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# Energy Management Guide for Selection and Use of Polyphase Motors

NEMA

ATIONAL ELECTRICAL MANUFACTURERS ASSOCIATION ■ 2101 L STREET, N.W., WASHINGTON, D.C. 20037

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NEMA MG 10-1983 (R 1988)

# MG 10

## *ENERGY MANAGEMENT GUIDE FOR SELECTION AND USE OF POLYPHASE MOTORS*

*Published by*

**National Electrical Manufacturers Association**
2101 L Street, N. W.
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## FOREWORD

The Motor and Generator Section of NEMA published the first edition of MG 10 with the statement to periodically review the guide for the purpose of keeping it up to date with advancing technology. This edition, MG 10-1983 (1988), is the result of this commitment.

The goal of this guide is to assist the reader in the choice of equipment for his application.

The practice of periodically reviewing and updating the guide will be continued. Comments on the guide from readers are welcomed and should be addressed to:

Manager, Engineering Department
National Electrical Manufacturers Association
2101 L Street, N.W.
Washington, DC 20037

## SCOPE

This energy management guide provides practical information concerning the proper selection and application of polyphase induction and synchronous motors including installation, operation, and maintenance.



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# Section 1
# INTRODUCTION

The shortage and large cost increases of vital national energy resources has demonstrated the need to conserve such resources. It is important that motor users and specifiers understand the selection, application, and maintenance of electric motors in order to improve the management of electrical energy consumption. *Energy Management* as related to electric motors is the consideration of the factors that contribute to reducing the energy consumption of a total electric motor drive system. Among the factors to be considered are the motor design and application.

An electric motor is an energy converter, converting electrical energy to mechanical energy. For this reason, an electric motor should be considered as always being connected to a driven machine or apparatus, with specific operating characteristics, which dictate the starting and running load characteristics of the motor. Consequently, the selection of the motor most suitable for a particular application is based on many factors, including the requirements of the driven equipment (e.g., starting and acceleration, speed, load, duty cycle), service conditions, motor efficiency, motor power factor, and initial motor cost. These application factors often conflict with one another. The driven system efficiency is the combination of the efficiencies of all of the components in the system. In addition to the motor, these components include the driven equipment (such as fans, pumps and compressors) power transmission components (such as belts, pulleys, gears and clutches). Other components which are not a part of the driven system will affect the overall system efficiency; some of these are refrigerator and air conditioning evaporator and condenser coils, piping associated with pumps, ducts and baffles associated with fans and blowers, and motor controllers (ac variable speed drives and power factor controller).

Good energy management is the successful application of the motor controller, motor, and the driven components that results in the least consumption of energy. Since all motors do not have the same efficiency, careful consideration must be given to their selection and application.

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# Section 2
# SELECTION AND APPLICATION

## 2.1 GENERAL

The proper selection and application of polyphase induction and synchronous motors involves the consideration of many factors affecting installation, operation, and maintenance. The basic steps in selecting a motor consist of determining the power supply, horsepower rating, speed, duty cycle, motor type, and enclosure. In addition, environmental conditions, mounting, connections of the motor to the load, and mechanical accessories or modifications must be considered. Motors must also be properly selected with respect to the known service conditions, often referred to as *usual* and *unusual*, as defined in NEMA Standards Publication MG1-1987, *Motors and Generators*. Usual service conditions are considered to be:

1. Exposure to an ambient temperature within the range of 0°C to 40°C.
2. Installation in areas or supplementary enclosures which do not seriously interfere with the ventilation of the machine.
3. Operation within a tolerance of ±10 percent of rated voltage.
4. Operation from a sine wave of voltage source (not to exceed 10 percent deviation factor).
5. Operation within a tolerance of ±5 percent of rated frequency.
6. Operation within a voltage unbalance of 1 percent or less.

Operation at other than usual service conditions may result in the consumption of additional energy.

## 2.2 POWER SUPPLY

### 2.2.1

In general, induction and synchronous motors are designed for a rated voltage, frequency, and number of phases. The supply voltage must be known in order to select the proper motor. For alternating-current motors, the motor nameplate voltage will normally be less than the nominal power system voltage as shown in the following table for three-phase, 60-hertz motors:

| Nominal Power System Voltage, Volts | Motor Utilization (Nameplate) Voltage Volts |
|---|---|
| 208 | 200 |
| 240 | 230 |
| 480 | 460 |
| 600 | 575 |
| 2400 | 2300 |
| 4160 | 4000 |
| 6900 | 6600 |
| 13800 | 13200 |

### 2.2.2 Effects of Variation in Voltage and Frequency

Operation outside of the rated conditions of voltage and frequency may decrease both efficiency and power factor and may adversely affect other performance characteristics. The same condition is true when operating the motor on other than a sine wave of voltage. The effect of a variation in supply voltage, wave form, or frequency on the motor's efficiency and power factor characteristics depends on the individual motor design.

### 2.2.3 Effects of Voltage Unbalance

A balanced voltage of the three-phase power supply to the motor is essential to the efficient operation of the system. For example, a voltage unbalance of 3.5 percent can increase motor losses by approximately 20 percent. For this reason, single-phase loads taken from a three-phase power supply should be carefully allocated so that the voltage unbalance will be kept as low as possible at the motor terminals.

## 2.3 EFFICIENCY

Motor efficiency is a measure of the effectiveness with which electrical energy is converted to mechanical energy, and is expressed as the ratio of power output to power input:

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

Motor efficiencies are usually given for rated load, ¾ load and ½ load.

The efficiency of a motor is primarily a function of load, horsepower rating, and speed, as indicated below:

1. A change in efficiency as a function of load is an inherent characteristic of motors, see Figure 2–1. Operation of the motor at loads substantially different from rated load may result in a change in motor efficiency.
2. Generally, the full load efficiency of motors increases as the motor horsepower rating increases, see Figure 2-1.
3. For the same horsepower rating, motors with higher speeds generally, but not necessarily, have a higher efficiency at rated load than motors with lower rated speeds. This does not imply, however, that all apparatus should be driven by high-speed motors. Where speed-changing mechanisms, such as pulleys or gears, are required to obtain the necessary lower speed, the additional power losses could reduce the efficiency of the system to a value lower than that provided by a direct-drive lower-speed motor.

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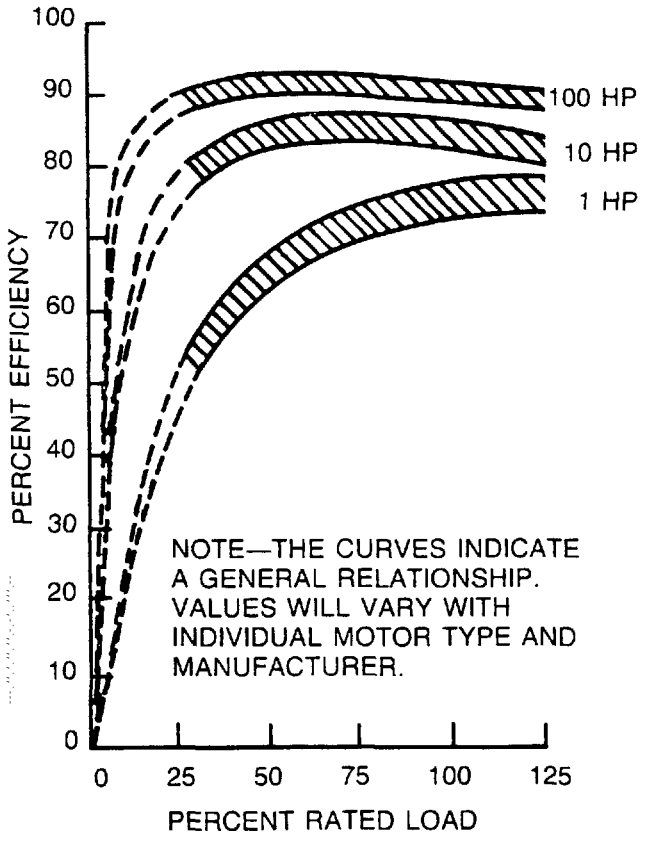



**Figure 2–1**
**TYPICAL EFFICIENCY VERSUS LOAD CURVES FOR 1800-RPM THREE-PHASE 60-HERTZ DESIGN B SQUIRREL-CAGE INDUCTION MOTORS**

A definite relationship exists between the slip and the efficiency of a polyphase induction motor, i.e., the higher the slip, the lower is the efficiency, for slip is a measure of the losses in the rotor winding. Slip of an induction motor is the difference between synchronous speed and full-load speed. Slip, expressed in percent, is the difference in speeds divided by the synchronous speed and multiplied by 100. Therefore, under steady load conditions, Design A, B, and C squirrel-cage induction motors having a slip of less than 5 percent are more efficient than Design D motors having a higher slip and should be used when permitted by the application (see Table 2–1). However, for applications involving pulsating inertia loads, such as punch press or oil well pumping, the overall efficiency of motors with high slip may be higher than that of motors having a slip of less than 5 percent. Additionally, high-slip motors may be necessary for applications requiring high starting (locked-rotor) torque.

If load permits, it may be possible to make a significant saving in energy by utilizing a multispeed motor operating on low speed whenever possible and using high speed only when necessary. However, it should be noted that the efficiency of a multispeed motor at each operating speed is somewhat lower than that of a single-speed motor having a comparable rating. Single-winding multispeed motors are generally more efficient than two-winding multispeed motors.

Motors which operate continuously or for long periods of time provide a significant opportunity for reducing energy consumption. Examples of such applications are processing machinery, air moving equipment, pumps, and many types of industrial equipment. A small change in motor efficiency will make a significant change in the total energy cost due to the lengthly operating time.

While many motors are operated continuously, some motors are used for very short periods of time and for a very low total number of hours per year. Examples of such applications are valve motors, dam gate operators, and industrial door openers. In these instances, a change in motor efficiency would not substantially change the total energy cost since very little total energy is involved.

A modest increase of a few percentage points in motor efficiency can represent a rather significant decrease in percentage of motor losses. For example, for the same output, an increase in efficiency from 75 to 78.9 percent, from 85 to 87.6 percent, or from 90 to 91.8 percent represents a 20 percent decrease in losses in each case.

### 2.3.1 Motor Losses

An electric motor converts electrical energy into mechanical energy and in so doing, incurs losses which are generally described as follows:

1. Electrical (stator and rotor) Losses (vary with load)—Current flowing through the motor windings produces losses which are proportional to the current squared times the winding resistance ($I^2R$).

2. Iron (core) Losses (essentially independent of load)—These losses are confined mainly to the laminated core of the stator and rotor. The magnetic field, essential to the production of torque in the motor, causes hysteresis and eddy current losses.

3. Mechanical (friction and windage) Losses (independent of load)—Mechanical losses occur in the bearings, fans, and brushes (when used) of the motor. These losses are generally small in open, low speed motors, but may be appreciable in large, high-speed or totally-enclosed fan-cooled motors.

4. Stray Load Losses (dependent on load)—Made up of several minor losses which result from such factors as leakage flux induced by motor currents, non-uniform current distribution in stator and rotor conductors, air gap, and so forth. These losses combined make up 10–15 percent of the total motor losses and tend to increase with load.

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## Table 2–1
## Characteristics and Applications of Polyphase Induction Motors

Design A motor performance characteristics are similar to those for Design B motors except that the starting current is higher than the values shown in the Table.

| Size | Classification | Starting Torque (Percent Rated Load Torque) | Breakdown Torque (Percent Rated Load Torque) | Starting Current (Percent Rated Load Current) | Slip | Typical Applications | Relative Efficiency |
|---|---|---|---|---|---|---|---|
| Medium<br>Large | Design B<br>Normal starting torque and normal starting current | 70–275*<br>60–100 | 175–300*<br>175–200 | 600–700<br>600–650 | 1–5%<br>0.5–2% | Fans, blowers, centrifugal pumps and compressors, motor-generator sets, etc., where starting torque requirements are relatively low | High |
| Medium<br>Large | Design C<br>High starting torque and normal starting current | 200–250*<br>150–200 | 190–225*<br>190–200 | 600–700<br>600–650 | 5% Max.<br>0.5–2% | Conveyors, crushers, stirring machines, agitators, reciprocating pumps and compressors, etc., where starting under load is required | High |
| Medium<br>Large | Design D<br>High starting torque and high slip | 275<br>250–300 | 275<br>275–325<br>250–300 | 600–700<br>600–650<br>500–600<br>450–550 | 5–8%<br>8–13%<br>5–8%<br>8–13% | High peak loads with or without flywheels such as punch presses, shears, elevators, extractors, winches, hoists, oil-well pumping and wire-drawing machines | Medium at 5–8% slip, low at 8–13% slip |
| Medium and Large | Wound Rotor | Any torque up to the breakdown value | 175–275* | Adjustable (depends on starting torque required) | Adjustable | Where high starting torque with low inrush, frequent starting, or limited speed control are required and where high inertias must be accelerated | Medium at full speed, lower at reduced speeds |

*Higher values are for motors having lower horsepower ratings.

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Listed below are the motor loss components, with the typical percent of the total motor losses they represent, and the design and construction factors which influence their magnitude.

| | Typical Percent of Losses 4 Pole Motors | Factors Affecting These Losses |
|---|---|---|
| Stator Losses | 35 to 40 | Stator conductor size |
| Rotor Losses | 15 to 20 | Rotor conductor size |
| Core Losses | 15 to 20 | Type and quantity of magnetic material |
| Stray Load Losses | 10 to 15 | Primarily manufacturing and design methods |
| Friction and Windage | 5 to 10 | Selection/design of fans and bearings |

In general, by increasing the active material in the motor. ie., the type and quantity of conductors and magnetic materials, the losses can be reduced.

### 2.3.2 Variations in Motor Losses

In the manufacture of motors, there are periodic variations in the motor characteristics even in motors of duplicate design and repetitive manufacture. These are caused by normal variations in purchased raw materials such as copper and steel. In addition, there are variations caused by manufacturing processes and testing accuracy deviations. Thus in forecasting the efficiency of a given motor, one can speak of the *nominal* efficiency (the average efficiency of a population of motors of duplicate design), or the *minimum* efficiency (the level reached when both raw materials and manufacturing processes are at the least favorable end of their specified tolerances). Both of these values are of use to the prospective purchaser of a motor. The *nominal* efficiency should be used in estimating the power required to supply a number of motors. The *minimum* efficiency permits the motor user the assurance of having received the specified level of performance. Thus, the NEMA system of specifying efficiency is required to include both values.

### 2.3.3 Efficiency Testing Methods

There are a number of test methods for determining motor efficiency. The standard method for testing induction machines in the United States is IEEE Standard 112-1984, *Standard Test Procedure for Polyphase Induction Motors and Generators*,* which recognizes five methods for determining motor efficiency, each of which has certain advantages as to accuracy, cost, and ease of testing, depending primarily on motor rating. The common practice for 1 to 125 horsepower is to test the motor with a load absorption device, called a dynamometer, and to carefully measure the power input and output to determine loss components and thus efficiency. This is IEEE 112—Method B and forms the basis of determining the NEMA efficiency rating.

### 2.3.4 Testing Variations

Even with the use of a consistent and accurate efficiency test method, variations in results do occur, primarily due to test equipment and instrument characteristics, and in the case of non-automated testing, personnel factors.

NEMA undertook to increase the motor manufacturing industry's level of knowledge about motor testing variations, with the end objective of enhancing existing test methods and standards. One activity was the 1978 NEMA Round Robin Test. This involved shipping three motors of different ratings (5, 25, and 100 horsepower) to a total of nine motor manufacturers with the request that they test them using their standard procedure based on IEEE 112—Method B. The results indicated an excessive deviation of test results among manufacturers, demonstrating the need for additional discipline in test method and data handling. Hence, each manufacturer was requested to use a defined procedure on raw test data that involved segregating the various types of losses and smoothing the stray load loss by linear regression analysis. Then the Round Robin Tests were repeated by each manufacturer using the above test and calculation procedure.

The results are summarized below:

**VARIATION IN FULL LOAD EFFICIENCY**

| Motor HP | Initial Test | Final Test |
|---|---|---|
| 5 | 87.1 ± 1.9 | 87.1 ± 0.7 |
| 25 | 89.7 ± 1.7 | 89.5 ± 0.8 |
| 100 | 92.2 ± 1.7 | 91.9 ± 0.9 |

*Available from IEEE, 345 E.47th St., New York, NY 10017.

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These results showed an average reduction in variation of 55 percent. Therefore, NEMA adopted a new Standard (MG 1-12.54 in NEMA Standards Publication No. MG 1-1987, *Motors and Generators*) which augments IEEE Standard 112-1984 to define motor efficiency testing to attain this improved accuracy.

### 2.3.5 Manufacturing Variations

All manufactured products are subject to variances associated with materials and manufacturing methods. No two products will perform exactly the same, even though they are of the same design and produced on the same assembly line.

This is also true for electric motors. Product variances in materials, such as steel used for laminations in the stator and rotor cores, will lead to variances in electromagnetic properties and ultimately affect losses and motor efficiency. Using a 10 horsepower motor as an example, a 10 percent increase in iron loss (300 to 330 watts), which is within the tolerance offered by steel suppliers, would increase total motor losses from 1167 to 1197 watts and reduce efficiency from 86.5 to 86.2 percent.

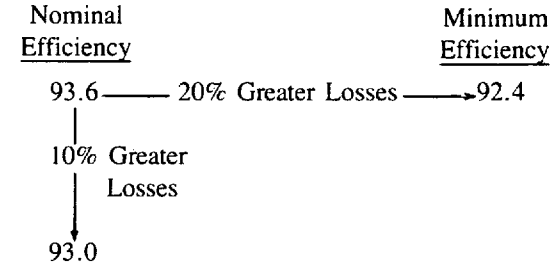
Variances also occur as the result of manufacturing process limitations. There is an economic limit to the practical dimensional tolerances on motor parts. Combinations of mating parts contribute to dimensional variations, such as the size of the air gap, which cause variations in stray load loss and hence motor efficiency.

Due to reasonable manufacturing variations in materials, components, and processes, as illustrated above, efficiencies of specific type and horsepower motors produced by the same manufacturer will vary. NEMA therefore undertook a second activity to evaluate these manufacturing variations. This evaluation involved 16 motor models from a number of manufacturers. Each manufacturer tested an average of 20 motors of a common design which were manufactured in his facility over a period of months. The data gave an indication of the manufacturing and testing variations within that facility over time. The results indicated that for a specific motor design variations in measured losses were frequently above ± 10 percent and as high as ± 19 percent.

### 2.3.6 NEMA Standards on Efficiency Nomenclature and Labeling

These electric motor industry studies resulted in the development of NEMA Standard MG 1-12.54, which defines efficiency nomenclature and labeling for polyphase induction motors 1 to 125 horsepower. This standard establishes a table of efficiencies defined by a nominal and minimum numeric full load efficiency value.

The NEMA nominal efficiency is defined as the average efficiency of a large population of motors of the same design. The spread between nominal efficiencies in the table is based on increments of 10 percent losses. The spread between the nominal efficiency and the associated minimum is based on an increment of 20 percent losses.




The motor nameplate efficiency marking is selected from the table of nominal efficiencies (Tables 12-6A & 6B in MG 1-1987) and represents the average efficiency of a population of motors as determined by the previously defined testing method. The use of a series of defined values for labeling was selected to avoid the inference of unrealistic accuracy that might be assumed from an infinite number of nominal efficiency values. As noted previously, the NEMA Round Robin Testing indicated a possible test variation on the same motor of ± 0.9 percent of efficiency, which, on a 90 percent efficient motor is a ± 10 percent variation in losses. Additionally, the combined variation in measured losses from both manufacturing and test can be as high as ± 19 percent.

The NEMA Standard requires that all polyphase squirrel-cage integral horsepower motors, 1 to 125 horsepower, designated as Design A and B (and equivalent Design C ratings) shall have the NEMA nominal efficiency value on the nameplate.

With this carefully defined data in accordance with NEMA Standards, a motor purchaser or user can determine the relative efficiencies and resultant economics of alternate motors. This data allows a common basis for comparison of the alternative motors available, and in conjunction with other motor application information it may be utilized to compute relative energy and energy cost savings.

## 2.4 EVALUATION OF EFFICIENCY ECONOMICS

In order to obtain accurate results during the economic evaluation process, it is extremely important that only efficiencies determined by the same method are compared. There are a number of ways to evaluate the economic impact of motor efficiency. Two of these methods are simple payback analysis and present worth life cycle analysis. A third method, not detailed here, is the cash flow and payback analysis. This method considers motor cost premium, motor depreciation life, energy cost and energy cost inflation rate, corporate tax rate, tax credit,

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and the motor operating parameters covered in the simple payback analysis. Details of this method are explained in current financial management texts.

### 2.4.1 Simple Payback Analysis

The simple payback method gives the number of years required to recover the differential investment for higher efficiency motors. To determine the payback period, the premium for the higher efficiency motor is divided by the annual savings. First, the annual savings must be determined using the following formula:

$$S = .746 \times HP \times L \times C \times N \left(\frac{100}{E_B} - \frac{100}{E_A}\right)$$

S = Annual dollar savings
HP = Horsepower
L = Percentage load ÷ 100
C = Energy cost in dollars per kilowatt hour
N = Annual hours of operation
$E_B$ = Lower motor efficiency
$E_A$ = Higher motor efficiency

The efficiencies for the percent load at which the motor will be operated must be used, since motor efficiency varies with load.

Then, the motor cost premium is divided by the annual savings to compute the payback period for the higher efficiency motor. If motor A costs $300 more than motor B and yields annual savings of $100, the simple payback period is $\frac{\$300}{\$100}$ or 3 years. The payback method is easy to apply but ignores savings occurring after the end of the payback period and does not consider the time value of money or changes in energy costs.

### 2.4.2 Present Worth Life Cycle Analysis

For greater precision, the present worth method of life cycle savings may be employed. This method considers both the time value of money and energy cost inflation. First, the user will determine the required internal rate of return and expected energy cost inflation. Then, the effective interest rate can be determined using the following formula:

$$i = \frac{1 + R_2}{1 + R_1} - 1$$

i = Effective interest rate
$R_1$ = Expected annual rate of energy cost inflation
$R_2$ = Required internal rate of return on investments

The next step is to determine present work by inserting the effective interest rate into the basic formula for the present value of an annuity.

$$PW = \frac{(1+i)^n - 1}{i\,(1+i)^n}$$

PW = Present worth
n = Expected operating lifetime of the motor

Once PW is solved, the present worth evaluation factor (PWEF) can be calculated.

$$PWEF \text{ (dollars per kilowatt)} = C \times N \times PW$$

As before, C = Energy cost in dollars per kilowatt hour
N = Annual hours of operation
PW = Present worth

Finally, the present worth of the life cycle savings resulting from the higher efficiency motor can be computed:

Present worth of savings =

$$.746 \times HP \times PWEF \left(\frac{100}{E_B} - \frac{100}{E_A}\right)$$

The present worth of savings due to the investment is the basis on which the investment decision is made.

*Sample Calculation*

Given: 100 HP Motor A 95% efficient
100 HP Motor B 92% efficient

Assumed: 5.5¢ KWhr
12% Inflation of energy costs
25% Return on Investment
8 yr. Expected life
4160 hr/yr. (2 shift 5 day/wk)

$$i = \left(\frac{1.25}{1.12} - 1\right) = .116$$

$$PW = \frac{1.116^8 - 1}{.116 \times 1.116^8} = 5.037$$

$$PWEF = .055 \times 4160 \times 5.037 = 1152$$

$$PW \text{ Saving} = .746 \times 100 \times 1152 \times \left(\frac{100}{92} - \frac{100}{95}\right) = \$2950$$

## 2.5 MOTOR CLASSIFICATION BY SIZE

The NEMA Standards Publication for Motors and Generators, MG 1–1978 classifies certain polyphase motors as "medium" or "large", based on equivalent frame size, as follows:

1. Medium Motor—A motor (1) built in a 3 or 4 digit frame number series in accordance with MG 1-11.01, and (2) having a continuous rating up to and including the following:

| Synchronous Speed | Horsepower |
|---|---|
| 3600 | 500 |
| 1800 | 500 |
| 1200 | 350 |
| 900 | 250 |
| 720 | 200 |
| 600 | 150 |
| 514 | 125 |

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2. Large Motor—A motor built in a frame larger than that required for medium motors.

## 2.6 MOTOR SELECTION

### 2.6.1 Induction Motors

The selection of the induction motor required depends on the performance characteristics of the driven machine and these, in turn, determine the operating characteristics of the motor.

The following lists the types of motors and the machines on which they are typically applied:

a. *Design A & B*—Used on machines, such as most fans, blowers, centrifugal pumps, and compressors, requiring a relatively low starting torque followed by an increasing torque with increasing speed up to the full-load speed and torque. Design A motors have a higher locked rotor current than Design B motors.

b. *Design C*—Used on machines, such as reciprocating air compressors and conveyors, requiring relatively high starting torque which is normally greater than the torque required at full-load speed.

c. *Design D*—Used on machines which impose pulsating loads or require frequent starting of the motor, such as punch press, oil well pumping, and hoist applications.

A summary of characteristics, typical applications and relative efficiencies for several types of induction motors is given in Table 2–1. Figure 2-2 shows representative speed-torque curves for Design A, B, C, and D motors.

### 2.6.2 Synchronous Motors

In general, large synchronous motors can be applied to any load that induction motors with Design A, B, or C characteristics can handle. They have a higher efficiency than an induction motor of the equivalent rating and are capable of improving the system power factor. When efficiency is a primary consideration in choosing a relatively large motor, a 1.0 power factor synchronous motor may provide the solution. Where system power factor improvement is a primary consideration, the use of an 0.8 leading power factor synchronous motor may provide the solution.

### 2.6.3 Multispeed Motors

Multispeed motors can be designed to have speed torque characteristics similar to those of Design A, B, C, or D motors of the equivalent rating. They can be designed for variable torque, constant torque or constant horsepower. For the highest efficiency, it is important to select the correct multispeed motor characteristic for the load at all operating speeds.

The following lists motor characteristics and the machines on which they are typically applied:

a. *Variable-torque*—Used on fans and centrifugal pumps.

b. *Constant-torque*—Used on conveyors, positive displacement pumps, and compressors.

c. *Contant-horsepower*—Used on machine tools and winches.

## 2.7 POWER FACTOR

The connected motor load in a facility is usually a major factor in determining the system power factor. Low system power factor results in increased losses in the distribution system. Induction motors inherently cause a lagging system power factor.

The power factor of an induction motor decreases as the load decreases, as shown in Figure 2–3. Figure 2–4 indicates that rated load power factor increases with an increase in the horsepower rating of the motor. A number of induction motors, all operating at light load, can cause the electrical system to have a low power factor. The power factor of induction motors at rated load is less for low-speed motors than for high-speed motors as shown in Figure 2–4. A small increase in voltage (≤10 percent) above rated voltage will decrease the power factor, and a

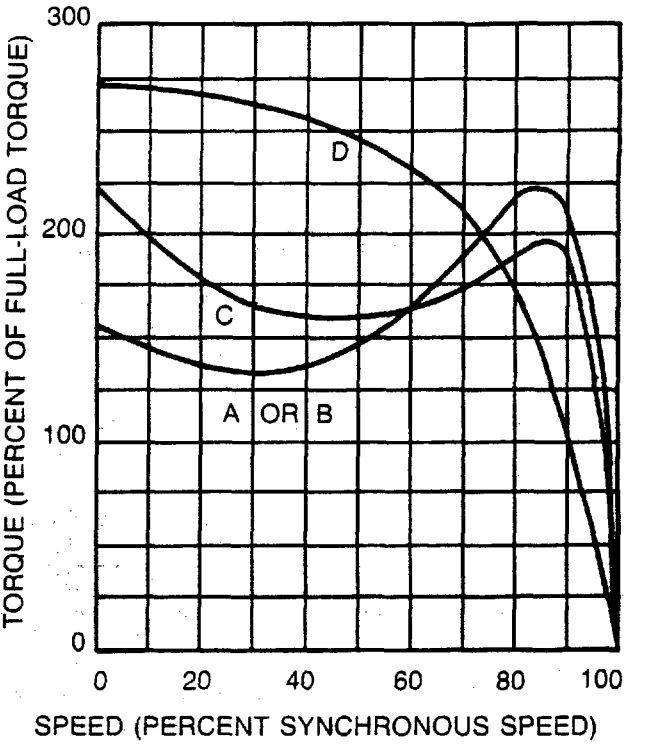



**Figure 2–2**
**GENERAL SHAPE OF SPEED-TORQUE CURVES FOR MOTOR WITH NEMA DESIGN A, B, C AND D**

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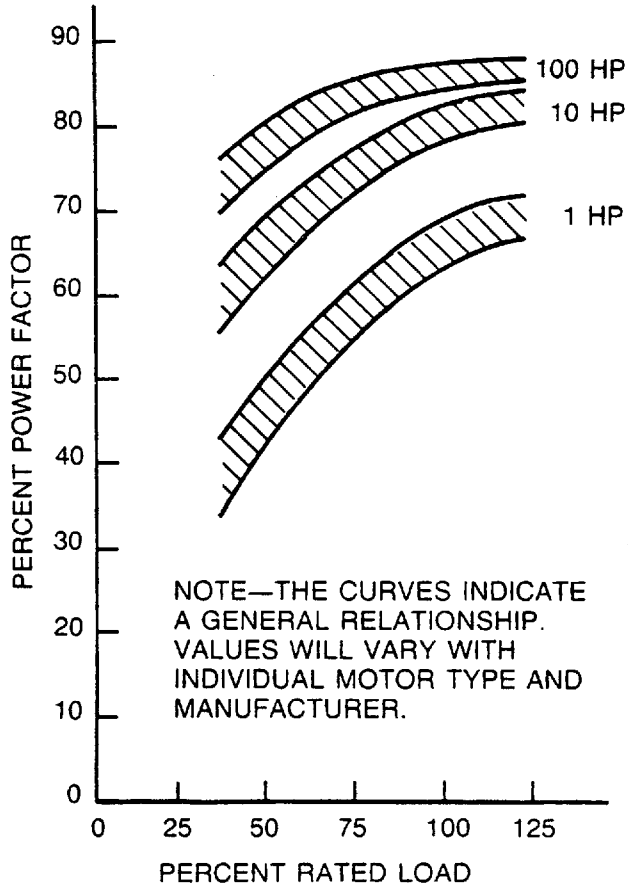



**Figure 2–3**
**TYPICAL POWER FACTOR VERSUS LOAD CURVES FOR 1800-RPM THREE-PHASE 60-HERTZ DESIGN B SQUIRREL-CAGE INDUCTION MOTORS**

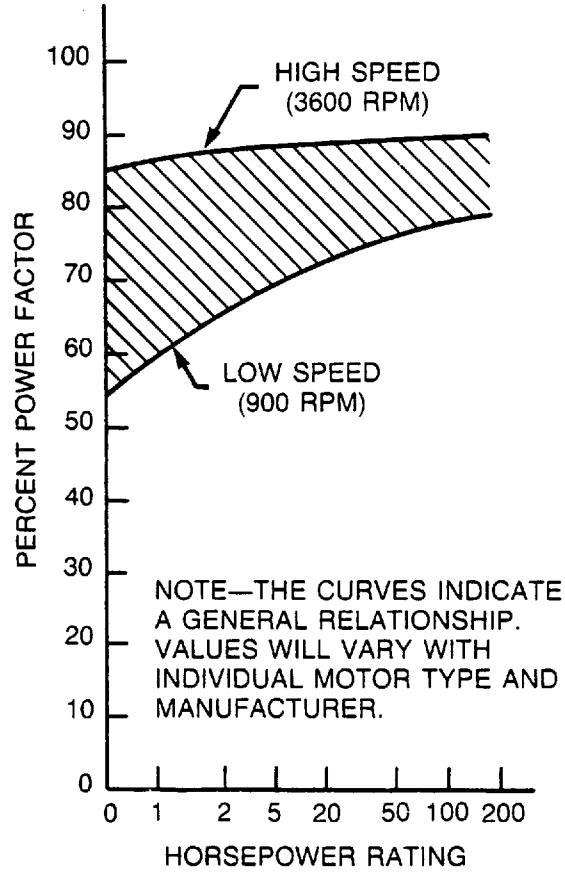



**Figure 2–4**
**TYPICAL FULL-LOAD POWER FACTOR VERSUS HORSEPOWER RATING CURVES FOR THREE-PHASE 60-HERTZ DESIGN B SQUIRREL-CAGE INDUCTION MOTORS**

small decrease in voltage (≤10 percent) below rated voltage will improve the power factor of an induction motor. However, other performance characteristics may be adversely affected by such a change in voltage; and operation as close as possible to the nameplate voltage and horsepower rating is recommended.

Power-factor-correction capacitors can be used to improve power factor of the electrical system. However, if they are used, they should be carefully selected and applied to avoid unsafe operating conditions. It is recommended that the motor manufacturer be consulted for the proper value of corrective capacitance.

The power factor of synchronous motors can range from 1.0 to approximately zero power factor leading, depending on the rated power factor, the field excitation, and the load. Standard designs are usually rated for either unity power factor or 0.8 leading power factor. As previously stated, synchronous motors have the capability of improving the power factor of the electrical system.

An analysis of the electrical system will indicate whether improvement in the power factor is needed and whether capacitors, synchronous motors, or other corrective measures should be used.

## 2.8 APPLICATION ANALYSIS

When the device being driven by an electric motor is producing a relatively constant and continuous level of useful work, the primary motor selection concern is its rated load efficiency. However, many applications are cyclic in nature. In these cases specific application techniques can be used to obtain substantial energy savings.

Other applications require intermittent or continuous absorption of energy. Again there are application techniques that will recover a significant percentage of the otherwise wasted energy.

A few of these cases are cited here to illustrate the technology that is available to the user. The motor manufacturer should be consulted to determine the most effective solution.

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### 2.8.1 Applications Involving Load Cycling

Some applications require running at load for a period of time followed by a period during which no useful work is being done by the driven machine. In this case energy may be saved by stopping the motor and restarting it at the beginning of the next load period.

The following example illustrates the savings to be realized by start-stop cycling. This example assumes that the friction and windage loss of the driven machine is 2.5 HP.

Assumptions:

1. Motor rating ..... 10 HP
2. Motor full load efficiency ..... 89.2%
3. Motor output with drive machine running idle ..... 2.5 HP
4. Motor efficiency at 2.5 HP .... 86%
5. Motor acceleration loss plus system stored energy ($Wk^2$ = 1.4 lb • $ft^2$ .....3750 watt-sec.
6. Driven machine is loaded for 15 minutes followed by a 15 minute idle period.
7. Utilization ..... 2000 hours per year.
8. Cost of energy ..... $.06 KW HR
9. Motor inertia .....7 lb • $ft^2$
10. Driven machine inertia .....7 lb • $ft^2$

Annual cost of energy if motor runs continuously:

a. Cost to run full load:

$$\$ = \frac{\text{RUN HOURS} \times \text{HP} \times .746 \times \$/\text{KW HR}}{\text{FL EFF}}$$

$$\$ = \frac{1000 \times 10 \times .746 \times .06}{.892} = 501$$

b. Cost to run driven machine idle:

$$\$ = \frac{1000 \times 2.5 \times .746 \times .06}{.86} = 130$$

Total Cost $ = 501 + 130 = $631

Annual cost of energy if motor is shut down after each load period:

a. Cost to run full load—same as above: $ = 501

b. Cost to restore system energy and to supply motor acceleration losses:

$$\$ = \frac{N_s \times J \times \$/\text{KW HR}}{1000 \times 60 \times 60}$$

*where* $N_s$ = number of starts per year
J = motor acceleration loss plus system stored energy in watt • sec

$$\$ = \frac{4000 \times 3750 \times .06}{1000 \times 60 \times 60} = \$.25$$

Total Cost = 501 + .25 = $501.25

Energy savings per year = 631 − 501.25 = $129.75

When making a decision to stop a motor or to run at no load a number of factors must be considered; these include motor type, horsepower rating, speed, starting frequency, restrictions on inrush current, power demand charges, and the extra winding stress imposed by repeated accelerations and associated reduction in life expectancy.

NEMA Standard MG 1–12.50 provides guidance on the number of successive starts (i.e. two starts from ambient or one start from rated load operating temperature), however, the information in MG–12.50 is not applicable to repetitive start-run-stop-rest cycles resulting from energy management programs. Accordingly, Table 2–2 has been prepared as a guide to: (1) the minimum off time required to allow the motor to cool sufficiently to permit another start; (2) the maximum number of starts per hour (irrespective of load $Wk^2$) to minimize the effect of winding stress imposed by repeated starts; and (3) a means of adjusting the number of starts per hour as a function of the load inertia. It should be recognized that each start is one factor in the life expectancy and reliability of the motor; and, as a result, some reduction in life expectancy and reliability must be accepted when a motor is applied at the upper range of the starting duty determined by Table 2–2.

Example 1:

50 HP, 4 Pole, Design B motor direct connected to a pump with a $Wk^2$ of 20 lb • $ft.^2$

From Table 2–2:

A = 6.8

B/Load $Wk^2$ = 232/20 = 11.6

Minimum off time = C = 72 seconds

The value of B/Load $Wk^2$ exceeds the maximum number of starts per hour. Therefore, the motor must be limited to the maximum of 6.8 starts per hour with a minimum off time between starts of 72 seconds.

Example 2:

25 HP, 2 Pole, 3550 rpm, Design B motor belt connected to a 5000 rpm blower with a $Wk^2$ of 3.7 lb • $ft.^2$

Load $Wk^2$ referred to motor shaft =

$$\left(\frac{5000}{3550}\right)^2 \times 3.7 = 7.34 \text{ lb} \cdot \text{ft.}^2$$

From Table 2–2:

A = 4.4

B/Load $Wk^2$ = 26/7.34 = 3.5

Minimum off time = C = 115 seconds

The value of B/Load $Wk^2$ is less than the maximum number of starts per hour and therefore the motor must be limited to 3.5 starts per hour with a minimum off time between starts of 115 seconds.

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**Table 2–2**
**Allowable Number of Starts and Minimum Time Between Starts For Design A and Design B Motors**

| | 2 Pole | | | 4 Pole | | | 6 Pole | | |
|---|---|---|---|---|---|---|---|---|---|
| HP | A | B | C | A | B | C | A | B | C |
| 1 | 15 | 1.2 | 75 | 30 | 5.8 | 38 | 34 | 15 | 33 |
| 1.5 | 12.9 | 1.8 | 76 | 25.7 | 8.6 | 38 | 29.1 | 23 | 34 |
| 2 | 11.5 | 2.4 | 77 | 23 | 11 | 39 | 26.1 | 30 | 35 |
| 3 | 9.9 | 3.5 | 80 | 19.8 | 17 | 40 | 22.4 | 44 | 36 |
| 5 | 8.1 | 5.7 | 83 | 16.3 | 27 | 42 | 18.4 | 71 | 37 |
| 7.5 | 7.0 | 8.3 | 88 | 13.9 | 39 | 44 | 15.8 | 104 | 39 |
| 10 | 6.2 | 11 | 92 | 12.5 | 51 | 46 | 14.2 | 137 | 41 |
| 15 | 5.4 | 16 | 100 | 10.7 | 75 | 50 | 12.1 | 200 | 44 |
| 20 | 4.8 | 21 | 110 | 9.6 | 99 | 55 | 10.9 | 262 | 48 |
| 25 | 4.4 | 26 | 115 | 8.8 | 122 | 58 | 10.0 | 324 | 51 |
| 30 | 4.1 | 31 | 120 | 8.2 | 144 | 60 | 9.3 | 384 | 53 |
| 40 | 3.7 | 40 | 130 | 7.4 | 189 | 65 | 8.4 | 503 | 57 |
| 50 | 3.4 | 49 | 145 | 6.8 | 232 | 72 | 7.7 | 620 | 64 |
| 60 | 3.2 | 58 | 170 | 6.3 | 275 | 85 | 7.2 | 735 | 75 |
| 75 | 2.9 | 71 | 180 | 5.8 | 338 | 90 | 6.6 | 904 | 79 |
| 100 | 2.6 | 92 | 220 | 5.2 | 441 | 110 | 5.9 | 1181 | 97 |
| 125 | 2.4 | 113 | 275 | 4.8 | 542 | 140 | 5.4 | 1452 | 120 |
| 150 | 2.2 | 133 | 320 | 4.5 | 640 | 160 | 5.1 | 1719 | 140 |
| 200 | 2.0 | 172 | 600 | 4.0 | 831 | 300 | 4.5 | 2238 | 265 |
| 250 | 1.8 | 210 | 1000 | 3.7 | 1017 | 500 | 4.2 | 2744 | 440 |

A = Maximum number of starts per hour
B = Maximum product of starts per hour times load $Wk^2$
C = Minimum rest or off time in seconds
Allowable starts per hour is the lesser of (1)A or (2)B divided by the load $Wk^2$ i.e.

$$\text{Starts per hour} \leq A \leq \frac{B}{\text{Load } Wk^2}$$

Note: Table is based on following conditions:

1. Applied voltage and frequency in accordance with MG 1-12.44.

2. During the accelerating period, the connected load torque is equal to or less than a torque which varies as the square of the speed and is equal to 100 percent of rated torque at rated speed.

3. External load $Wk^2$ equal to or less than the values listed in MG1–12.50.

For other conditions, the manufacturer should be consulted.

### 2.8.2 Applications Involving Extended Periods of Light Load Operation

A number of methods have been proposed to reduce the voltage applied to the motor in response to the applied load, the purpose of this being to reduce the magnetizing losses during periods when the full torque capability of the motor is not required. Typical of these devices is the power factor controller. The power factor controller is a device that adjusts the voltage applied to the motor to approximate a preset power factor.

These power factor controllers may, for example, be beneficial for use with small motors operating for extended periods of light loads where the magnetization losses are a relatively high percentage of the total loss. Care must be exercised in the application of these controllers. Savings are achieved only when the controlled motor is operated for extended periods at no load or light load.

Particular care must be taken when considering their

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use with other than small motors. A typical 10 horsepower motor will have idle losses in the order of 4 or 5 percent of the rated output. In this size range the magnetization losses that can be saved may not be equal to the losses added by the controller plus the additional motor losses caused by the distorted voltage wave form introduced by the controller.

### 2.8.3 Applications Involving Throttling or Bypass Control

Many pump and fan applications involve the control of flow or pressure by means of throttling or bypass devices. Throttling and bypass valves are in effect series and parallel power regulators that perform their function by dissipating the difference between source energy supplied and the desired sink energy.

These losses can be dramatically reduced by controlling the flow rate or pressure by controlling the speed of the pump or fan with a variable speed drive.

Figure 2–5 illustrates the energy saving potential of the application of variable speed drive to an application that traditionally uses throttling control.

A simplistic example will serve to illustrate the savings to be achieved by the use of this powerful energy conservation tool.

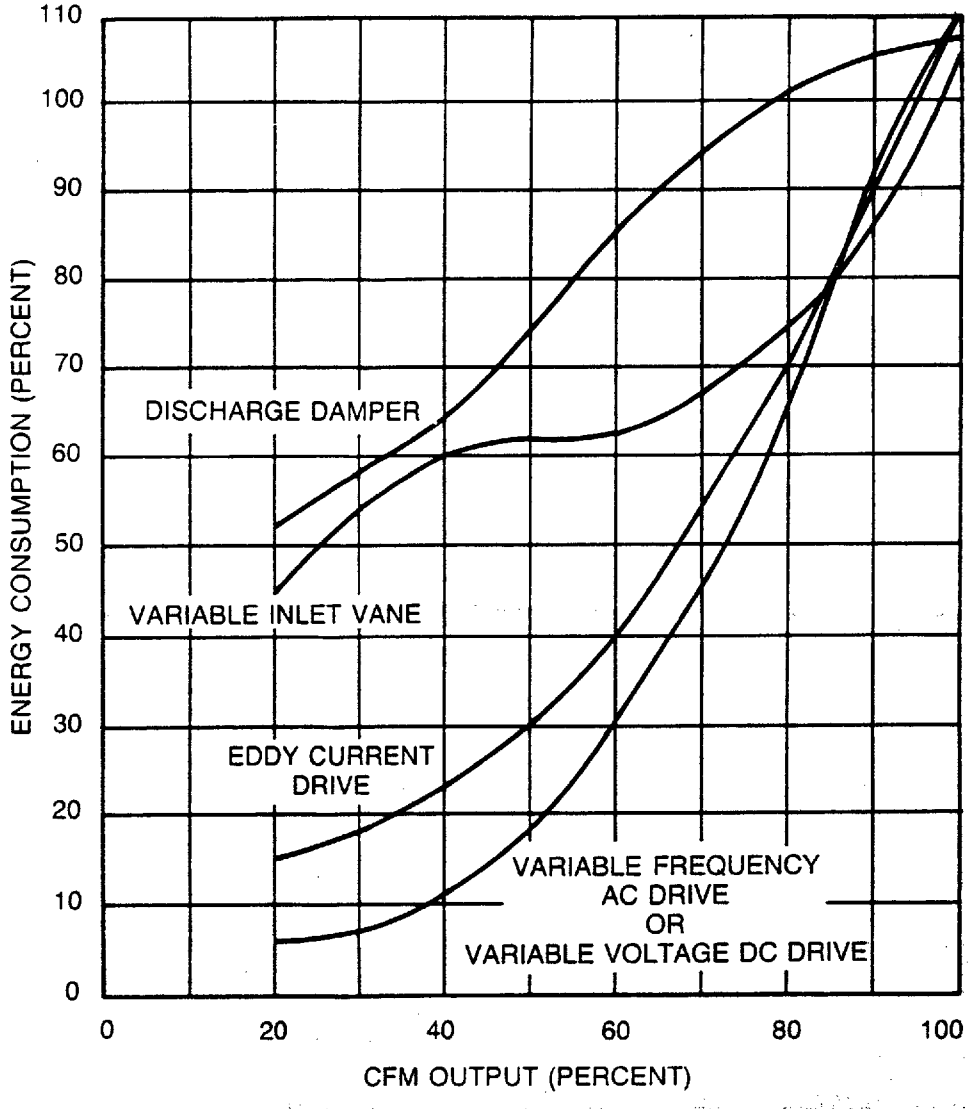



**Figure 2–5**
**TYPICAL ENERGY CONSUMPTION OF A CENTRIFUGAL FAN SYSTEM WITH DISCHARGE DAMPER CONTROL, VARIABLE INLET VANE CONTROL, AND VARIABLE SPEED CONTROL WITH EDDY CURRENT AND VARIABLE FREQUENCY DRIVES.**

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Assumptions:

Line Power Required by Fan at full CFM without flow control device ..... 100HP

Full CFM required ..... 1000 hours per year

75% CFM required ..... 3000 hours per year

50% CFM required ..... 2000 hours per year

Cost of energy ..... $.06 per KW HR

% Power consumption with various flow control methods per Figure 2–5.

Annual Cost of Energy

$$\$ = \frac{\text{HRS} \times \text{HP} \times 746 \times \%\ \text{ENERGY CONSUMPTION} \times \$/\text{KW HR}}{1000 \times 100}$$

Annual Cost of Energy Summary:

| | |
|---|---|
| Discharge Damper | $24,600 |
| Variable Inlet Vane | $19,600 |
| Eddy Current Drive | $15,900 |
| Variable Frequency AC Drive or Variable Voltage DC Drive | $13,900 |

### 2.8.4 Applications Involving Overhauling Loads

Overhauling loads typically result in energy waste if some form of dissipative braking is used. Examples of overhauling loads are: deceleration of high inertia loads, absorption test stands, unwind stands, web process stands, and downhill conveyors. In these cases energy can be saved by the use of regenerative devices.

### 2.8.5 Products Available

Typical products available to address the application concerns described above are illustrated in Table 2–3.

**Table 2–3**
**Typical Products for System Applications**

| Type | Speed Characteristics | Regeneration |
|---|---|---|
| AC Variable Frequency | Continuously Variable | Available |
| AC Variable Voltage | Continuously Variable | Not Available |
| AC Wound Rotor | Continuously Variable | Available |
| DC Variable Voltage | Continuously Variable | Available |
| Eddy Current Clutch | Continuously Variable | Not available |
| Mechanical Drive | Continuously Variable | Not available |
| AC Multi Speed Motor | Discrete speed steps | Available when used as an induction generator |
| AC Single Speed | One speed | Available when used as an induction generator |

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# Section 3
# MAINTENANCE

The electric motor generally needs little maintenance, therefore proper maintenance is often forgotten. There are a number of common abnormalities which have an adverse effect on a motor's performance:

—insufficient ventilation
—high ambient temperatures
—mechanical misalignment
—improper V-belt application
—improper lubrication
—excessive moisture
—contamination
—sustained overload
—abnormal voltage

Insufficient ventilation or high ambient temperatures result in higher resistance in the winding. On the average, the efficiency of a motor will decay by .2 to 1.0 percentage points from room temperature to its operating temperature. Furthermore, excessive temperature rises caused by poor maintenance or misapplication reduces the operating life of the motor and increases energy consumption.

Sometimes additional friction gradually develops within the driven machine. This could be caused by a buildup of dust on a fan, the wearing of parts, misalignment of gears or belts, or insufficient lubrication in the driven machine. These conditions cause the driven machine to become less efficient, which reduces system efficiency and increases energy consumption. To assure continued efficient operation and long motor life, a regular schedule for inspecting motors and driven equipment should be established.

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# NEMA STANDARDIZATION

The purpose of NEMA Standards, their classification and status, are set forth in certain clauses of the NEMA *Standardization Policies and Procedures* manual and are referenced below.

## Purpose of Standards

National Electrical Manufacturers Association standards are adopted in the public interest and are designed to eliminate misunderstandings between the manufacturer and the purchaser and to assist purchasers in selecting and obtaining the proper product for their particular needs. Existence of a National Electrical Manufacturers Association standard does not in any respect preclude any member or nonmember from manufacturing or selling products not conforming to the standard. *(Standardization Policies and Procedures, p. 1)*

## Definition of a Standard

A standard of the National Electrical Manufacturers Association defines a product, process, or procedure with reference to one or more of the following: nomenclature, composition, construction, dimensions, tolerances, safety, operating characteristics, performance, rating, testing, and the service for which they are designed.

*(Standardization Policies and Procedures, p. 2)*

## Dimensions

Where dimensions are given for interchangeability purposes, alternate dimensions satisfying the other provisions of the Standards Publication may be capable of otherwise equivalent performance.

*(Standardization Policies and Procedures, p.8)*

## Categories of Standards

National Electrical Manufacturers Association Standards are of two classes:

1. NEMA Standard, which relates to a product, process, or procedure commercially standardized and subject to repetitive manufacture, which standard has been approved by at least 90 percent of the members of the Subdivision eligible to vote thereon;
2. Suggested Standard for Future Design, which may not have been regularly applied to a commercial product, but which suggests a sound engineering approach to future development, which standard has been approved by at least two-thirds of the members of the Subdivision eligible to vote thereon.

*(Standardization Policies and Procedures, pp. 7 & 16)*

## Authorized Engineering Information

Authorized Engineering Information consists of explanatory data and other engineering information of an informative character not falling within the classification of NEMA Standard or Suggested Standard for Future Design, which standard has been approved by at least two-thirds of the members of the Subdivision eligible to vote on the standard.

*(Standardization Policies and Procedures, pp. 7 & 16)*

## Official Standards Proposal

An Official Standards Proposal is an official draft of a proposed standard which is formally recommended to an outside organization(s) for consideration, comment, and/or approval, and which has been approved by at least 90 percent of the members of the Subdivision eligible to vote thereon.

*(Standardization Policies and Procedures, pp. 7 & 16)*

## Identification of Status

Standards in NEMA Standards Publications are identified in the foreword or following each standard as "NEMA Standard" or "Suggested Standard for Future Design." These indicate the status of the standard. These words are followed by a date which indicates when the standard was adopted in its present form by the Association.

The material identified as "Authorized Engineering Information" and "Official Standards Proposal" is designated similarly.

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