CEE PREMIUM-EFFICIENCY MOTORS INITIATIVE

GUIDANCE SPECFICATION FOR LARGE (250-500 HP), LOW-VOLTAGE, GENERAL-PURPOSE MOTORS

Contents

1. Introduction

This Guidance specification provides general performance and application information for program administrators to consider when developing incentive programs for large (250-500 hp), low-voltage, general-purpose motors[1]. The information is based on results of an analysis of the motors listed in the U.S. Department of Energy's MotorMaster+ database, discussions within the CEE Motors & Motor Systems Committee and motor industry input.

The subject motors in this discussion are higher horsepower than those included in CEE's *Premium Efficiency Motor Specification*[2] or in the EPAct 1992 legislation (see Product Definition below)[3]. Because of their size, large motors are more expensive, consume more

[1]Note: This Guidance Specification will become an integral part of CEE's *Premium-Efficiency Motors Initiative*. Integrating this document into the overall initiative will require expanding the initiative's scope beyond the categories of motors covered by the EPAct 1992 legislation; revising the participation section; and clarifying that the technical considerations provided for large motors are applicable to all motors with the degree of impact generally increasing as motor size increases.

[2] CEE's *Premium-Motor Specification* and the federal EPAct 1992 legislation cover motors that fall within the following parameters: 1-200 hp, low-voltage, general-purpose motors. The *NEMA Premium Specification* includes these motor categories plus 1) motors from 250-500 hp, 2) medium voltage motors and 3) special and definite purpose motors. CEE's Motors & Motor Systems Committee has been considering whether to revise the CEE Specification to include one or more of these additional NEMA Premium categories. This document addresses the first of these categories: 250-500 hp, low-voltage, general-purpose motors.

[3] This document provides recommendations for 250-500 hp, low-voltage, general purpose motors. It is expected that CEE's Motors & Motor Systems Committee will consider additional categories of motors at a future time.

energy, and have a greater potential for energy savings than their smaller counterparts. Correspondingly, duty cycle, loading factor, operating hours and other application parameters have greater impact on overall efficiency and energy savings than for smaller motors. This document is intended to clarify some of the performance issues affecting large, low-voltage, general-purpose motors as well as to provide recommendations for program administrators to consider when developing incentive programs for them. Please note that while these considerations were developed for large industrial motors, the same considerations apply to motors below the 250 hp level. And, as with smaller motors, not all applications benefit from the installation of NEMA Premium motors.

2. CEE Recommendation for Large, Low-Voltage, General-Purpose Motor Programs

Providing incentives for large motors is a voluntary component of *CEE's Premium-Efficiency Motors Initiative*; that is, organizations may participate in the initiative without adopting this large motor component or may modify this component to suit their purposes. Alternately, organizations may choose to adopt certain portions of the large motor component or address large motors through a separate program. Requirements for participation in the Premium-Efficiency Motor Initiative are defined in that document. CEE encourages participating programs to adopt this component because of the energy savings potential with large motors and to provide consistency of terms and definitions across organizational boundaries.

- CEE encourages program administrators to consider providing incentives for 250-500 hp, low-voltage, general-purpose motors that meet or exceed the NEMA Premium™ efficiency levels.
- CEE recommends a custom approach to providing incentives for these motors.
- CEE recommends that program administrators consider the motor's operating and application parameters, including but not limited to those listed in this document.

This recommendation strikes a balance between the energy savings opportunities for large motors; their application-specific nature; and the value of leveraging the NEMA Premium brand in the market.

Participation in this component of the initiative is consistent with participation in the initiative overall. Specifically, participants includes….

3. Product Definition

The motors covered by this Guidance Specification include: general-purpose, single-speed, polyphase, 250-500 horsepower, 2,4, and 6 pole, squirrel cage induction motors, NEMA Design A or B, continuous rated which meet or exceed the nominal energy efficiency levels presented in NEMA Standards Publication MG1-2003, in Table 12-12 and as specified in Appendix A.

This range of motors differs from those covered by the NEMA Premium Specification in that only low-voltage, general-purpose motors as defined in the EPAct 1992 legislation are included. Medium voltage motors, and special and definite purpose motors, which are covered by the NEMA Specification, are scheduled to be considered (in the order shown) in the 2007 work plan.

4. Potential Energy Savings for Large Motors

According to the Department of Energy's *1998 United States Industrial Electric Motor Systems Market Opportunities Assessment*[4], industrial motor systems account for approximately twenty-three per cent of all electricity consumed in the United States and that consumption could be reduced by up to 18 per cent through the use of currently available products and practices. The study goes on to state that while large industrial motors, i.e. those over 200 horsepower, represent a small percentage of the overall industrial motor population, they represent a significant amount of the overall energy consumed by the industrial motor systems. It provides this supporting data:

- Motors over 200 horsepower account for only one percent of the motors in the entire manufacturing inventory, but use 45 percent of the energy use. By way of contrast, motors in the 1-5 hp range account for 59 percent of the inventory but account for only 5 percent of the energy use.
- Approximately 70% of motors which are >200 horsepower, fall into the 250-500 hp size range.
- Over 80% of the motors in this size range are pre-EPAct models.
- Average annual motor system operating hours exceed 6,100 hours per year.

The 1998 DOE study estimates 24.6 billion kWh could be saved annually through motor efficiency upgrades and best practice rewinding. If we use that estimate as a starting point and then apply factors to reflect that 45% of the total motor system energy is consumed by motors over 200 hp; and that 70% of the motors greater than 200 hp are between 250-500 hp, *we calculate potential estimated energy savings of more than 7.7 billion kWh annually*[5].

It should be noted that the DOE study was published in 1998. Whether the energy savings opportunities it identifies remain relevant to the current market is a subject open for discussion. Recent studies by individual CEE members as well as program experience assessing motor opportunities at customer facilities have confirmed that the opportunities for energy savings through the use of premium efficient motors and motor system optimization remains significant in those regions. Based on this limited regional information and the fact that the 1998 study remains the most comprehensive information available, this document includes the DOE data to estimate the magnitude of the potential savings. The data is not intended to approximate actual savings and program administrators are encouraged to consider the data's relevance in their individual territories.

5. Potential Market Implications

By participating in this component of the initiative, program administrators will help to draw attention to the possible energy savings from the installation of large, low-voltage motors which meet or exceed the NEMA Premium specification in appropriate applications. Consistent support by programs across North America helps to condition the market for energy savings and increase customer confidence in the savings potential of these products.

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[4] *United States Industrial Motor Systems Market Opportunities Assessment*, prepared by Xenergy for the U.S. DOE's Office of Industrial Technologies and Oak Ridge National Laboratory, 1998

[5] (24.6 billion kWh projected total savings) x (45% of energy consumed by large motors) x (70% of large motor population is 250-500 hp) = 7.7 billion kWh. Note: For this simple calculation, the % of energy consumed by large motors is assumed to equal the % of energy savings available from large motors.

Using the words "NEMA Premium" to specify premium-efficient motors can serve to clear up misperceptions in the market. Based on collective experience, there is a lack of awareness in the market about motor efficiency. Customers who are interested in efficiency often order "energy efficient" motors, thinking they are ordering the highest efficiency motors available. However, because the EPAct 1992 legislation defines "energy efficient" as motors meeting the minimum federal standard, these orders are generally filled with motors meeting the minimum federal standard, not the NEMA Premium levels. Incorporating the NEMA Premium brand name can help to alleviate this confusion and simplify promotion of NEMA Premium motors by all stakeholders in the market. Consistent support may also condition end-use customers to equate the NEMA Premium brand name with energy savings and enhance the level of manufacturer attention to these higher efficiency products.

Committee members anticipate a stronger market effect in their territories when efficiency programs join manufacturers, vendors and service providers to promote a single specification and recognizable brand to their customers. Consistency among these diverse stakeholder groups coupled with member's public recognition of the value of NEMA Premium for large motors creates a clear and credible signal to the market. The *Motor Decisions Matter* campaign sponsors, including representatives from each of these stakeholder groups, have developed a consistent message plus educational materials and resources for delivering it to the market[6]. Increasing the number of participating organizations delivering this consistent message may further condition the market about energy savings potential in appropriate large motor applications.

There is government support for NEMA Premium general-purpose motors up to 500 hp. EPAct 2005 and the ensuing FEMP ruling requires federal agencies to purchase motors which meet the NEMA Premium efficiency levels for all federal motor purchases up to 500 hp. For more information, please visit http://www.eere.energy.gov/.

6. Operating Parameters

The motor's specific application is an important consideration when calculating projected savings with NEMA Premium motors. This is especially true for large motors where variations in operating parameters are more likely to significantly impact energy consumption. Program administrators should consider setting eligibility guidelines for one or more of these parameters including but not limited to:

Motor Sizing: Many motors are oversized for their applications. Motor efficiency drops off sharply below 40 percent of rated load and motors operating in this range run far below their nameplate efficiency. As a rule of thumb, it is best to operate with a load factor between 60 percent and 85 percent. For motors operating below this range, downsizing the motor or installing an ASD may reduce energy consumption in some applications.

Duty Cycle (and the use of Adjustable Speed Drives): Some motors experience significant variations in load. For these motors, particularly in centrifugal applications (like pumps and fans), program administrators should be aware of the opportunity to save energy through the use

[6] These resources are freely available for use on the MDM web site, www.motorsmatter.org or by contacting Jenny Harvey, jharvey@cee1.org.

of adjustable speed drives (ASDs). Many NEMA Premium motors are "inverter duty", i.e. built with a higher class of insulation, which simplifies connection to ASDs.

Hours of Operation: The more hours a motor operates, the greater the opportunity for energy savings through efficiency. This is especially true for large motors as they require proportionally more power to operate than smaller motors. According to the DOE Study sited previously[7], larger motors generally experience long operating hours, often two to three shifts per day[8]. A number of efficiency programs offering incentives for large motors specify a minimum number of hours in their program criteria.

Motor Connections: How the motor is connected to the load is also important. Motor design and selection must include whether the motor experiences an across the line, part winding or soft start. The use of ASDs and inverter duty motors are included in this consideration.

Voltage Unbalance: occurs when there are unequal voltages on the lines to a polyphase motor resulting in a dramatic increase in motor losses and heat generation. Both decrease the efficiency of the motor and shorten its life[9]. Voltage unbalance may also reduce motor torque. The *Energy-Efficient Motor Systems: A Handbook on Technology, Program and Policy Opportunities*[10] provides a brief introduction to this topic including formulas for calculating voltage unbalance and possible solutions.

7. Design Factors

Because industrial processes include a wide range of applications, manufacturers have designed products to optimize a variety of performance characteristics. In-rush current, torque and power factor are a few examples. Efficiency may be independent of, in direct relationship to or inversely proportional to these other characteristics. Industrial process designers, engineers and managers must consider which characteristics need to be optimized for their specific application and choose the motor accordingly. It is important for efficiency program administrators to recognize the possibility that efficiency may or may not be the primary consideration in all applications.

Below are definitions of a few common design characteristics; their relationship to efficiency is provided where possible. This list is intended as a brief introduction to the topic and not as a comprehensive technical resource. For more information, please refer to NEMA's MG1 specification, or consult your local motor vendors. You many also contact any of the motor manufacturer or EASA sponsors of the Motor Decisions Matter Campaign (contact Ilene Mason, imason@cee1.org for details).

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[7] *United States Industrial Motor Systems Market Opportunities Assessment*, prepared by Xenergy for the U.S. DOE's Office of Industrial Technologies and Oak Ridge National Laboratory, 1998

[8] Calculated as follows: (8 hours/shift) x (3 shifts/day) x (5 days/week) x (50 weeks/year) = 6000 hours/year

[9] Efficient Motors: Selection Application Considerations, Consortium for Energy Efficiency, Boston MA 1999

[10] Nadel, Steven, et al, "*Energy-Efficient Motor Systems: A Handbook on Technology, Program and Policy Opportunities*", ACEEE Washington DC, 2002.

While program administrators are encouraged to consider all the factors described below, two are of particular importance: slip and inrush current. Attention to a motor's slip rate is important to ensure that energy savings are achievable. Inrush current is an important consideration to avoid nuisance tripping during start up. These factors are described in more detail below.

Motor System Optimization: Optimizing industrial processes may offer additional significant savings opportunities. When considering motor purchases and application parameters, program administrators are encouraged to also consider system design changes that might reduce the total amount of horsepower required.

Current (in amperes or percent of rated current): the amount of current the motor draws at a particular time or under particular operating conditions. There are many points of defined current which can be important considerations in a given application. These include but are not limited to starting current, instantaneous peak inrush current, and locked-rotor current.

> Instantaneous Peak In-Rush Current: the transient current that occurs immediately (within ½ of an AC cycle) after the contacts are closed.
>
> Locked-Rotor Current (also called In-Rush or Starting Current): the root mean square (RMS) current the motor draws between peak inrush and the time it reaches full operating speed. Design B units have a "normal" starting current of approximately five times the full-load current. Design A motors are six to seven times the full-load current because of the design tradeoffs necessary to increase peak torque.
>
> Full Load Amps: the amount of current the motor can be expected to draw under full-load (torque) conditions when operating at the rated voltage. This value is printed on the nameplate.

ATTENTION: Higher efficiency motors generally have a slightly higher locked-rotor current than lower-efficiency motors. Therefore, replacing a lower efficiency motor with a NEMA Premium motor may cause nuisance tripping in some applications. This is seldom a problem for Design B motors where the maximum allowable locked-rotor current is defined. It is more common with Design A motors where the maximum allowable locked-rotor current is not defined. For more information, please refer to U.S. Department of Energy Tip Sheet, "Avoid Nuisance Tripping with Premium Efficiency Motors," available on the EERE website, http://www1.eere.energy.gov/industry/bestpractices/tip_sheets_motors.html

Design: NEMA design letters (A through D) are an indication of the shape of the torque-speed curve. The designation also defines a number of electrical and mechanical criteria including but not limited to: voltage rating, frame size, winding temperature requirements, full-voltage starting and locked-rotor torque, pull-up torque, breakdown torque, locked-rotor current, efficiency losses and slip. All performance testing is performed in accordance with IEEE Std 112.

NEMA Premium motors must be *Design A* or *Design B.*

> Design B motors are the dominant type on the market and are used for most applications including fans, pumps, some compressors, and many other types of machinery. Normal torque is defined as that which is produced by a Design B motor.
>
> Design A motors are similar to Design B motors except that the maximum torque and starting currents are higher. A common application for Design A motors is injection molding machines.

Efficiency: the ratio (in percent) of mechanical power output to the electrical power input. Apparent efficiency is the product of a motor's efficiency and its power factor.

NEMA's MG1 defines both "energy-efficient" and "NEMA Premium-efficient" performance levels for open and closed enclosures for each motor size between 1 and 500 hp. The "energy-efficient" performance levels are the same as those specified in EPAct 1992 (the federally mandated minimum efficiency) where the two specifications overlap. The term "energy efficient" is sometimes misinterpreted in the market as "premium-efficient".

Power factor (in percent): the ratio between the real power (measured in W or kW) and the apparent power (measured in VA or kVA). Power factor is related to core length, material properties, and air gap among other things. It is generally better for larger motors than for smaller ones. ASDs can have negative effect on power factor. Capacitors are often used to correct low power factor. It is not a design criterion for NEMA Premium motors.

Slip (in percent or rpm): the difference between the motor's synchronous (design) speed and its actual speed. Since power consumption is related to the cube of the speed, slip becomes an important consideration in centrifugal applications like fans and centrifugal pumps.

ATTENTION: To avoid unintentional increases in power consumption when replacing a motor, program administrators should consider the application to assess whether changes in the slip rate will be of concern, e.g. centrifugal loads.

Service Factor specifies the capacity of the motor to withstand prolonged overload conditions. When the service factor is 1.0, prolonged operation above full load can damage the insulation and cause the motor to fail. If the service factor is 1.15, the motor can work at 1.15 times its rated horsepower without failing, although insulation life may be reduced. Service factors as high as 1.5 are available on special order. In general, the class of insulation on the motor windings determines the service factor.

Temperature Rise the amount of temperature rise that can be expected within the windings of the motor when going from non-operating (cool condition) to full load and continuous operation.

Torque (in pound-feet, pound inches, ounce-feet, or percent of full-load torque): the twisting force exerted by the motor shaft on the load. There are many defined terms related to torque such as pull-out torque, peak torque and pull-up torque. Two commonly used definitions are:

> Locked-Rotor Torque (also called Starting Torque): the amount of torque the motor produces when energized at full-rated voltage with the shaft locked in place. It is the

amount of torque available when the motor is energized to break the load away (start it moving) and begin accelerating it up to speed.

Full-Load Torque the rated continuous torque that the motor can support without overheating within its time rating.

8. Efficiency Program Participation

Current Program Approaches

A large majority of the CEE members who provide incentives for large motors (≥250 hp) do so on a custom basis[11]. Approaches include both direct and third-party programs (such as standard performance contracting). Incentives may be provided on a case-by-case basis or within the context of a larger project proposal. According to program administrators, the benefits of following a custom approach include more accurate forecasting of projected energy savings, opportunities to identify additional system savings (like installation of adjustable speed drives), and reduced risk of promoting an inappropriate motor. Many administrators are comfortable with a custom approach in light of the small number of large motor requests they receive each year (often < 5% of overall applications) and the fact that large motors are often special orders and application-specific.

Generally, incentive payments are based on the calculated savings arising from the difference in efficiency between the old motor and its replacement. Because these motors are so large, small increases in efficiency can generate significant savings and most programs provide incentives for any motor which exceeds the EPAct 1992 minimum standard. The calculations account for specific operating parameters such as run hours, percent load and current motor efficiency (nameplate or measured).

Recommended Program Strategies

As stated in section 2, CEE recommends that participating programs adopt a custom approach to promoting large, low-voltage, general-purpose motors that meet or exceed NEMA Premium efficiency levels where appropriate and offer assistance to help identify the highest performance level that is economically feasible for each application.

CEE recommends a custom approach for the following reasons:

1. Large motors - by their very nature - are costly to purchase and to operate. As a result, the financial consequences of promoting a premium-efficiency motor when it may not be the appropriate choice can be more significant than for smaller motors.
2. The amount of energy consumed by large motors is more sensitive to changes in operating parameters than for small motors. Because there is wide variation in large motor applications, basing savings calculations on assumed operating parameters is more likely to lead to inaccurate projections.
3. A nationally applicable baseline cannot be established. There is no federal minimum standard for large motors. Baseline performance cannot be inferred from "typical" or "mass market" operating parameters given the large regional variation in C&I customers

[11] For specific information about how individual programs are addressing large motors, please refer to the CEE Motor and Drive Program Summary posted on the CEE web site, http://www.cee1.org/ind/motrs/2004_MS.pdf.

across North America. Finally, a baseline cannot be predicated on available product models since the 2001 introduction of the NEMA Premium brand into the market has affected the distribution of motors offered for sale in the U.S.

Terminology: CEE recommends encouraging customers to consider purchasing motors which meet or exceed the NEMA Premium Specification. Specifying NEMA Premium can help customers avoid mistakes when purchasing the higher efficiency they desire. It may also serve to raise awareness among those who are uninformed about these products. CEE recommends using the terms "meets or exceeds NEMA Premium" or "NEMA Premium efficient or higher" for motors that meet or exceed the NEMA Premium specification; and "Energy Efficient" or "EPAct Level" for motors that meet the EPAct 1992 minimum federal efficiency standard.

Educational and Promotional Materials: To promote consideration of NEMA Premium motors in appropriate applications, program administrators are encouraged to incorporate clear terminology in relevant program descriptions, flyers and other promotional materials as well as in educational materials, presentations and workshops. Program administrators are also encouraged to educate account representatives, channel managers and others within the organization about motor efficiency definitions, life-cycle costing and other relevant information. Informing staff, trade allies and customers about proper terminology can alleviate confusion about efficiency performance in the market.

Leveraging Trade Allies: Working in a coordinated fashion with local vendors and trade allies may result in increased awareness levels and increased demand for NEMA Premium motors within program territories[12]. Program support enhances the credibility of manufacturer claims regarding potential savings for large motors. In working with CEE to develop the NEMA Premium brand, the motor manufacturers and their trade association, NEMA, embraced the concept of premium efficient motors. By promoting the brand to their customers, program administrators, manufacturers and other trade allies are delivering mutually supported messages to their customers.

9. Current Program Approaches to Establishing a Baseline

Program administrators have shared their strategies for establishing baseline information in both custom and prescriptive approaches[13]. In custom programs, the old motor's nameplate efficiency is commonly used as the baseline for calculating projected savings. For motors without nameplate data, some programs reference the MotorMaster+ 4.0 *Table of Pre-EPAct Motors Efficiencies*. This table was developed by DOE in the early 1990s based on motors available for sale in the market at that time. The Motor Decisions Matter campaign (with the support of the campaign sponsors) references this table in both the *1-2-3 Approach to Motor Management* and the *Annual Estimated Savings Chart* for motors without nameplate efficiencies (see Appendix C, Table C1).

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[12] In addition, CEE staff are available to facilitate coordination with MDM vendors and other trade allies at the local level. Please contact Ilene Mason for more information, imason@cee1.org.

[13] For specific information about how individual programs are addressing large motors, please refer to the CEE Motor and Drive Program Summary posted on the CEE web site, http://www.cee1.org/ind/motrs/2004_MS.pdf.

As an added consideration, some efficiency programs assume that age and/or previous repairs are likely to have reduced a motor's efficiency and discount the nameplate value accordingly. Efficiency reductions from ½% to 1 ½ % have been identified. There is some controversy in this approach, however. A recent EASA study demonstrated that motor repair can have a range of effects on efficiency depending on the specific procedures followed[14] . These effects ranged all the way from improvement to degradation. MDM's *1-2-3 Approach to Motor Management* assumes best-practice repair procedures and no resulting change in efficiency. The MotorMaster+ 4.0 software inserts a ½% reduction in efficiency for motors that have been repaired which the user can override.

Another source of data that may be considered when developing a baseline is NEMA's Energy-Efficient (EE) specification[15] . The efficiency values listed in this table are equivalent to those specified in the EPAct 1992 legislation for motors common to both specifications. Unlike EPAct 1992, however, NEMA EE includes motors up to 500 hp (see Appendix C, Table C2).

[14] *The Effect of Repair/Rewinding on Motor Efficiency: EASA/AEMT Rewind Study*, EASA, 2003 (http://www.easa.com/indus/rwstdy1203.pdf)

[15] As defined by NEMA MG-1 2003 Table 12-11

CEE PREMIUM-EFFICIENCY MOTORS INITIATIVE

NEMA PREMIUM™ EFFICIENCY SPECIFICATIONS FOR 250-500 HP MOTORS

(Terms of Usage follow)

EFFECTIVE DATE: TBD

Table 1: Nominal Full Load Efficiencies for Industrial Three-Phase Motors 250-500 hp ODP, NEMA Design A and B, Low-voltage, General Purpose, 1200, 1800 and 3600 RPM

Open Drip-Proof (ODP)			
	1200 RPMs	1800 RPMs	3600 RPMs
HP	NEMA Premium Efficient[1]	NEMA Premium Efficient[1]	NEMA Premium Efficient[1]
250	95.4	95.8	95.0
300	95.4	95.8	95.4
350	95.4	95.8	95.4
400	95.8	95.8	95.8
450	96.2	96.2	95.8
500	96.2	96.2	95.8

Table 2: Nominal Full Load Efficiencies for Industrial Three-Phase Motors 250-500 hp TEFC, NEMA Design A and B, Low-voltage, General Purpose, 1200, 1800 and 3600 RPM

Totally Enclosed Fan-Cooled (TEFC)			
	1200 RPMs	1800 RPMs	3600 RPMs
HP	NEMA Premium Efficient[1]	NEMA Premium Efficient[1]	NEMA Premium Efficient[1]
250	95.8	96.2	95.8
300	95.8	96.2	95.8
350	95.8	96.2	95.8
400	95.8	96.2	95.8
450	95.8	96.2	95.8
500	95.8	96.2	95.8

[1] EPAct 2005 requires all federal motor purchases to meet FEMP-designated performance requirements. FEMP has adopted requirements that are equivalent to these NEMA Premium specification levels.

CEE PREMIUM-EFFICIENCY MOTORS INITIATIVE
NEMA PREMIUM^{TM} EFFICIENCY SPECIFICATIONS FOR 250-500 HP MOTORS

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Appendix B: Results of CEE's Analysis of the Motors Catalogued in DOE's MotorMaster+ 4.0 Software

Early in the consideration process (December 2004), the Motor & Motor Systems Committee raised several basic questions regarding the performance, availability and incremental cost of 250-500 hp motors. Specifically, the questions were:

1. Are the energy efficiency gains for 250-500 hp motors (non-NEMA Premium to NEMA Premium) equivalent to those seen in smaller motors?
2. Is there a significant difference in the amount of slip exhibited by 250-500 hp motors than by smaller motors?
3. How does the incremental cost difference between the NEMA Premium and non-NEMA Premium models compare?
4. Are there sufficient products available?

To answer these questions, CEE contracted with Washington State University to provide an analysis of the motors listed in the MotorMaster+ 4.0 database. The results of that analysis appear below. For more information about the data, analysis plan or the results, please contact Ilene Mason, imason@cee1.org.

Question 1: Motor Efficiency

To assess the significance of the efficiency improvements available through the use of NEMA Premium motors, we compared mean nominal efficiencies for motors 100-200 hp with motors 250-500 hp for three motor classes (all motors; motors which meet or exceed the NEMA Premium efficiency; and motors that fall below the NEMA Premium value). The differences were then quantified based on the standard deviation which had been calculated for that category and compared to the nominal efficiency defined by the NEMA Premium specification.

This was a unique approach to assessing efficiency. Specifically, we assumed that the "normal" mix of products one would expect to find in the market had been skewed upward by the introduction of the NEMA Premium brand in 2001. Therefore the number of NEMA Premium models available could not be used to approximate their market share. This shift in product mix, combined with the mandated minimum performance criteria for 1-200 hp motors (due to the enactment of the 1992 EPAct legislation), rendered CEE's normal process for establishing "premium performance" levels unsuitable. Therefore, in this analysis, we compared the mean efficiency deltas for categories of motors under consideration to categories where CEE had defined performance levels prior to the market adoption of EPAct and NEMA Premium. During the discussions, there was general agreement that this methodology for comparing the efficiency levels of motors above and below 200 hp was logical and reasonable. For more information, please contact Ilene Mason, imason@cee1.org.

Results:

Conventional wisdom was that large motors are generally more efficient than smaller ones. Therefore, the efficiency improvement for purchasing a NEMA Premium motor would be smaller. Our analysis did not prove this assumption. Rather, the results showed a larger percentage of motor categories where the mean efficiency fell further below the NEMA Premium nominal value for motors 250-500 hp than for motors 100-200 hp.

Specifically, our analysis showed a larger percentage of size/speed/enclosure categories where the mean efficiency fell more than one standard deviation away from the NEMA Premium specification nominal value for large motors (250-500 hp) than for smaller ones (100-200 hp) (see Table 1) . Another unexpected result was that there were a number of categories where the category mean fell more than two standard deviations from the NEMA nominal value for these large motors. (Obviously, there were no categories of motors <200 which fell this far from the nominal due to EPAct 1992's mandated minimum efficiency levels.)

Table 1: Distribution of Mean Efficiency Relative to NEMA Premium Nominal Values

Motor Size	# Categories	# Motors	Percentage of Categories that are within 1 'Ω below nominal	Percentage of Categories that are between 1 and 2 'Ω's below nominal	Percentage of Categories that are more than 2 'Ω's below nominal
ALL Motors: Closed					
100-200 hp	12	607	50%	50%	0%
250-500 hp	18	332	56%	33%	11%
ALL Motors: Open					
100-200 hp	12	374	83%	17%	0%
250-500 hp	18	185	80%	13%	7%
Non-NEMA Premium Motors Only: Closed					
100-200 hp	12	406	17%	83%	0%
250-500 hp	18	229	0%	80%	20%
Non-NEMA Premium Motors Only: Open					
100-200 hp	12	184	50%	50%	0%
250-500 hp	18	111	7%	93%	0%

<u>Question 2: Motor Slip</u>

Since power consumption is related to the cube of the speed, slip becomes an important consideration in centrifugal applications like fans and centrifugal pumps. Replacing a motor with a more efficient model but which has less slip may actually increase the amount of power consumed and so is an important consideration. We anticipated that large motors would generally exhibit less slip than smaller ones.

Results: No firm conclusions could be drawn from this analysis. A brief, subsequent look at individual motor data in two categories (by WSU) showed significant variation in the amount of slip exhibited by motors within a given category. The data suggests that for slip-sensitive applications (like pumps and fans), the data needs to be considered on an individual basis.

Question 3: Motor Costs

Definition: This analysis looked at the difference in mean cost between NEMA Premium and non-NEMA Premium motors for each of the sixty categories based on manufacturer reported prices contained in the MotorMaster+ database.

Results: The data showed that the difference in list price between NEMA Premium and non-NEMA Premium motors was consistently greater for motors 250-500 hp than for motors 100-200 hp. It is important to keep in mind that this analysis looked at reported pricing. Actual motor costs are likely to vary by region, purchase quantity, the buyer/seller relationship, existing contracts, or other relevant factors.

Question 4: Motor Availability

There are a reasonable number of NEMA Premium products available in most categories. Specifically, products were available in 54 of the 60 categories we analyzed; 45 of the 60 categories had ten or more motor models listed. Three categories had less than three motors (n<3). NEMA posts a table listing the participating manufacturers who provide products in various categories on their web site, http://www.nema.org/gov/energy/efficiency/premium/.

Based on manufacturer information, additional products are also available. Our analysis was based on motors reported in the MotorMaster+ 4.0 database and includes only "standard" or "off-the-shelf" models. According to the manufacturers, more configurations are available but, since they are often considered specialty items, are not included in the MotorMaster+ listing. Specialty in this case may refer to special testing, specific performance characteristics, or special mounting configurations.

Appendix C, Table 1: Comparing Efficiency Specifications

MotorMaster+ 4.0 PreEpact Default Values : NEMA Premium Specification MG1-1998 (rev 3 2002) Table 12-12

Note: There is a seeming discrepancy between this Appendix and the conclusions drawn regarding efficiency in Appendix A. This discrepancy is due to the difference in the data sources. This table provides information about performance specifications while the Appendix A data provides information regarding the models available in the market today.

Open Drip-Proof (ODP)							Totally Enclosed Fan-Cooled (TEFC)						
	1200 RPMs		1800 RPMs		3600 RPMs			1200 RPMs		1800 RPMs		3600 RPMs	
HP	MM+ 4.0 Pre- 1992 Defaults[16]	NEMA PREMIUM Efficient[17]	MM+ 4.0 Pre- 1992 Defaults[10]	NEMA PREMIUM Efficient[11]	MM+ 4.0 Pre- 1992 Defaults[10]	NEMA PREMIUM Efficient[11]	HP	MM+ 4.0 Pre- 1992 Defaults[10]	NEMA PREMIUM Efficient[11]	MM+ 4.0 Pre- 1992 Defaults[10]	NEMA PREMIUM Efficient[11]	MM+ 4.0 Pre- 1992 Defaults[10]	NEMA PREMIUM Efficient[11]
1	74.5	**82.5**	77.6	**85.5**	76.2	**77**	***1***	73.4	**82.5**	76.7	**85.5**	73.0	**77.0**
1.5	77.6	**86.5**	79.3	**86.5**	77.3	**84**	***1.5***	77.9	**87.5**	79.1	**86.5**	75.2	**84.0**
2	79.9	**87.5**	80.5	**86.5**	79.6	**85.5**	***2***	78.3	**88.5**	80.8	**86.5**	78.9	**85.5**
3	81.7	**88.5**	82.4	**89.5**	79.1	**85.5**	***3***	80.4	**89.5**	81.5	**89.5**	79.6	**86.5**
5	83.6	**89.5**	83.8	**89.5**	82.6	**86.5**	***5***	83.1	**89.5**	83.3	**89.5**	82.4	**88.5**
7.5	85.5	**90.2**	85.2	**91.0**	82.9	**88.5**	***7.5***	84.4	**91.0**	85.5	**91.7**	82.6	**89.5**
10	87.4	**91.7**	86.1	**91.7**	85.0	**89.5**	***10***	85.0	**91.0**	85.7	**91.7**	85.0	**90.2**
15	87.0	**91.7**	87.8	**93.0**	86.6	**90.2**	***15***	87.0	**91.7**	86.6	**92.4**	85.7	**91.0**
20	87.7	**92.4**	88.3	**93.0**	88.1	**91.0**	***20***	87.7	**91.7**	88.5	**93.0**	86.6	**91.0**
25	89.0	**93.0**	88.9	**93.6**	88.5	**91.7**	***25***	88.9	**93.0**	89.3	**93.6**	87.5	**91.7**
30	89.5	**93.6**	88.9	**94.1**	87.7	**91.7**	***30***	89.6	**93.0**	89.6	**93.6**	87.7	**91.7**
40	89.4	**94.1**	90.0	**94.1**	88.6	**92.4**	***40***	89.9	**94.1**	90.2	**94.1**	88.5	**92.4**
50	89.7	**94.1**	90.7	**94.5**	89.1	**93.0**	***50***	90.6	**94.1**	91.3	**94.5**	89.0	**93.0**
60	90.8	**94.5**	91.3	**95.0**	90.4	**93.6**	***60***	90.8	**94.5**	91.8	**95.0**	89.4	**93.6**
75	91.5	**94.5**	91.9	**95.0**	90.4	**93.6**	***75***	91.6	**94.5**	91.7	**95.4**	90.6	**93.6**
100	92.2	**95.0**	92.1	**95.4**	90.5	**93.6**	***100***	91.4	**95.0**	92.3	**95.4**	90.9	**94.1**
125	92.0	**95.0**	92.2	**95.4**	91.2	**94.1**	***125***	92.1	**95.0**	92.2	**95.4**	90.9	**95.0**
150	92.6	**95.4**	92.8	**95.8**	91.7	**94.1**	***150***	93.1	**95.8**	93.0	**95.8**	91.5	**95.0**
200	92.9	**95.4**	93.0	**95.8**	91.5	**95.0**	***200***	92.6	**95.8**	93.5	**96.2**	92.7	**95.4**
250	94.1	**95.4**	94.4	**95.8**	93.0	**95.0**	***250***	94.4	**95.8**	94.2	**96.2**	94.7	**95.8**
300	94.4	**95.4**	94.6	**95.8**	93.9	**95.4**	***300***	94.4	**95.8**	94.4	**96.2**	94.7	**95.8**
350	94.5	**95.4**	94.1	**95.8**	94.2	**95.4**	***350***	94.3	**95.8**	94.6	**96.2**	94.7	**95.8**
400	95.4	**95.8**	94.7	**95.8**	94.4	**95.8**	***400***	95.0	**95.8**	94.8	**96.2**	94.8	**95.8**
450	95.4	**96.2**	95.0	**96.2**	94.6	**95.8**	***450***	95.0	**95.8**	94.9	**96.2**	94.5	**95.8**
500	95.4	**96.2**	95.0	**96.2**	94.6	**95.8**	***500***	95.0	**95.8**	94.9	**96.2**	94.5	**95.8**

[16] These values are taken from DOE's MotorMaster+ database (circa 1992) for standard motors referenced to the NEMA 6-B. Source: Personal communication with Gilbert McCoy, P.E. Energy Systems Engineer, OIT Clearinghouse, August 19, 2003. They are used as default values for pre-EPAct 1992 motors by MotorMaster+ 4.0 and MDM's *1-2-3 Approach to Motor Management*.

[17] This is NEMA's "Premium-Efficient" specification level (MG1-1998 (Rev 3 2002) Table 12-12). It is equivalent to CEE's Premium Motor Specification for motors common to both. It also meets the Federal Energy Management Program (FEMP) designated performance requirement for federal motor purchases.

Appendix C, Table 2: Comparing Efficiency Specifications

NEMA Energy Efficient Spec MG1-1998 (rev 3 2002) Table 12-11 : NEMA Premium Spec MG 1-1998 (rev 3 2002) Table 12-12

Note: There is a seeming discrepancy between this Appendix and the conclusions drawn regarding efficiency in Appendix A. This discrepancy is due to the difference in the data sources. This table provides information about performance specifications while the Appendix A data provides information regarding the models available in the market today.

Open Drip-Proof (ODP)							Totally Enclosed Fan-Cooled (TEFC)						
	1200 RPMs		1800 RPMs		3600 RPMs			1200 RPMs		1800 RPMs		3600 RPMs	
HP	NEMA EE : Energy Efficient[18]	NEMA PREMIUM Efficient[19]	NEMA EE: Energy Efficient[12]	NEMA PREMIUM Efficient[13]	NEMA EE: Energy Efficient[12]	NEMA PREMIUM Efficient[13]	HP	NEMA EE: Energy Efficient[12]	NEMA PREMIUM Efficient[13]	NEMA EE: Energy Efficient[12]	NEMA PREMIUM Efficient[13]	NEMA EE: Energy Efficient[12]	NEMA PREMIUM Efficient[13]
1	80.0	**82.5**	82.5	**85.5**	…	**77.0**	***1***	80.0	**82.5**	82.5	**85.5**	75.5	**77.0**
1.5	84.0	**86.5**	84.0	**86.5**	82.5	**84.0**	***1.5***	85.5	**87.5**	84.0	**86.5**	82.5	**84.0**
2	85.5	**87.5**	84.0	**86.5**	84.0	**85.5**	***2***	86.5	**88.5**	84.0	**86.5**	84.0	**85.5**
3	86.5	**88.5**	86.5	**89.5**	84.0	**85.5**	***3***	87.5	**89.5**	87.5	**89.5**	85.5	**86.5**
5	87.5	**89.5**	87.5	**89.5**	85.5	**86.5**	***5***	87.5	**89.5**	87.5	**89.5**	87.5	**88.5**
7.5	88.5	**90.2**	88.5	**91.0**	87.5	**88.5**	***7.5***	89.5	**91.0**	89.5	**91.7**	88.5	**89.5**
10	90.2	**91.7**	89.5	**91.7**	88.5	**89.5**	***10***	89.5	**91.0**	89.5	**91.7**	89.5	**90.2**
15	90.2	**91.7**	91.0	**93.0**	89.5	**90.2**	***15***	90.2	**91.7**	91.0	**92.4**	90.2	**91.0**
20	91.0	**92.4**	91.0	**93.0**	90.2	**91.0**	***20***	90.2	**91.7**	91.0	**93.0**	90.2	**91.0**
25	91.7	**93.0**	91.7	**93.6**	91.0	**91.7**	***25***	91.7	**93.0**	92.4	**93.6**	91.0	**91.7**
30	92.4	**93.6**	92.4	**94.1**	91.0	**91.7**	***30***	91.7	**93.0**	92.4	**93.6**	91.0	**91.7**
40	93.0	**94.1**	93.0	**94.1**	91.7	**92.4**	***40***	93.0	**94.1**	93.0	**94.1**	91.7	**92.4**
50	93.0	**94.1**	93.0	**94.5**	92.4	**93.0**	***50***	93.0	**94.1**	93.0	**94.5**	92.4	**93.0**
60	93.6	**94.5**	93.6	**95.0**	93.0	**93.6**	***60***	93.6	**94.5**	93.6	**95.0**	93.0	**93.6**
75	93.6	**94.5**	94.1	**95.0**	93.0	**93.6**	***75***	93.6	**94.5**	94.1	**95.4**	93.0	**93.6**
100	94.1	**95.0**	94.1	**95.4**	93.0	**93.6**	***100***	94.1	**95.0**	94.5	**95.4**	93.6	**94.1**
125	94.1	**95.0**	94.5	**95.4**	93.6	**94.1**	***125***	94.1	**95.0**	94.5	**95.4**	94.5	**95.0**
150	94.5	**95.4**	95.0	**95.8**	93.6	**94.1**	***150***	95.0	**95.8**	95.0	**95.8**	94.5	**95.0**
200	94.5	**95.4**	95.0	**95.8**	94.5	**95.0**	***200***	95.0	**95.8**	95.0	**96.2**	95.0	**95.4**
250	95.4	**95.4**	95.4	**95.8**	94.5	**95.0**	***250***	95.0	**95.8**	95.0	**96.2**	95.4	**95.8**
300	95.4	**95.4**	95.4	**95.8**	95.0	**95.4**	***300***	95.0	**95.8**	95.4	**96.2**	95.4	**95.8**
350	95.4	**95.4**	95.4	**95.8**	95.0	**95.4**	***350***	95.0	**95.8**	95.4	**96.2**	95.4	**95.8**
400	…	**95.8**	95.4	**95.8**	95.4	**95.8**	***400***	…	**95.8**	95.4	**96.2**	95.4	**95.8**
450	…	**96.2**	95.8	**96.2**	95.8	**95.8**	***450***	…	**95.8**	95.4	**96.2**	95.4	**95.8**
500	…	**96.2**	95.8	**96.2**	95.8	**95.8**	***500***	…	**95.8**	95.8	**96.2**	95.4	**95.8**

[18] This is NEMA's "Energy-Efficient" designation (MG1-1998 (Rev 3 2002) Table 12-11). It is equivalent to EPACT 1992 for motors common to both performance specifications.

[19] This is NEMA's "Premium-Efficient" specification level (MG1-1998 (Rev 3 2002) Table 12-12). It is equivalent to CEE's Premium Motor Specification for motors common to both. It is also equivalent to FEMP- designated performance requirement for federal motor purchases.

Appendix D: Historical Background

EPAct 1992 and CEE: In 1992, the federal government mandated a minimum efficiency level for all three-phase, squirrel cage, low-voltage, general-purpose motors in the 1-200 horsepower size range sold in the U.S. The legislation is commonly referred to as EPAct 1992. Recognizing the opportunity to promote motors with higher efficiency levels than EPACT 1992 required, CEE developed a premium energy efficiency specification for the same classes of motors. The efficiency levels specified were generally two NEMA efficiency bands (Table 12-10, NEMA MG-1 Revision 3) above those required by EPACT. This voluntary specification covered the following motors:

speed	2, 4, and 6 pole
size	1-200 hp
design	NEMA A and B
enclosure type	ODP and TEFC
voltage	low voltage

NEMA and CEE: In 2001, there remained a great deal of confusion in the marketplace as to what constituted the most efficient motors currently available in the market. NEMA, CEE, and other stakeholders responded by developing and adopting the NEMA Premium specification in 2001. This voluntary specification was adapted from the CEE criteria and serves as the benchmark for premium energy efficient motors. NEMA Premium also denotes a brand name for motors which meet this specification. The NEMA Premium Specification (Tables 12-12 and 12-13 of MG-1, Revision 3) covers a wider range of motors than the EPACT 1992 and CEE Specifications:

speed	2, 4, and 6 pole
size	1-500 hp
design	NEMA A and B
enclosure type	open and enclosed
voltage	low and medium voltage
class	general, definite, and special purpose

CEE Today: In 2005, CEE's Motors & Motor Systems Committee members began considering whether to revise the CEE Premium Motor Specification to more closely align with the NEMA Premium Specification. As a first step in this process, the committee considered the category of low-voltage motors from 250-500 hp and in 2006 recommended including those motors in the CEE Specification. Given the application-specific nature of these large motors, however, and the possible large-scale consequences of incorrectly promoting a NEMA Premium motor when it may not be the appropriate choice, the group also supported developing a guidance document that would highlight the potential energy savings as well as provide general performance and application information that would be helpful to those interested in providing incentives for these motors.

EPAct 2005: Section 104 of the Energy Policy Act of 2005 requires federal agencies to procure only Energy Star-qualified or FEMP- designated products except where such products will not be cost-effective over their life or no product is reasonably available.

The Federal Energy Management Program (FEMP) has designated performance requirements for general purpose motors of 1-500 horsepower (low voltage) and 250-500 horsepower (medium voltage). FEMP's performance requirements match NEMA Premium performance levels and also match CEE's performance levels for motors of 1-200 horsepower (low voltage).