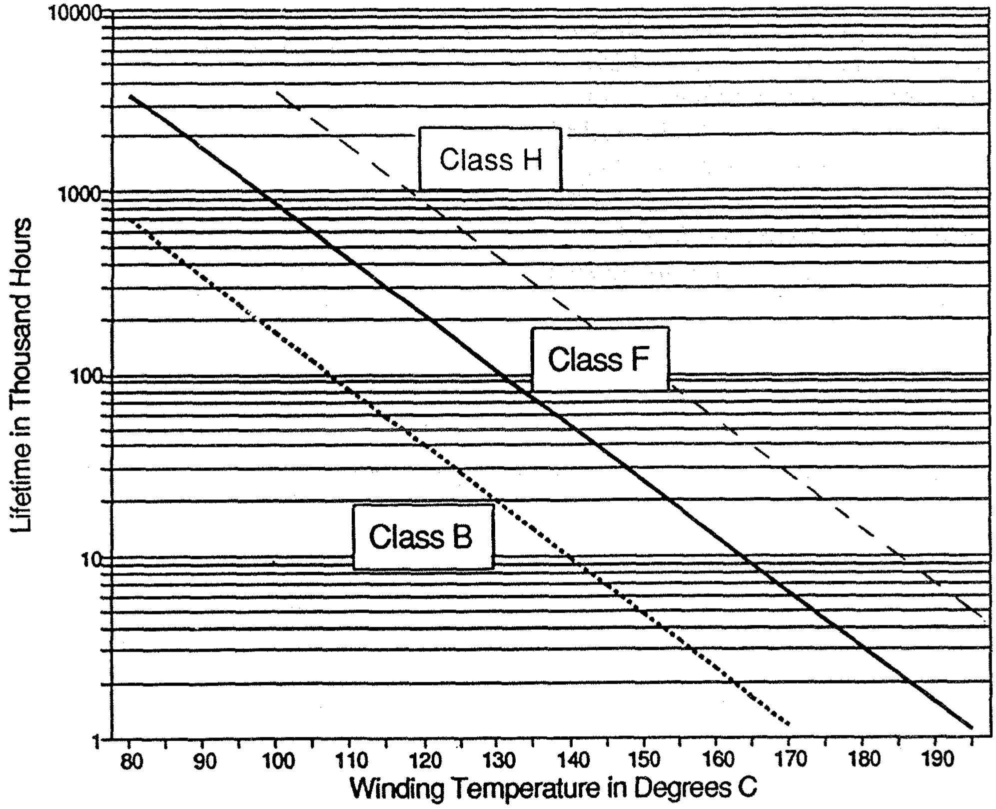
Motor Speed, Slip, and Torque Relationships

When selecting the proper motor speed, consider the original equipment cost and the requirements of the driven system. Generally, large high-speed standard or energy efficient motors have improved efficiency and power factor characteristics.

Load, torque, and horsepower requirements determine the type and size of motor required for a particular application. Torque is a measure of the rotational force that a motor can produce. As the physical size of a motor is proportional to its torque capability, high-torque motors are larger and cost more.[8]

Induction motors are standardized according to their torque characteristics (Design A, B, C, and D).[8] Torque is in turn characterized by starting or locked-rotor torque, which is the minimum torque produced by the motor at rated voltage and frequency at all angular positions of the rotor; pull-up torque, which is the

Figure 24
Service Life versus Operating Temperature for Insulation Systems



minimum torque developed by the motor during acceleration; and breakdown torque, which is the maximum torque that the motor can supply before stalling. Representative speed-torque curves for Design A through D induction motors are shown in Figure 25.[50]

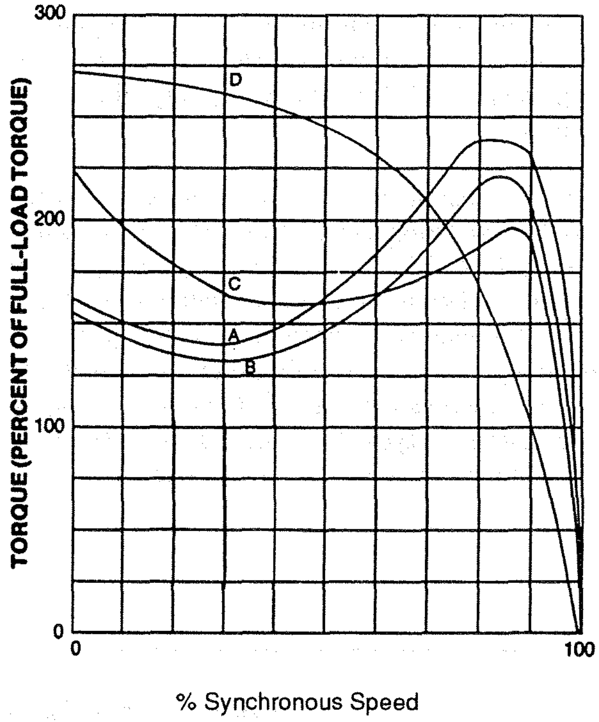
The motor design selected must have adequate torque capability to start a load and accelerate it to full speed. The relationship between torque and delivered motor horsepower is:

$$HP = \frac{\text{Torque (ft-lb)} \times RPM}{5250}$$

A standard efficiency motor, operating at a slower speed, or with increased slip has to develop slightly more torque and draw more current to produce the same output as its energy efficient counterpart. The higher winding and rotor resistance of the standard efficiency motor also means that the rotor cuts through more lines of magnetic flux created by the stator and produces a greater accellerating torque.[50] The amount of torque reduction to be expected with energy efficient motors is seldom harmful except for high torque loads such as full conveyors that shouldn't be using a NEMA Design B motor.[51]

NEMA Design B motors can be used with constant speed centrifugal fans, pumps and blowers, unloaded compressors, some conveyors, and cutting machine tools.[28] Most induction motors are Design B, with Design A being the second most common.[8] While NEMA limits for locked rotor torque for Design A and B motors are the same, Design A motors have higher starting current and start-up torque characteristics. Speed-torque characteristics for polyphase motors are given in Table 26.[47]

Figure 25
Typical Speed/Torque Comparisons
NEMA Design A-D Induction Motors



Source: Reliance Electric

Table 26
NEMA Torque Characteristics for Medium Polyphase Induction Motors[1]

NEMA Design	Starting Current (% Rated Load Current)	Locked Rotor Torque (% Rated Load Torque)	Breakdown Torque (% Rated Load Torque)	Percent Slip
B[2]	600 - 700	70 - 275	175 - 300	1 - 5
C	600 - 700	200 - 250	190 - 225	5
D	600 - 700	275	275	5 - 8

[1] NEMA Standards Publication for Motors and Generators MG1-1993 classifies motors as medium or large. 3600 or 1800 RPM motors rated up to 500 hp are defined as medium motors. The rating declines to 350 and 250 hp for 1200 and 900 RPM motors, respectively.
[2] Design A motors have characteristics similar to those for Design B motors except that starting currents are not limited.

Design E Motors

While Design E motors are not yet available, NEMA released specifications for a Design E motor in the October, 1994 revision to its MG1 standards. The letter "E" was assigned because it is the next design to be standardized following the Design D motor, not because "E" stands for "efficiency". Nonetheless, the Design E specification has among its requirements a table of minimum efficiency values, Table 12-11. Those efficiencies are greater than the efficiencies in Table 12-10[1] which are the minimum efficiencies for motors which may be designated as "energy efficient".

The Design E motor was specified to meet an international standard promulgated by the International Electrotechnical Commission (IEC). IEC has a standard that is slightly less restrictive on torque and starting current than the Design B motor. This standard allows designs to be optimized for higher efficiency. It was decided to create a new Design E motor which meets both the IEC standard and also an efficiency criterion higher than the Table 12-10 standard.[52]

For most moderate to high usage applications normally calling for a Design A or B motor, the Design E motor should be a better choice. One should be aware however of slight performance differences.

Design E locked rotor torque requirements are different from Design B. They are required to be somewhat higher than Design B levels for many motors under 20 HP and some motors over 200 HP, but allowed to be lower for most motors from 20 HP to 200 HP.

Except for very small motors (i.e. under 3 HP) Design E motors are allowed to have considerably higher locked rotor (starting) current than Design B motors. (Note that Design A motors still have no upper limit whatsoever for their locked rotor current.) In the first ten milliseconds of start up, any motor's current can exceed the nominal locked rotor current. This momentary current spike is called "inrush" current and is likely to be highest of all in Design E motors. High inrush current can cause false trips in across the line starts where fast magnetic-only motor circuit protectors (MCPs) are used.[52,53]

Although the NEMA standard allows the same slip (up to 5%) for Designs A, B, and E motors, the range of actual slip of Design E motors is likely to be lower than for Designs A and B. This should be factored into savings calculations in retrofit situations for variable torque (e.g. pump and fan) applications.

No efficiency standards pertain to part load operation. For applications requiring significant utilization at less than 75% load, consult *MotorMaster* or manufacturer data for part load efficiencies of alternative motors.

[1] Table 12-10 was numbered 12-6C and titled, *Suggested Standard for Future Design* in the version of NEMA MG1 which was current when its efficiencies were adopted into the National Energy Act of 1992. Since that adoption, NEMA has entitled the table, *Full Load Efficiencies of Energy Efficient Motors* and eliminated the less stringent table which previously bore that name. No efficiencies in Table 12-10 have been revised since its inception, but when it was renamed, it was extended to higher horsepower motors than were previously covered.

Chapter 9
Starting Your Motor Management Program

Four basic elements are essential to any energy management or motor efficiency improvement program: 1) top management commitment, 2) clearly designated program responsibility, 3) defined realistic goals, and 4) program planning and implementation.[54] Program planning, in turn, requires conducting field tests to obtain information regarding where and how energy is being used and/or wasted.

Begin your motor management program by screening to select the best candidates for immediate retrofit or future replacement with energy efficient units. Complete a Motor Nameplate and Field Test Data Form (see Appendix B) for each motor used in excess of 2,000 hours per year.[23] A recording wattmeter may be useful for analyzing varying loads over a representative period of time.

Information provided on the Motor Nameplate and Field Test Data Forms may be used to determine the quantity of energy annually consumed by each piece of motor-driven equipment or process train within your industrial facility. The costs of operating each piece of equipment can also be readily determined and used to "target" or focus efficiency-improvement activities on energy intensive loads or processes. Remember that the energy savings potential is likely greatest where the bulk of energy is actually being used.

The data summarized on the Field Data Test Forms can also be used to determine the load imposed on each motor by its driven equipment plus estimate the efficiency of the motor at that load point (see Chapter 4). This information can be input to *MotorMaster* or used in conjunction with the equations presented in Chapter 3 to determine the annual energy and dollar savings associated with repairing or replacing the existing motor with an energy efficient unit.

You should also check with your local utility regarding the availability of financial incentives such as energy efficient electric motor rebates or commercial/industrial sector energy conservation programs, technical assistance, billing credit offers, or low interest loans.

If financial incentives are available, it may be cost effective to complete a "group" conversion of eligible motors, rather than wait for operable standard-efficiency motors to fail. A disadvantage of waiting until failure to replace motors is that unscheduled down time occurs. Also, once a motor fails, it is no longer possible to check whether the motor is properly matched to the load.[35] Too often, immediate replacement needs outweigh energy management objectives and a failed standard-efficiency motor is replaced by a standard-efficiency spare. Immediate replacement locks in future energy savings at today's capital cost.[23]

Replacement of an operable standard-efficiency motor may also be wise from a preventative maintenance standpoint. Downtime costs are application specific and can be substantial. Some would argue that "...the most efficient motor is one that runs consistently...thus reducing downtime to an absolute minimum."[55] Replacement of aged standard-efficiency motors with new, more reliable energy efficient units should provide secondary economic benefits through prevention of unexpected failures and increased productivity.

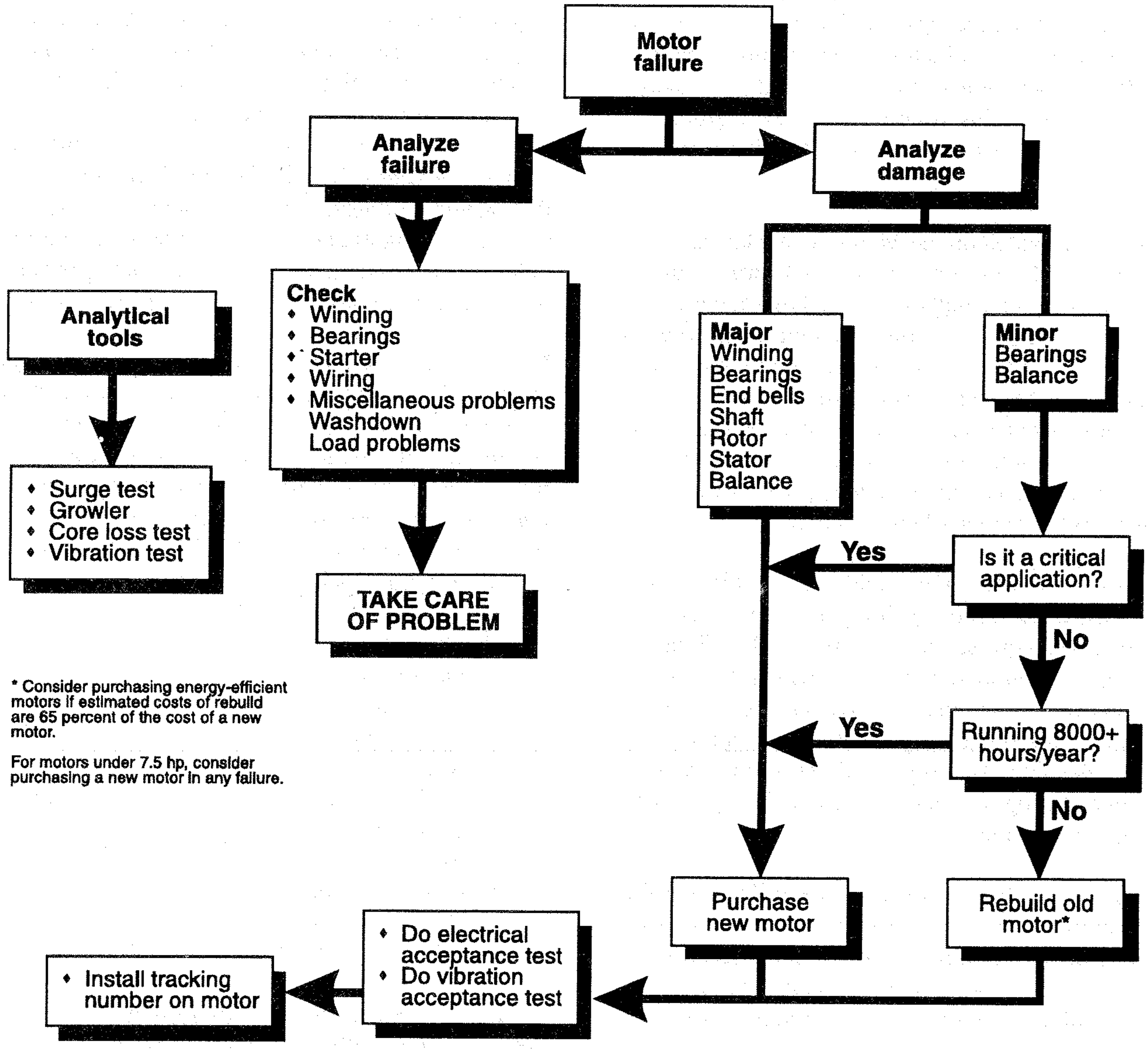
Motor service lifetimes can be extensive, typically exceeding 10 years when the unit is properly matched to its driven load and operated under design power supply conditions. Historically, the single largest cause of motor failure has been overloading due to improper matching of motors to the load or placing motors into operation under conditions of voltage unbalance. Causes of failure include:[56]

Overloading	25%
Contamination	
Moisture	17%
Oil and Grease	20%
Chemical	1%
Chips and dust	5%
Single Phasing	10%
Bearing Failure	12%
Normal Insulation Deterioration	5%
Other	6%

Your motor management program should include a procedure for dealing with motor failures. The Weyerhauser Corporation has developed a motor management process that includes failure analysis and damage assessments, electrical and vibration acceptance testing of new and rebuilt motors, preventative maintenance, and good alignment practice.[57] The identification and correction of conditions that contribute to a motor failure plus improved alignments and surge testing have extended the expected service lives of replacement motors and decreased motor rebuilds by 50 percent within five years. Weyerhaeuser's motor management flowchart is reproduced in Figure 26.

Motor and motor-driven system related questions may be addressed to the Motor Challenge Information Clearinghouse. The Clearinghouse features a toll free national hotline (800) 862-2086, an Information Resource center, electronic Bulletin Board Service (BBS), in-house technical assistance, publication lists, and a national technical information network. You may also access the Motor Challenge Website on the Internet at www.motor.doe.gov.

Figure 26
Motor Management Flowchart



* Consider purchasing energy-efficient motors if estimated costs of rebuild are 65 percent of the cost of a new motor.

For motors under 7.5 hp, consider purchasing a new motor in any failure.

Chapter 10
Energy Efficient Motors: Thirty Questions and Answers

To help you assess the viability of energy efficient motors for your operation, here are answers to typical technical and financial questions. Many of these questions are adapted from information provided by R. L. Nailen of the Wisconsin Electric Power Company and British Columbia Hydro's Power Smart Publication entitled *High-Efficiency Motors.*[8,58]

1. What is an energy efficient motor?

An "energy efficient" motor produces the same shaft output power (hp), but uses less input power (kW) than a standard-efficiency motor. Energy efficient motors must have nominal full-load efficiencies that meet or exceed the NEMA threshold standards given in Table 5.

Many motor manufacturers produce models significantly exceeding the NEMA standard. These may have the term "premium" or other superlatives in the model name, but there is no NEMA standard for any terminology other than "energy efficient".

2. How is an energy efficient motor different than a standard motor?

Energy efficient motors are manufactured using the same frame as a standard T-frame motor, but have:

- Higher quality and thinner steel laminations in the stator.
- More copper in the windings.
- Optimized air gap between the rotor and stator.
- Reduced fan losses.
- Closer machining tolerances.
- A greater length.

3. Are all new motors energy efficient motors?

No, you generally have to ask for them.

Starting in October 1997, however, the Energy Policy Act of 1992 requires most general purpose induction motors between 1 and 200 horsepower to meet more stringent minimum efficiency standards.

4. Where can I buy an energy efficient motor?

Energy efficient motors can be purchased directly from most motor distributors. If not available "off the shelf," they are usually obtainable from warehouse stock within 48 hours. They can often be specified in any equipment package you may be ordering.

5. Are energy efficient single-phase motors available?

NEMA has no standard for "energy efficient", single phase motors, but efficiency ranges widely among models. A few manufacturers are beginning to produce higher efficiency lines of single phase motors.

6. Do energy efficient motors require more maintenance?

No. Energy efficient motors have the same maintenance requirements as standard motors.

7. What hp, speed, and voltage ranges are available?

Energy efficient motors are available for most motor sizes 1 to 500 hp at speeds of 3600, 1800, 1200, and 900 RPM and three-phase voltages of 208, 230, 460, 575, and higher.

8. Can an energy efficient motor replace my present U or T-frame motor?

Yes. Since T-frame, energy efficient motors generally use the same frame casting as a standard motor, standard T-frame to energy efficient T-frame should be a straight replacement.

An adapter or transition base is required for a U-frame to T-frame replacement. In addition, some manufacturers now make energy efficient U-frame motors. Talk to motor dealers for specifics.

9. Should I rewind my standard-efficiency motor or purchase an energy efficient motor?

An energy-efficiency motor will result in lower energy costs when compared with a rewound standard-efficiency motor. Its cost effectiveness will depend on the hours operated, motor efficiencies, utility rates, and the difference in cost between the rewind and the energy efficient motor.

Current rewind shop practices are outlined in the EPRI/BPA report *Industrial Motor Repair in the United States: Current Practice and Opportunities for Improved Energy-Efficiency* and the companion document *Quality Electric Motor Repair: A Guidebook for Electric Utilities.*

10. Can a standard motor be rewound as an energy efficient motor?

It is sometimes possible for a standard motor to be rewound with slightly larger diameter wire. This rewind procedure can slightly increase the efficiency and (adversely) starting current of a standard motor above its initial level. However, the efficiency would still be lower than that of a new energy efficient motor because of its unique physical characteristics. Energy efficient motors can also be rewound to maintain their original efficiency.

11. What is the efficiency of an energy efficient motor at different load points?

The efficiency of any motor varies with such factors as size, speed and loading. As indicated in Figure 20, energy efficient motors offer performance improvements over standard-efficiency motors under full, partial, and unloaded conditions.

12. Do energy efficient motors maintain the same percentage edge over standard motors when the load range drops from full-load?

Yes. Most manufacturers are designing their energy efficient motors to provide peak efficiency at 75 percent to 100 percent load. As shown in Figures 14 and 15, efficiency stays fairly constant from full down to 50 percent load, but the power factor drops significantly.

13. Do energy efficient-motors require more starting current?

Sometimes. There are two terms (often misused) pertaining to starting current, "inrush" current and "locked rotor" current. The familiar "locked rotor" current begins after contact closure and tapers off over several seconds while the motor accelerates. Locked rotor current is limited by NEMA standards identically for both standard and energy efficient Design B motors, to roughly six times full load current. Design E motor standards are consistent with European standards and allow a higher locked rotor current in most horsepower ranges, roughly 10 times full load current.

The more insidious aspect of starting current is the momentary "inrush" current which persists for less than a hundredth of a second and can substantially exceed locked rotor current. Inrush current can spike as high as 13 times full load current in standard motors and as high as 20 times full load current in Design E and energy efficient Design B motors. Inrush current is too brief to trip thermal protection devices, but energy efficient motors powered through magnetic circuit protectors can sometimes experience nuisance starting trips.

14. What is the power factor of an energy efficient motor?

Power factors vary tremendously depending on motor loading and manufacturer. While some energy efficient motor models offer power factor improvements of two to five percent, others have lower power factors than their standard motor counter-parts.

Overall, replacement of a standard with an energy efficient motor isn't likely to have much influence on power factor. On the average, a power factor improvement of less than one percent is expected. In any event, power factor correction is easily achieved by adding external capacitors.

15. I have heard different types of efficiencies quoted. What are they?

The following motor efficiency definitions are used: Quoted, Nominal, Average, Expected, Calculated, Minimum, Guaranteed, and Apparent. The most commonly used are Nominal and Minimum, defined as:

- Nominal efficiency is the efficiency that goes on the nameplate. It is the lower bound of an efficiency band which brackets the statistical mean full load efficiency of a large number of motors of the same design. NEMA specifies these bands which are fairly narrow, e.g. spanning about 1% in the 85% efficiency range. The band becomes tighter at higher efficiency.
- Minimum efficiency. For every nominal efficiency band prescribed by NEMA, a minimum efficiency is also prescribed. Individual motor efficiency is allowed to vary from nominal, but no motors are supposed to fall below the minimum. Minimum efficiency is set equal to the nominal value of two bands lower. It represednts losses about 20% greater than nominal losses (See Table 11).

16. What are IEEE 112, IEC 34.2, and JEC 37?

These are motor efficiency test or product standards:

- The IEEE Standard 112 Method B motor efficiency testing methodology is the most commonly used North American standard.
- CSA C-390-M1993, is a Canadian-developed standard.
- IEC 34-2 is the European motor test standard.
- JEC 37 is the Japanese motor test standard.

17. Can I compare motor efficiencies using nameplate data?

Per NEMA MG1-12.54.2, the efficiency of Design A and Design B motors in the 1-500 hp range for frames in accordance with MG13 shall be marked on the motor nameplate. As nameplate full-load efficiencies are rounded values, you should always obtain nominal full and part-load efficiency values from the motor manufacturer or *MotorMaster*.

18. Is the service factor any different from that of a standard motor?

No. Service factors for both standard and energy efficient motor range from 1 to 1.25, with about 88 percent of motors at 1.15.

19. How much do energy efficient motors cost?

Generally, they average 15 to 30 percent more than standard motors, but depending on the specific motor manufacturer and market competition, they can be even less expensive. It is often possible to negotiate a lower price premium when purchasing a large quantity of energy efficient motors. The price premium per horsepower is lower for the larger motor ratings.

20. What is the payback period for selecting an energy efficient versus a standard-efficiency motor?

The payback period varies according to the purchase scenario under consideration, cost difference, hours of operation, electrical rates, motor loading, and difference in motor efficiencies. For new purchase decisions, the simple payback on the incremental cost of a continuously operated energy efficient motor can be recovered through energy savings in well under two years.

21. Do terms such as "premium," "high," "super," "ultra," "plus," or "extra" describe specific motor efficiency characteristics?

Manufacturers are free to select descriptive terminology for use in identifying and marketing motor lines. The term **energy efficient**, however, is restricted to motors meeting the NEMA MG1 Table 12-10 full-load efficiency standards.

22. Are oversized motors less efficient than motors which are matched to their load?

Surveys indicated that most motors are underloaded by one-fourth to one-third. The efficiency of typical motor designs, however, typically peaks at three quarters load and remains relatively uniform down to the 50 percent load point. A motor replacement analysis should be conducted for motors operating below 40 percent of their full-rated load.

Oversized motors will require greater starting currents and operate with a lower power factor than motors which are closely matched to load.

23. Don't energy efficient motors always cost less to operate?

Energy efficient motors have a lower rotor and stator resistance and thus a higher inrush current and full-load speed than standard-efficiency motors. Speed changes significantly affect the power draw by centrifugal loads. The shaft power requirement for centrifugal fan or pump loads varies as the cube of the speed while the flow of air or fluid discharge varies linearly with speed.

An increase in driven-equipment load can result in a greater power or kilowatt draw despite the lower inherent losses of the energy efficient motors.

The cost penalty due to operating at a higher full-load speed is related to load characteristics. For instance, a motor driving a pump which fills a reservoir tank may operate in an on/off mode. While the kilowatt draw may be higher, the operating time is reduced due to the provision of increased flow. In contrast, given a continuously operating system, the extra pumping capacity may be wasted in throttling and friction losses. The entire system or process should be examined prior to replacing a standard with an energy efficient motor. Also, not all energy efficient motors have higher speeds than their standard counterparts.

24. Don't energy efficient motors operate "cooler"?

External temperature readings are often interpreted as a measure of heat rejection.

If two motors are identical, the one with the lower losses will indeed operate at a lower temperature due to decreased internal heat production. Lower losses, however, result in diminished need for ventilation air, and fan cooled energy efficient motors are often equipped with a smaller fan to reduce windage losses. The consequence of fan design modifications is that an energy efficient motor may have a running temperature as high or higher than that of a standard-efficiency motor with significantly higher losses.

25. Do energy efficient motors suffer a loss in efficiency when they are repaired?

Not necessarily. Efficiency losses can occur in either standard or energy efficient motors when poor quality control is observed. The core can be damaged by excess heat during winding removal. Any deviation from original wire gage and winding pattern generally increases losses. Machine work that alters original clearance and tolerance, and substitution of non-equivalent parts such as sealed bearings for shielded bearings can also reduce efficiency. Standard and energy efficient motors have comparable susceptibility to these offenses.

26. Don't energy efficient motors have to be oversized because they don't develop enough starting torque?

The same minimum allowable locked rotor (starting) torque is specified by NEMA for all Design A and B motors regardless of efficiency. NEMA standards for Design E motor locked rotor torque are higher than Designs A and B levels for some horsepower and speed combinations and lower for others. While some energy efficient motors may exhibit a slightly lower locked rotor torque than their standard-efficiency counterparts, no problems should be posed except for special applications such as heavily loaded conveyors. NEMA Design C motors should probably be specified for such applications anyway. Full-load, breakdown and locked rotor torque values are available for most energy efficient and standard motor models within the *MotorMaster* Electric Motor Selection software.

27. Isn't the efficiency gain insignificant between large standard and energy efficient motors?

While the percentage efficiency improvement obtainable decreases as motor size increases, the energy and dollar savings per hour of motor operation increases substantially. A one point efficiency improvement for a 100 horsepower motor will save more energy than a nine point efficiency gain for a ten horsepower motor.

The price premium per kW saved is comparable across a broad range of hp. Small improvements are worth pursuing.

28. Don't energy efficient motors have a longer expected service life due to their being equipped with better and oversized bearings?

Most motor bearings are not oversized. Improved bearings are available for both standard and energy efficient motors. Motor life is not significantly correlated to efficiency. Conversely, it is highly dependent upon proper application, maintenance, and environmental conditions.

29. Aren't energy efficient motors unsuitable for adjustable speed drive applications?

"Severe-duty" application conditions are not effected by motor efficiency. Energy efficient motors may, in fact, be more suited for variable speed drive use than their standard-efficiency counterparts. Many manufacturers now produce energy efficient ASD, inverter drive or inverter duty motors. These motors are provided with a totally enclosed non-ventilated enclosure or are equipped with a fixed-speed fan or blower system.

30. Isn't a quality rewind of an old motor just as good as purchasing a new energy efficient motor?

No. It is sometimes possible to slightly improve efficiency of an old motor by using larger diameter wire or replacing aluminum wire with copper, but this is rare. A quality rewind can usually equal, but not exceed original efficiency.

Chapter 11
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Appendix A

Efficiencies for 900 RPM Standard Motors

Motor Size	ODP			TEFC		
Load Level	100%	75%	50%	100%	75%	50%
10	87.2%	87.6%	86.3%	86.8%	87.6%	86.8%
15	87.8%	88.8%	88.2%	87.5%	88.7%	88.1%
20	88.2%	89.2%	88.0%	89.2%	89.9%	89.2%
25	88.6%	89.2%	88.0%	89.7%	90.3%	89.1%
30	89.9%	90.7%	90.2%	89.6%	90.5%	86.5%
40	91.0%	91.8%	91.7%	90.5%	91.4%	85.5%
50	90.8%	91.9%	91.1%	90.2%	91.0%	90.2%
75	91.7%	92.4%	92.1%	91.6%	91.8%	91.0%
100	92.2%	92.2%	91.8%	92.4%	92.5%	92.0%
125	92.9%	92.3%	91.7%	93.0%	93.1%	92.1%
150	93.3%	93.1%	92.6%	93.0%	93.4%	92.5%
200	92.8%	93.5%	93.1%	93.7%	91.1%	93.4%
250	93.1%	93.5%	93.0%	91.7%	94.8%	94.5%
300	93.1%	93.7%	92.9%	94.4%	94.2%	93.7%

Efficiencies for 1,200 RPM Standard Motors

Motor Size	ODP			TEFC		
Load Level	100%	75%	50%	100%	75%	50%
10	87.3%	86.9%	85.7%	87.1%	87.7%	86.4%
15	87.4%	87.5%	86.8%	88.2%	88.1%	87.3%
20	88.5%	89.2%	88.8%	89.1%	89.7%	89.4%
25	89.4%	89.7%	89.3%	89.8%	90.5%	89.8%
30	89.2%	90.1%	89.8%	90.1%	91.3%	90.7%
40	90.1%	90.4%	90.0%	90.3%	90.1%	89.3%
50	90.7%	91.2%	90.9%	91.6%	92.0%	91.5%
75	92.0%	92.5%	92.3%	91.9%	91.6%	91.0%
100	92.3%	92.7%	92.2%	92.8%	92.7%	91.9%
125	92.6%	92.9%	92.8%	93.0%	93.0%	92.6%
150	93.1%	93.3%	92.9%	93.3%	93.8%	93.4%
200	94.1%	94.6%	93.5%	94.0%	94.3%	93.6%
250	93.5%	94.4%	94.0%	94.6%	94.5%	94.0%
300	93.8%	94.4%	94.3%	94.7%	94.8%	94.0%

Efficiencies for 1,800 RPM Standard Motors

Motor Size	ODP			TEFC		
Load Level	100%	75%	50%	100%	75%	50%
10	86.3%	86.8%	85.9%	87.0%	88.4%	87.7%
15	88.0%	89.0%	88.5%	88.2%	89.3%	88.4%
20	88.6%	89.2%	88.9%	89.6%	90.8%	90.0%
25	89.5%	90.6%	90.0%	90.0%	90.9%	90.3%
30	89.7%	91.0%	90.9%	90.6%	91.6%	91.0%
40	90.1%	90.0%	89.0%	90.7%	90.5%	89.2%
50	90.4%	90.8%	90.3%	91.6%	91.8%	91.1%
75	91.7%	92.4%	92.0%	92.2%	92.5%	91.3%
100	92.2%	92.8%	92.3%	92.3%	92.1%	91.4%
125	92.8%	93.2%	92.7%	92.6%	92.3%	91.3%
150	93.3%	93.3%	93.0%	93.3%	93.1%	92.2%
200	93.4%	93.8%	93.3%	94.2%	94.0%	93.1%
250	93.9%	94.4%	94.0%	93.8%	94.2%	93.5%
300	94.0%	94.5%	94.2%	94.5%	94.4%	93.3%

Efficiencies for 3,600 RPM Standard Motors

Motor Size	ODP			TEFC		
Load Level	100%	75%	50%	100%	75%	50%
10	86.3%	87.7%	86.4%	86.1%	87.2%	85.7%
15	87.9%	88.0%	87.3%	86.8%	87.8%	85.9%
20	89.1%	89.5%	88.7%	87.8%	89.6%	88.3%
25	89.0%	89.9%	89.1%	88.6%	89.6%	87.9%
30	89.2%	89.3%	88.3%	89.2%	90.0%	88.7%
40	90.0%	90.4%	89.9%	89.0%	88.4%	86.8%
50	90.1%	90.3%	88.7%	89.3%	89.2%	87.3%
75	90.7%	91.0%	90.1%	91.2%	90.5%	88.7%
100	91.9%	92.1%	91.5%	91.2%	90.4%	89.3%
125	91.6%	91.8%	91.1%	91.7%	90.8%	89.2%
150	92.0%	92.3%	92.0%	92.3%	91.7%	90.1%
200	93.0%	93.0%	92.1%	92.8%	92.2%	90.5%
250	92.7%	93.1%	92.4%	92.7%	92.5%	91.2%
300	93.9%	94.3%	93.8%	93.2%	92.8%	91.1%

Appendix B

Motor Nameplate and Field Test Data Form

Employee Name ____________________

Company ____________________

Date ____________________

Facility/Location ____________________

Process ____________________

Motor Type (AC, DC, etc.) ____________________

1. General Data

Application ____________________
Type of equipment that motor drives

Serving Electrical Utility ____________________

Energy Rate ____________________ **Cents/kWh**

Monthly Demand Charge $/kW ____________

Annual Operating Hours ____________________

2. Motor Nameplate Data

1. **Manufacturer** ____________________
2. **Motor ID Number** ____________________
3. **Model** ____________________
4. **Serial Number** ____________________
5. **NEMA Design Type** ____________________
6. **Size (hp)** ____________________
7. **Enclosure Type** ____________________
8. **Synchronous Speed (RPM)** ____________
9. **Full Load Speed (RPM)** ____________
10. **Voltage Rating** ____________________
11. **Frame Designation** ____________________
12. **Full Load Amperage** ____________________
13. **Power Factor (%)** ____________________
14. **Full Load Efficiency (%)** ____________
15. **Service Factor Rating** ____________
16. **Temperature Rise** ____________________
17. **Insulation Class** ____________________

3. Measured Data

Supply Voltage ____________________
By Voltmeter
Vab __________
Vbc __________ **Average** __________
Vca __________

Input Amps ____________________
By Ampmeter
a __________
b __________ **Average** __________
c __________

Power Factor ____________________

Operating Speed ____________________
By Tachometer

Motor Purchase Date ____________________

4. Calculated Values

Full Load (FL) Slip ____________________
[Synchronous RPM- FL RPM Rating]

Operating Slip ____________________
[Synchronous RPM - Operating Speed]

kVA Input ____________________
[Input Volts x Input Amps x 0.001732]

Power Factor ____________________
[(Average kW/kVA) x 100%]

Input kW ____________________
[input Volts x input Amps x Power Factor x 0.001732]

Annual Operating Cost (Energy) ____________
[Input kW x Annual Operating Hours x Energy Rate] **(For Constant Loads Only)**

Annual Demand Cost ____________________
[Monthly Demand Rate x number of months motor operates during peak demand period]

Total Annual Operating Cost ____________
[Annual Energy + Demand Costs]

Appendix C

MOTOR MANUFACTURER ADDRESS LIST

A. O. Smith
531 N. Fourth
Tippcity, OH 45731
(513) 667-6800
FAX: (513) 667-5873

Baldor
5711 South Seventh
Fort Smith, AR 72902
(501) 646-4711
FAX: (501) 648-5792

Brook Crompton, Inc.
3186 Kennicott Avenue
Arlington Heights, IL 60004
(708) 253-5577
FAX: (708) 253-9880

Dayton/Grainger
5959 W. Howard
Niles, IL 60714
(800) 323-0620
FAX: (800) 722-3291

General Electric (G.E.)
Technical Data Bureau
P.O. Box 2205
Fort Wayne, IN 46801
(219) 439-2000

Leeson
2100 Washington Avenue
Grafton, WI 53024
(414) 377-8810
FAX: 377-9025

Lincoln
22801 St. Clair Avenue
Cleveland, OH 44117
(216) 481-8810
FAX: (216) 481-5473

MagneTek/Century/Louis Allis
1881 Pine Street
St. Louis, MO 63103
(800) 325-7344
FAX: (800) 468-2045

Marathon
P.O. Box 8003
Wausau, WI 54402
(715) 675-3311
FAX: (715) 675-6361

Reliance
24701 Euclid Avenue
Cleveland, OH 44117
(800) 245-4501
(216) 266-7000
FAX: (216) 266-7536

Siemens
4620 Forest Avenue
Norwood, OH 45212
(513) 841-3100
FAX: (513) 841-3103

Sterling
16752 Armstrong Avenue
Irvine, CA 92714
(800) 654-6220
FAX: (714) 474-0543

Tatung Electric
14381 Chambers Road
Tustin, CA 92680
(800) 838-3293
FAX: (714)838-3295

Teco American
6877 Wynnwood
Houston, TX 77008
(713) 864-5980
FAX: (713) 864-9502

Toshiba
13131 W. Little York Road
P.O. Box 40906
Houston, TX 77240
(713) 466-0277
FAX: (713) 466-8773

US Motors/Emerson/
Leroy Somer
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Electric Motors
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(800) 343-9996
FAX: (410) 576-9040

Westinghouse Motors
IH-35 Westinghouse Road
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Round Rock, TX 78680-0277
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