# OPTIMIZING YOUR MOTOR-DRIVEN SYSTEM

*Electric motor-driven systems are estimated to consume over half of all electricity in the United States and over 70% of all electricity in many industrial plants. This fact sheet presents an overview of electric drive systems and highlights common ways you can improve system efficiency and reliability. By optimizing the efficiency of your motor-driven systems, you can increase productivity while saving significant amounts of energy and money.*

## Introduction

A motor-driven system consists of several components: the electrical power supply, motor controls, the electric motor, and a mechanical transmission system. For example, the heating, ventilating, and air conditioning (HVAC) systems in many buildings use single or three-phase electrical power controlled by timers and thermostats to drive motors. These motors supply mechanical energy through shafts or belts to compressors and fans. Each component of this system can be optimized for reliability and efficiency.

This fact sheet is designed to help the management staff at your facility identify opportunities to improve drive system efficiency. It is divided into three categories: power quality, motor and transmission efficiency, and monitoring and maintenance. The categories provide a series of steps for checking each of your motors. Some of these steps require the one-time involvement of an electrical engineer or technician. Others are implemented when motors fail or major capital changes are made in the facility. Yet others involve development of motor monitoring, energy management, and predictive and preventive maintenance programs. For more information, contact the Motor Challenge Information Clearinghouse at (800) 862-2086 or consult the publications listed in the bibliography at the end of this fact sheet.

## Power Quality

It is important to design and install electrical systems that meet safety codes, minimize downtime, and reduce electrical losses. A qualified electrical engineer should oversee any major electrical system modifications since poor power distribution within a facility is a common cause of energy losses.

**Note:** Existing facilities should be checked periodically for electrical problems. Since electrical codes are designed primarily for safety, optimizing efficiency often means surpassing code requirements.

### 1. Maintain Voltage Levels

Voltage at the motor should be kept as close to the nameplate value as possible, with a maximum deviation of 5%. Although motors are designed to operate within 10% of nameplate voltage, large variations significantly reduce efficiency, power factor, and service life (see Figure 1). When operating at less than 95% of design voltage, motors typically lose 2 to 4 points of efficiency, and service temperatures increase up to 20°F, greatly reducing insulation life. Running a motor above its design voltage also reduces power factor and efficiency. Because voltage decreases with distance from the stepdown transformer, all voltage measurements should be taken at the motor terminal box.

## 2. Minimize Phase Unbalance

The voltage of each phase in a three-phase system should be of equal magnitude, symmetrical, and separated by 120°. Phase balance should be within 1% to avoid derating of the motor and voiding of manufacturers' warranties.

Several factors can affect voltage balance: single-phase loads on any one phase, different cable sizing, or faulty circuits. An unbalanced system increases distribution system losses and reduces motor efficiency.

Voltage unbalance is defined by the National Electrical Manufacturers Association (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. For example, if the measured line voltages are 462, 463, and 455 volts, the average is 460 volts. The voltage unbalance is:

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

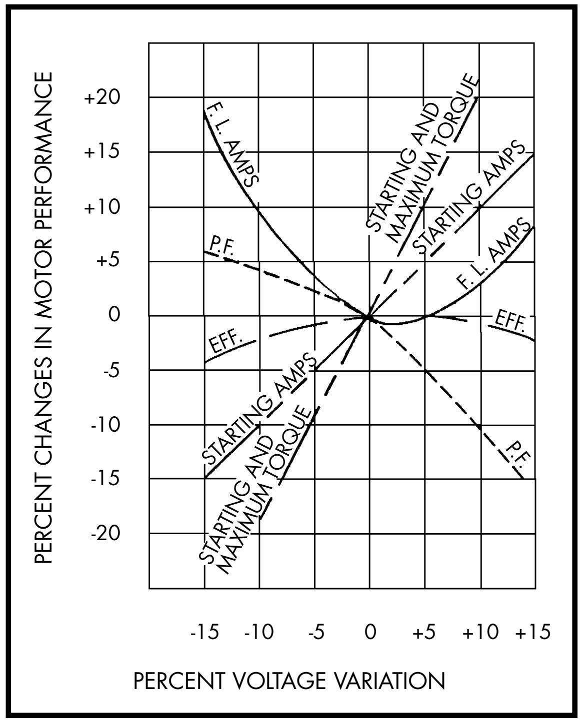


**Figure 1**
**Voltage Variation Effect on Motor Performance**

## 3. Maintain High Power Factor

Low power factor reduces the efficiency of the electrical distribution system both within and outside of your facility. Low power factor results when induction motors are operated at less than full load. Many utilities charge a penalty if power factor dips below 95%. Installing single capacitors or banks of capacitors either at the motor or the motor control centers addresses this problem.

## 4. Maintain Good Power Quality

Motors are designed to operate using power with a frequency of 60 hertz and a sinusoidal wave form. Using power with distorted wave forms will degrade motor efficiency.

## 5. Select Efficient Transformers

Install efficient and properly sized step-down transformers. Older, underloaded, or overloaded transformers are often inefficient.

## 6. Identify and Eliminate Distribution System Losses

Regularly check for bad connections, poor grounding, and shorts to ground. Such problems are common sources of energy losses, hazardous, and reduce system reliability. A number of specialized firms can search for such problems in your facility using electrical monitoring equipment and infrared cameras.

## 7. Minimize Distribution System Resistance

Power cables that supply motors running near full load for many hours should be oversized in new construction or during rewiring. This practice minimizes line losses and voltage drops.

## Motor Controls

To reduce electrical consumption, use controls to adjust motor speeds or turn off motors when appropriate. For example, equipment often can run at less than full speed or be turned off completely during part of a process cycle. When correctly used, motor controls save significant amounts of energy, reduce wear on the mechanical system, and improve performance.

### 8. Use Adjustable Speed Drives (ASDs) or Two-Speed Motors Where Appropriate

When loads vary, ASDs or two-speed motors can reduce electrical energy consumption in centrifugal pumping and fan applications—often by 50% or more. For more information, consult the *Adjustable Speed Drive Application Guidebook.*

### 9. Consider Load Shedding

Use controls to turn off idling motors. NEMA Publication MG 10, *Energy Management Guide for Selection and Use of Polyphase Motors,* includes comprehensive load shedding guidelines. The maximum number of on/off cycles per hour and the maximum amount of time off between cycles is affected by motor size, type of load (variable or fixed), and motor speed.

## Motor and Transmission Efficiency

When replacing a motor, purchase the most efficient model you can afford (see Figure 2). Motors with a wide range of efficiencies are available in most classes (horsepower, speed, and enclosure type). An energy-efficient motor will typically cost 10% to 20% more than a standard model. However, this higher cost is often repaid in less than 2 years through energy savings. Optimize motor efficiency by making certain the motor is properly sized. Oversizing and underloading can lead to low power factor and increased losses.

### 10. Choose a Replacement Before a Motor Fails

If you wait until a motor fails, your primary concern will be speedy replacement. Evaluate all motors in your facility. You may determine that it is cost effective to save energy and increase reliability by replacing some working motors with correctly sized, energy-efficient models.

Develop a replacement plan for all critical motors. Decide which motors should be replaced with an energy-efficient or smaller sized model upon failure. Then, contact motor distributors to determine whether the energy-efficient motor model you want will be available. If not, consider purchasing critical replacement motors now as backups.

### 11. Choose Energy-Efficient Motors

Select the most efficient motor possible within your price range. An energy-efficient motor that costs up to 20% more than a standard model is typically cost effective if used more than the number of annual hours listed in Table 1. Table 1 lists the minimum annual hours your motor should operate, depending on the cost of electricity (¢/kWh).

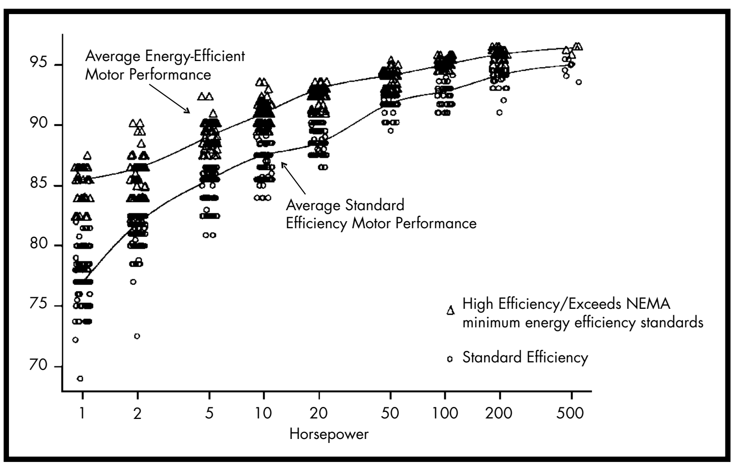


**Figure 2**
**Standard and Energy-Efficient Motor Performances**

**Table 1**
**Selection Criteria**

| Minimum | Average Price Per kWh | | | |
|---|---|---|---|---|
| | 2¢ | 4¢ | 6¢ | 8¢ |
| Payback Criteria | Annual Hours | | | |
| 2-Year | — | 5250 | 3500 | 2600 |
| 3-Year | 7000 | 3500 | 2300 | 1750 |
| 4-Year | 5250 | 2600 | 1750 | 1300 |

For example, if electricity costs 4¢/kWh and you are replacing a motor that runs as few as 3500 annual hours, an energy-efficient model would be cost effective with a 3-year payback.

Energy-efficient motors offer other benefits. They are usually higher quality, more reliable, have longer warranties, run quieter, and produce less waste heat than their less efficient counterparts. Many utilities offer rebates for energy-efficient motors and other efficiency improvements.

For more information:

- Consult the *Energy Efficient Motor Selection Handbook.* This publication provides motor selection guidelines plus a comprehensive review of motor field load and efficiency estimation techniques.
- Obtain *An Energy Management Guide for Motor Driven Systems.* This publication addresses power factor correction, preventive and predictive maintenance, and troubleshooting and tuning your in-plant distribution system.
- Acquire and use the MotorMaster+ motor analysis software program, available through the Motor Challenge Information Clearinghouse.
- Contact your electrical utility conservation office.

## 12. Match Motor Operating Speeds

The energy consumption of centrifugal pumps and fans is extremely sensitive to operating speed. For example, increasing operating speed by 2% can increase the power required to drive the system by 8%. To maintain system efficiency, it is critical to match full-load speeds when replacing pump and fan motors.

Motor manufacturers stamp "full-load rpm" ratings on motor nameplates and often publish this data in catalogs (the MotorMaster+ database also provides full-load rpm). This operating speed rating varies by as much as 50 rpm. In general, try to select a replacement fan or pump motor with a full-load rpm rating equal to or less than that of the motor being replaced.

## 13. Size Motors for Efficiency

Size motors to run primarily in the 65% to 100% load range. Consider replacing motors running at less than 40% load with properly sized motors. You can address applications with occasional high peak loads by a variety of design strategies including ASDs for pumps and fans, reservoirs for fluids, and fly wheels for mechanical equipment.

## 14. Choose 200 Volt Motors for 208 Volt Electrical Systems

When choosing motors for a 208 volt electrical system, use a motor specifically designed for that voltage rather than a "Tri-Voltage" motor rated at 208-230/460. Tri-Voltage motors are a compromise design that run hotter and are less efficient and reliable than a 200 volt motor operating at 200 or 208 volts.

## 15. Minimize Rewind Losses

Rewinding can reduce motor efficiency and reliability. The repair-versus-replace decision is quite complicated and 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, availability of a utility rebate, and simple payback criteria.

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 almost always best to replace non-specialty motors under 15 hp.
- If the rewind cost exceeds 50% to 65% 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.* Also refer to *How to Determine When to Repair and When to Replace a Failed Electric Motor* and *Evaluating Motor Repair Shops,* sections of the Electric Power Research Institute and Bonneville Power Administration publication, *Quality Electric Motor Repair: A Guidebook for Electrical Utilities.*

## 16. Optimize Transmission Efficiency

Transmission equipment including shafts, belts, chains, and gears should be properly installed and maintained. When possible, use synchronous belts or chains in place of V-belts. Helical gears are more efficient than worm gears; use worm gears only with motors under 10 hp.

# Monitoring and Maintenance

Preventive maintenance maximizes motor reliability and efficiency. Develop a monitoring and maintenance program for all three-phase motors based on manufacturers' recommendations and standard industrial practices.

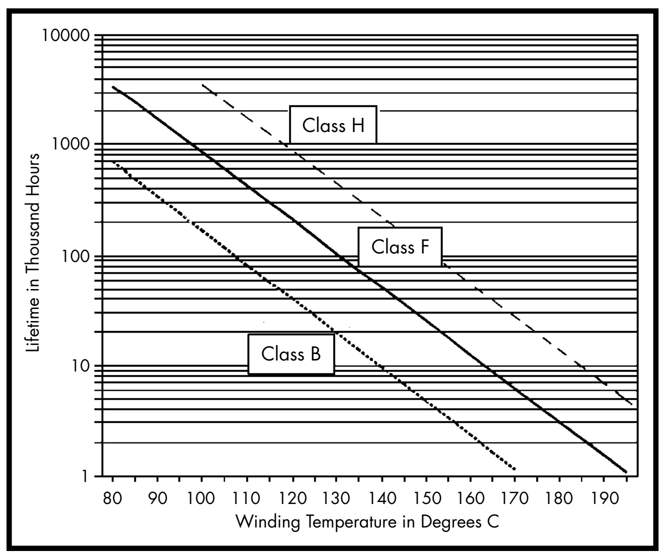


**Figure 3**
**Service Life versus Operating Temperature for Insulation Systems**

## 17. Perform Periodic Checks

Check motors often to identify potential problems. Inspections should include daily or weekly noise, vibration, and temperature checks. Approximately twice a year, test winding and winding-to-ground resistance to identify insulation problems. Periodically check bearing lubrication, shaft alignment, and belts. A variety of specialized instruments is available for monitoring purposes.

## 18. Control Temperatures

Keep motors cool because high temperatures reduce insulation life and motor reliability (see Figure 3). Make certain motors are shaded from the sun, located in well ventilated areas, and kept clean, since dirt acts as an insulator.

### 19. Lubricate Correctly

Lubricate motors according to manufacturers' specifications. Apply high-quality greases or oils carefully to prevent contamination by dirt or water.

### 20. Maintain Motor Records

Maintain a separate file on each motor to keep technical specifications, repair, testing, and maintenance data. Maintain time-series records of test results, such as winding resistance. This information will help you identify motors that are likely to develop mechanical or electrical problems. In addition, these records may be necessary for the proper repair of a failed motor.

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## About Motor Challenge

Motor Challenge is a partnership program between the U.S. Department of Energy and the nation's industries. The program is committed to increasing the use of industrial energy-efficient electric motor systems and related technologies.

The program is wholly funded by the U.S. Department of Energy and is dedicated to helping industry increase its competitive edge, while conserving the nation's energy resources and enhancing environmental quality.



BONNEVILLE POWER ADMINISTRATION

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## For More Information

Contact the Motor Challenge Information Clearinghouse: 1-800-862-2086. The Motor Challenge Information Clearinghouse is your one-stop resource for objective, reliable, and timely information on electric motor-driven systems.

Access the Motor Challenge website on the Internet at www.motor.doe.gov.

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