


EFFICIENT MOTORS: SELECTION AND APPLICATION CONSIDERATIONS



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In the fiercely competitive global marketplace, keeping process costs down can mean the difference between success and failure for many products. Efficient motors help businesses streamline costs and reduce downtime in the production process.

Utilities are promoting premium-efficiency motors as a customer service to help U.S. industries improve their competitiveness and to enhance environmental quality. Lower operating and maintenance costs—coupled with typical payback periods of 6 months to 3 years—make these motors a sound business investment.

But are these motors right for *your* business? Since most industries spend a significant percent of their electricity bill in powering motor loads, you might want to read on.

ABOUT CEE

The Consortium for Energy Efficiency (CEE) is a national non-profit organization comprised of utilities, energy and environmental groups and state energy offices. CEE's mission is to encourage the market for super-efficient products and practices that save energy, enhance environmental quality and satisfy customers.

CEE has worked cooperatively with motor manufacturers, trade associations and motor experts to develop (and gain broad acceptance of) a set of motor efficiency levels that are significantly higher than those specified in the Energy Policy Act (EPACT), effective as of October 1997. Motors with these higher efficiency levels are referred to as "CEE Premium EfficiencySM" motors. They are currently available from major manufacturers. Several U.S. utilities will offer technical information, rebates and/or financing for motors meeting the CEE Premium EfficiencySM levels.



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HOW DO YOU DEFINE AN EFFICIENT MOTOR?

The "efficient" motor category covers two separate motor classes: energy efficient and premium efficiency.

Energy-Efficient Motors

In 1994 the National Electrical Manufacturers Association (NEMA) issued definitions for "energy efficient motors," which are from 2 to 6 percentage points higher in efficiency than conventional motors. These definitions cover all standard combinations of horsepower (1 to 500 HP), enclosure, and synchronous speed (900 to 3,600 RPM). The efficiency values for T-frame, single-speed, foot-mounted, continuous-rated, polyphase, squirrel-cage induction motors conforming to NEMA designs A and B can be found in NEMA's "Table 12-10."¹ A motor's nominal efficiency must meet or exceed the efficiency levels given in Table 12-10 to be classified as "energy efficient." Effective October 24, 1997, the Energy Policy Act (EPACT) requires most 1 to 200 HP general purpose motors manufactured or imported for sale in the United States to meet minimum efficiency standards equivalent to those described in NEMA's Table 12-10.

CEE Premium-Efficiency Motors

Wherever possible, companies should try to purchase the most efficient motors available because of their greater bottom-line value. The Consortium for Energy Efficiency (CEE) has worked with motor manufacturers and experts to develop a new set of guidelines that are even higher than NEMA levels for energy-efficient motors. Motors that meet these guidelines (referred to as "CEE Premium EfficiencySM" motors) have 0.8% to 4% higher efficiency than the energy-efficient motors required under EPACT.

¹ National Electrical Manufacturers Association,
1300 North 17th Street, Suite 1847, Rosilyn VA 22209

BENEFITS OF EFFICIENT MOTORS

You've turned the page on high energy costs. Read on to learn how efficient motors can work for you.

This booklet provides a brief guide to understanding and selecting efficient motors. Improved design, material, and manufacturing techniques enable energy-efficient motors to *accomplish more work per unit of electricity* than their standard counterparts. *Premium-efficiency motors are even more effective in reducing operating costs.*

Many energy-efficient and premium-efficiency motors have other benefits, such as:

- Many efficient motors run cooler and are more likely to withstand voltage variations and harmonics better than less efficient motors.
- Many efficient motors have a slightly higher power factor on average than their standard counterparts.
- Most efficient motors operate more quietly than standard motors.

In addition, manufacturers often provide extended warranties on energy-efficient and premium-efficiency motors.

DESIGN DIFFERENCES BETWEEN STANDARD AND EFFICIENT MOTORS

Efficient motors usually feature some of the following design improvements (individual features depend on the manufacturer and model):

- 20% to 60% more copper in the windings
- More and thinner laminations of higher quality steel—35% more electrical steel
- Optimized air gap between stator and rotor
- More efficient rotor bar designs
- Improved overall design to reduce windage, friction and stray load losses
- Reduced fan losses
- Better quality control during manufacturing
- Longer core to reduce I^2R (resistance) losses

ECONOMICS OF A PREMIUM EFFICIENCY MOTOR PURCHASE VS. MOTOR REWIND FOR A 20 HP, 1800 RPM, TEFC MOTOR

SCENARIO	EFFICIENCY IMPROVEMENT	PRICE PREMIUM	ELECTRIC RATE	ANNUAL SAVINGS	SIMPLE PAYBACK
Purchase of CEE Premium Efficiency SM versus Purchase of EPAct motor	1.3%	28.3% (or \$199)	\$0.04	\$59	3.4 years
			\$0.06	\$85	2.4 years
			\$0.08	\$110	1.8 years
Purchase CEE Premium Efficiency SM versus Rewind of Standard Motor	5.9%	50.5% (or \$303)	\$0.04	\$256	1.2 years
			\$0.06	\$368	0.8 years
			\$0.08	\$480	0.6 years

Values based on 8,000 operating hours/year at 75% load factor. Motor price and efficiency are average values based on 1999 MotorMaster+ 3.0® data.

WHO GETS THE MOST FROM A CEE PREMIUM EFFICIENT MOTOR?

A CEE premium efficiency motor can cost 15% to 30% more than an EPart efficient motor.

However, in almost every situation, premium efficiency motors pay off—it's just a question of how fast.

The average standard motor easily consumes 50 to 60 times its initial purchase price in electricity during a typical ten-year operating period. Thus, spending \$600 to repair a 20 HP, standard efficiency motor that operates 8,000 hours per year obligates you to purchase over \$80,000 worth of energy to operate it!¹ The \$303 price premium spent on replacing a standard motor with a premium efficiency motor is negligible compared to saving \$2,570 over the life of the motor. The chart opposite highlights how premium efficiency models are even more impressive at higher utility rates—and the payback information doesn't even include the avoided costs from downtime and production losses, or other costs associated with older, less efficient motors.

When Is a CEE Premium Efficiency Motor Cost Effective?

While the specific economics and application of every motor purchase should be evaluated, there are a few rules of thumb that can be used as an initial screening. To determine if you are a good candidate to reap the benefits of efficient motors, consider the following factors:

¹ Based on: 75% load factor, a 10% discount rate, an electricity rate of \$0.04/kWh, and a 35% motor list price discount (using 1999 MotorMaster+ 3.0® data).

CALCULATING THE ANNUAL ENERGY SAVINGS AND SIMPLE PAYBACK FROM REPLACING AN EXISTING STANDARD MOTOR WITH A PREMIUM EFFICIENCY MOTOR VERSUS REPAIRING A STANDARD EFFICIENCY MOTOR

Energy Cost Savings (\$/year) =

$$\text{HP} \times \text{LF} \times 0.746 \text{ kW/HP} \times \text{hrs} \times [100/E_{\text{sta}} - 100/E_{\text{PE}}] \times \$/\text{kWh} + \text{Demand Savings}$$

Simple Payback (years) =

$$\frac{\text{Price premium}}{\text{Annual dollar savings}}$$

EXAMPLE: Simple Payback Analysis for an average 20 HP, 1800 RPM, TEFC Motor Repair or Replacement:

	AVERAGE EFFICIENCY (at a 75% Load Factor)	AVERAGE COST
Rewind of Standard Efficiency Motor	88.3%	\$600
Premium Efficiency Motor	93.5%	\$903
Operating Hours	8,000	
Load Factor (LF)	75%	
Utility Rate	\$0.04/kWh	

Energy Cost Savings =

$$20 \text{ HP} \times 0.75 \times 0.746 \times 8,000 \text{ hrs} \times [100/88.3 - 100/93.5] \times \$0.04/\text{kWh} + \$32 = \mathbf{\$257/\text{year}}$$

Simple Payback =

$$\frac{(\$903 - \$600)}{\$257/\text{year}} = \mathbf{1.2 \text{ years}}$$

At a Utility Rate of **\$0.06/kwh :**

Energy Cost Savings = \$368/year, and

Simple Payback = 0.8 years

At a Utility Rate of **\$0.08/kwh :**

Energy Cost Savings = \$480/year, and

Simple Payback = 0.6 years

New Motor Purchase. Premium efficiency motors are typically cost effective in industrial applications when they operate more than 4,000 hours a year, given a 2-year simple payback criterion (and taking into account such factors as operating hours, efficiency improvement, and utility rates). Premium motors that operate 2,000 hours or less per year are unlikely to yield quick or substantial paybacks. An analysis like the one shown opposite will help you determine your payback.

Failed 1 to 200 HP Motors. If the failed motor is already energy efficient, it may be more cost effective to repair it than to upgrade to a more efficient model. With today's premium efficiency motors offering substantial advances in efficiency, however, it is worth analyzing the economics of both scenarios. In general, if the costs to repair a standard motor exceed 60% of the price of a new efficient motor, it is more beneficial to upgrade.¹ Furthermore, if the failed motor enclosure type is ODP, the benefits and payback suggest it would be more profitable to invest in a new efficient motor.

Working Motor Replacement. Oversized motors, particularly those oversized by 50% or more, can be cost effectively replaced with smaller efficient motors. Replacing oversized standard motors with efficient models can offer a fast payback. To calculate the annual energy savings and simple payback from selecting a more efficient motor use the formula presented opposite. Note that some costs are not included here: For example, when replacing a pre-1964 motor with a NEMA or U-frame size, be sure to include the cost of adapting the mounting for a T-frame motor in the analysis.

¹ Based on common percentages used in industry and calculations assuming a motor life of 40,000 hours from *HorsePower, Implementing a Basic Policy for Industrial Motor Repair/Replacement*, Industrial Electrotechnology Laboratory.

COMPUTER SOFTWARE HELPS IDENTIFY EFFICIENT MOTORS FOR DETAILED SPECIFICATIONS

The key to optimizing motor performance and reducing operating costs is to develop a specification for a particular motor application and to select the motor based on that specification. Your electric utility may be able to provide you with assistance. In addition, the Department of Energy's MotorMaster+ 3.0 software program can help you select the best motor for your application and calculate the dollar savings and simple payback associated with a more efficient motor, taking into account motor size, price, efficiency, annual hours of use, load factor, electricity costs, and utility rebates.

MotorMaster+ 3.0 contains price and performance data on over 10,000 1 to 500 HP motors sold in the United States. It can be used to analyze a new motor purchase, whether to replace or rewind a failed motor, or replace a working motor. Motor prices vary widely from model to model. One manufacturer's efficient motor might cost no more than another's standard efficiency motor. This software will allow you to identify the most cost effective motor for your application. It also includes a motor inventory feature which allows you to easily track the maintenance repairs and operating hours of your motors. For a copy of the MotorMaster+ 3.0 software, contact the Motor Challenge Information Clearinghouse at (800) 862-2086 or visit:
<http://www.motor.doe.gov/mcsnew.shtml>.

SELECTING AND SPECIFYING AN EFFICIENT MOTOR¹

When comparing motor efficiencies, use a consistent measure. Nominal efficiency (which is stamped on the motor nameplate) is best.

Nominal efficiency is an average value obtained through standardized testing of a given motor model population. Compare motors using nominal efficiency at the expected load factor.

Motors at all efficiency levels range widely in speed, starting current and starting torque. You can find an efficient motor that meets most combinations of these parameters. Select a motor that meets the performance requirements of the motor system. A good motor specification should define performance requirements and describe the environment in which the motor operates. To optimize efficiency, a motor should be sized to operate with a load factor between 60% and 75%. The common, but unwise, practice of oversizing motors by 50% or more results in less efficient operation and a lower power factor. Performance requirements should include:

- Motor horsepower and service factors
- Temperature rise and insulation class
- Starting torque
- Maximum starting current (inrush current)
- Full load operating motor speed
- Minimum stall time
- Load inertia and expected number of starts
- Use of Adjustable Speed Drive (as applicable)
- Ambient conditions such as altitude, temperature, humidity, and dust levels.

¹ More information on selection considerations can be found in the *Energy Efficient Motor Selection Handbook*, Bonneville Power Administration, United States Department of Energy, 1995, Report Number DE-B179-93-BP08158.

REALIZING MAXIMUM ENERGY SAVINGS

Several operational procedures will ensure you get the predicted energy savings from efficient motors.

(1) Size the selected motor properly. The common practice of oversizing results in less efficient motor operation. Some situations may require oversizing for peak loads, but otherwise select a motor that will operate with a load factor between 60% and 75%.

(2) Make sure the motor is matched to the needs of the driven equipment. For example, on centrifugal loads (fans or pumps), the existing motor should be replaced with an efficient motor of like speed.

(3) Correct adverse operating conditions.

Even with a properly specified motor, several parameters can reduce energy savings. The following conditions apply to any motor:

- **Voltage Variations.** Above 10% over voltage, both efficiency and power factor decrease. This situation reduces motor life by overheating the insulation system. Low voltage can also shorten motor life and prevent the motor from developing an adequate starting torque. Operating on too low a voltage reduces the motor's effective horsepower. For example, a fully loaded 5 HP motor operated at 10% below rated voltage becomes a 4 HP motor. Efficiency will be degraded by up to 3% and power factor by about 10%. The motor will try to drive the load it was intended to drive, become overloaded, draw more current, and overheat.

- *Phase Voltage Unbalance.* A voltage unbalance occurs when there are unequal voltages on the lines to a polyphase induction motor. This unbalance causes line currents to be out of balance, which results in a dramatic increase in motor losses and heat generation. Both decrease the efficiency of the motor and shorten its life. For example, a voltage unbalance of 3.5% can increase motor losses by approximately 20%. Since the percentage temperature rise is equal to $2 \times (\% \text{ voltage unbalance})^2$, a motor operating with a 3.5% voltage unbalance will experience an additional temperature rise of approximately 25% above its rated temperature rise. Generally speaking, each 10°C rise above rated temperature cuts a motor's life in half. It will also require a derating of the motor horsepower, which will void most manufacturers' warranties. There is no distinction between standard and efficient motors in these cases.
- *Motor alignment.* Correct shaft alignment and mechanical placement are critical to the successful operation of any motor. Vibration readings after installation of a new motor will verify that the alignment is correct.
- *Ambient conditions.* Keep motors cool and clean. Ambient conditions, such as high temperature, excessive dust or moisture can all adversely affect both motor performance and motor life. Moisture, for example, can deteriorate a motor's insulation, thus reducing motor life.

COMMONLY ASKED QUESTIONS

Aren't efficient motors harder to repair, thus losing more efficiency during repair? And doesn't this mean you can't maintain the high efficiency over time?

According to a recent national study of motor repair practices,¹ efficient motors are no more difficult to repair than standard efficiency motors. Recent laboratory tests² suggest that their efficiency is actually degraded less than that of standard motors in blind repairs at shops.

It is essential—with both standard and efficient motors—to provide your motor repair shop with specifications indicating the procedures, materials, and verification tests required for your motor repairs. EASA's brochure on quality motor repair contains a section on efficient motors.³ Model repair specifications, which include forms that can be given to your motor repair shop, are also available.⁴

Is it true that efficient motors have a lower starting torque and may not be able to accelerate the load?

No. Starting torque (also referred to as locked rotor torque), is the minimum torque produced by the motor at rated voltage and frequency, at all angular positions of the rotor. On average, starting torque does not vary significantly for standard and efficient motors of the same size. NEMA requirements hold both standard and efficient Design A and B motors to the same standards for starting torque. In selecting a motor, it is important to specify needed starting torque since it varies widely across motor sizes and models.

¹ Electric Power Research Institute, Bonneville Power Administration, U.S. Department of Energy, Report Number DOE/BP-2749: *Industrial Motor Repair in the United States*.

² Zeller, Markus, *Rewound High-Efficiency Motor Performance*, Vancouver, British Columbia, Canada: BC Hydro in association with Powertec Labs Inc., 28, August, 1992.

³ Electric Apparatus Service Association, 1331 Baur Boulevard, St. Louis, MO 63132.

⁴ Bonneville Power Administration, Electric Power Research Institute, and United States Department of Energy, "Electric Motor Model Repair Specifications, 1994.

If efficient motors have a higher inrush current than standard efficiency motors, do they cause breakers to trip?

Inrush current is a spike, extremely short in duration, that occurs during startup. Because efficient motors have a lower winding resistance than standard motors, their inrush current can spike as high as 13 times the full load current in standard efficiency motors. However, rated inrush current varies widely at each efficiency level. For example, starting current for 100 HP efficient motors varies from 400 to 800 amperes, and from 500 to 775 amperes for standard motors. The average for efficient models is 685 amperes, while the average for standard efficiency models in this size range is slightly higher: 696 amperes.

The inrush current duration is too short to trip hybrid or thermal breakers. Efficient motors equipped with magnetic circuit protectors that do not have a time delay can sometimes experience nuisance starting trips. If you have magnetic breakers, you have three options: select an efficient motor that meets your maximum allowable inrush current specifications, adjust the breaker setpoints, or replace the breakers. The National Electric Code has increased the allowable breaker setpoint for magnetic breakers to insure proper functioning with efficient motors. If you can adjust the breaker setpoints, reset them to the values indicated in the new electric code.

Since efficient motors operate faster, can this higher speed (or decreased slip) negate any energy savings due to efficiency increases?

All induction motors have an operating speed that is slightly lower than their rated synchronous speed. For example, a motor with a synchronous speed of 1800 RPM will typically operate under full load at about 1750 RPM. Efficient motors tend to operate at reduced “slip” or slightly higher full-load speed (5 to 10 RPM on average for 1800 RPM motors) than their standard-efficiency counterparts. *Centrifugal loads such as fans or pumps are very sensitive to this rotational speed - higher rotational speeds mean more product (air, liquid material) flow and increased energy consumption.* This is because the horsepower loading imposed on a motor by a centrifugal load varies as the third power

or cube of its rotational speed. An increase of just 5 RPM can significantly affect the pump or fan operation, leading to increased flow, reduced efficiency, and increased energy consumption. A 20 RPM increase (from 1740 to 1760 for example) can result in a 3.5% increase in the motor load. A 40 RPM speed increase in motor can result in a 7% increase in energy consumption - completely offsetting the energy and dollar savings typically expected from the purchase of an efficient motor.¹

There is a solution however. While, on average, efficient motors operate at higher speeds than their standard efficiency motor counterparts, there is a large overlapping range of speeds available in both efficient and standard efficiency motor models. *For centrifugal loads, a standard efficiency motor should be replaced with an efficient unit of like speed in order to capture the full energy conservation benefit.* If the motor is indirectly coupled, the higher speed can also be reduced in the field by changing pulley sheaves, trimming impellers, adjusting the pitch of fan blades or re-calibrating transmissions with some resulting loss of system efficiency.

Are efficient motors unsuitable for adjustable speed applications?

Not necessarily. Negative side effects may occur when applying ASDs to motors, whether standard or efficient, such as greater vibration, heat rise, and an increase in audible noise. The high pulsing frequency that occurs with ASDs can cause a high rate of voltage rise, which in turn can cause insulation breakdown of the end turns of motor windings. In some cases, specially designed motors may be warranted. Special inverter duty motors are available, for example, that are designed to meet or exceed the voltage amplitudes and rise times that may occur with ASDs. See your motor dealer or contact your utility or the Motor Challenge Clearinghouse for more information on this subject.

¹ *Energy Efficient Motor Selection Handbook*, Bonneville Power Administration, United States Department of Energy, 1995, Report Number DE-B179-93-BP08158.

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WHERE TO FIND MORE INFORMATION

Your local utility may be able to provide resources and information on efficient motors. You can also contact the United States Department of Energy Motor Challenge Clearinghouse by calling (800) 862-2086 or electronically at www.motor.doe.gov. This clearinghouse is a one-stop resource for objective, reliable, and timely information on electric motor-driven systems. The Department of Energy's Office of Industrial Technologies developed the Motor Challenge Program to supply U.S. industries with free information that helps them to create productive and efficient motor-driven systems.