Reducing Electricity Cost through Use of Premium Efficiency Motors

Guillermo J. Costa

Management Summary

A report published in 1998 by the U.S. Department of Energy showed that electric motor applications consume approximately 679 billion kilowatt-hours, i.e.—63% of all electricity used by U.S. industry. The Department of Energy report also revealed that the electrical consumption of these industrial motors could be reduced by up to 18 percent if "proven efficiency technologies and practices" were applied by businesses. Thus, efforts directed toward the replacement of standard industrial motors with premium efficiency counterparts presents businesses with a significant opportunity to reduce operating costs. A comparison between premium and standard efficiency motors from 0.25 to 10 horsepower is conducted; comparisons of full-load efficiencies are shown, and estimated payback periods are calculated. Methods for calculating the yearly kilowatt-hour consumption and yearly cost savings of premium efficiency motors for this horsepower range are also given. The cost advantages of premium efficiency motors are summarized, and relevant examples of real world cost savings are shown.

The need for energy efficiency continues to become increasingly important in various industries as energy costs continue to rise and competitive pressures increase. When these factors are coupled with the uncertainty of available electricity—such as during the California electricity crisis of 2000–2001 (Refs. 1–2)—potential actions on the part of businesses that increase the overall efficiencies of their operations gain increasing relevance. Of course, seeking a profit advantage over competitors is hardly novel, and premium efficiency motors are unique in that they allow a business to realize cost savings while changing very little of its current operating procedures. And, in many cases, switching to premium efficiency motors is all a business needs to recoup cost savings that are worth several times the cost of the motors. This practice of continued energy improvements is not only a wise business philosophy, but is also a legal requirement: the Energy Policy Act of 1992 established minimum efficiency stan-

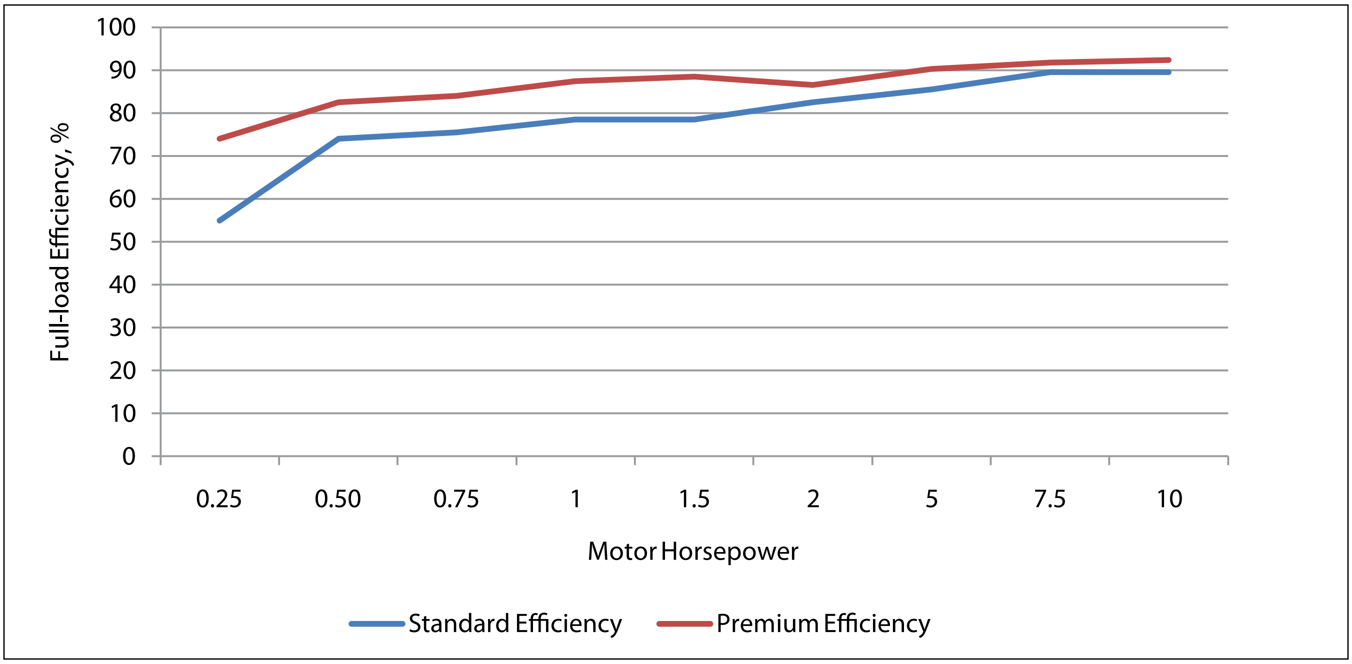

Figure 1—Comparison of full-load efficiency ratings by horsepower—standard versus premium efficiency class motors.

dards for all industrial electric motors manufactured after October 1997, yet only about 10 percent of all motors currently in use comply with these minimum levels (Ref. 4). Newer laws, such as the Energy Independence and Security Act of 2007, impose even more stringent standards of energy efficiency (Ref. 5). Even a cursory examination of the industrial landscape regarding the future of electric motors demonstrates a constant trend towards increased motor efficiency. Thus, the employment of premium efficiency motors rather than their standard efficiency counterparts represents a very real potential cost savings for industry.

Factors That Determine Energy Costs

There are several key factors that determine the electrical cost of a facility; however three are the most crucial to reducing energy costs. These factors are (Ref. 6):

1. Kilowatt-hour consumption
2. Fuel charge adjustments
3. Kilowatt demand

Kilowatt-hour consumption. Kilowatt-hour consumption is the easiest of the four factors for most to understand, as it is the most familiar measure of energy consumption. The kilowatt-hour consumption rate is the amount of electrical energy that has been consumed during a given billing period; the total consumption is then determined at a given interval (usually monthly). Note that this rate does not differentiate between when or how the energy was used.

Fuel charge adjustments. Fuel charge adjustments are given within the same billing period as kilowatt-hour consumption, and represent an adjustment cost based upon the utility's cost of producing power. The fuel charge adjustment is normally given as a rate- per-kilowatt-hour consumed. Note that this adjustment may change several times per year, based upon the utility's production needs. For instance, if waterpower can contribute greatly during the spring to the utility's ability to produce electricity, the fuel charge adjustment might be very low; conversely, if the utility then has to burn a great amount of oil or coal later in the year to meet its production needs, the fuel charge adjustment will increase.

Kilowatt demand. Demand is based upon the amount of power consumed during a given period of time and is perhaps the least understood factor in determining energy costs (Ref.7). Demand is measured in kilowatts, and is used to determine the amount and type of equipment (transformers, wire, generators, etc.) needed by the utility to supply a customer's maximum energy consumption at any given time. In many ways, kilowatt demand is analogous to the horsepower rating of a car: the engine is sized for the maximum amount of energy needed to accelerate the car at a predetermined rate at any point in time, although the actual amount of horsepower used at a given time might be relatively low, such as when cruising at a steady speed on the freeway. Similarly, kilowatt demand is not constant throughout the day, but can vary as equipment is turned on

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Nomenclature	
C	electricity cost in dollars-per-kilowatt-hour
E	motor nameplate efficiency
E_{pe}	nameplate efficiency of premium motor, decimal
E_s	nameplate efficiency of standard motor, decimal
HP_{load}	average load horsepower
K	kilowatt-hours
S	dollar savings per year
$T_{operating}$	operating hours per year

and off as needed. Note that kilowatt demand is never zero; even during periods of shutdown, certain constant-load devices such as lighting, HVAC and security systems incur a demand.

Additional Advantages of Premium Efficiency Motors

Reduced lifetime cost. In order to fully understand the advantages of premium efficiency motors, one must look beyond the initial purchase price of the motor itself, which in many cases is 15–30% greater than the acquisition cost of a standard efficiency motor of identical output (Ref. 8). This difference in acquisition cost is due to the differences in design between the two motor types: premium efficiency motors feature larger-diameter copper windings, laminations of higher steel grades, specially designed precision air gaps between the rotor and stator, etc.

However, one must keep in mind that the initial purchase price of a motor will account for less than 2% of the motor's total lifetime cost. The bulk of the motor's lifetime cost is in its electricity use, which accounts for up to 97% of a motor's lifetime cost (Refs. 9–10). For instance, if a motor has a purchase price of $1,600, its total energy costs would be over $80,000 (Ref. 11). The difference in initial purchase price also quickly becomes irrelevant when one considers that the energy savings quickly eclipse the difference in acquisition costs, which in many cases means that the motor has recouped the difference in purchase price in just a few months, and a large percentage of premium efficiency motors have paid for themselves completely through energy savings in less than two years (Ref. 12). Of course, the savings continue even after the motor has paid for itself, and over the course of its useful life, a premium efficiency motor will repay many times its original value (Ref. 13).

Increased motor life and ancillary savings. The design differences between the standard and premium

Table 1—Operating Cost and Savings Comparison at Continuous Operation—Standard versus Premium Efficiency.

Type	Data	Horsepower								
		0.25	0.50	0.75	1	1.5	2	5	7.5	10
Standard	Efficiency	55	74	75.5	78.5	78.5	82.5	85.5	89.5	89.5
	Annual consumption, kWh	2,970	4,416	6,492	8,325	12,487	15,843	38,216	54,672	73,016
	Average purchase price	$120.32	$140.63	$149.65	$175.89	$179.17	$188.19	$259.94	$589.38	$629.33
	Annual operating cost	$464.28	$690.14	$1,014.65	$1,301.16	$1,951.75	$2,476.16	$5,973.18	$8,559.34	$11,412.45
Premium	Efficiency	74	82.5	84	87.5	88.5	86.5	90.2	91.7	92.4
	Annual consumption, kWh	2,200	3,947	5,815	7,443	11,038	15,058	36,101	53,092	70,789
	Average purchase price†	$191.76	$320.23	$349.68	$388.53	$410.47	$410.47	$449.36	$886.11	$983.24
	Price difference	$71.44	$179.60	$200.03	$212.64	$231.30	$222.28	$189.42	$296.73	$353.91
	Annual operating cost	$343.89	$616.92	$908.85	$1163.33	$1725.28	$2353.56	$5642.55	$8298.23	$11064.31
	Efficiency Difference	19%	8.5%	8.5%	9%	10%	4%	4.7%	2.2%	2.9%
	Annual savings, kWh	770.24	468.50	676.88	881.84	1448.91	784.34	2115.36	1670.55	2227.40
	Annual savings, dollars	$120.39	$73.23	$105.8	$137.83	$226.47	$122.59	$330.63	$261.11	$348.14
	Differential payback period, years	**0.59**	**2.45**	**1.89**	**1.54**	**1.02**	**1.81**	**0.57**	**1.14**	**1.02**
	Total payback period, years	**1.59**	**4.37**	**3.31**	**2.82**	**1.81**	**3.35**	**1.36**	**3.39**	**2.82**

† Average purchase price from factory-authorized distributors, not list price from vendor.

efficiency motors are more than just superficial. Premium efficiency motors will tend to run cooler than standard efficiency motors, resulting in less wear on motor bearings, lubricants and insulators. This reduced operating temperature also generates less waste heat into the air (Ref. 10) surrounding the motor, leading to reduced ventilation and air conditioning requirements for the motor and yielding additional energy savings. Premium efficiency motors will also operate with less slip than a conventional motor, resulting in an increase in output shaft rotation speed. Additionally, premium efficiency motors offer a reduction in operating cost even at zero-load. Given the tighter tolerances in design and manufacturing, premium efficiency motors will tend to last longer than their standard efficiency counterparts, reducing maintenance and replacement costs.

Premium Efficiency Motor Costs and Savings Calculations

The most important aspect of premium efficiency motors is that the difference in efficiency is not constant throughout a given horsepower range. Typically, the difference in motor efficiency will be greatest for smaller-horsepower motors, and the greatest difference in efficiency is found in the fractional horsepower range, as shown in Fig. 1. This must be taken into account when analyzing a given application for possible cost savings to be found through premium efficiency motors.

Simple calculations can show the cost savings that may be realized by premium efficiency motors in any given situation. These are given by the following equations:

$$K = \frac{HP_{load} \cdot 0.746 \cdot T_{operating}}{E} \quad (1)$$

$$S = 0.746 \cdot HP_{load} \cdot C \cdot T_{operating} \left[\frac{1}{E_s} - \frac{1}{E_{pe}} \right] \quad (2)$$

As may be seen, operating costs and potential savings are directly related to motor horsepower, motor efficiency and the number of hours that a motor operates. The savings gained from switching to a premium efficiency motor are directly related first and foremost to the motor's rated horsepower and the number of hours per year that the motor will be in operation. Due to the reduced field slip of premium efficiency motors (resulting in higher output shaft rotation speeds), "sizing down" a motor for an application becomes a possibility, as shown in the story of International Paper, which appears later in this article.

Real-World Examples of Cost Savings with Premium Efficiency Motors

Although premium efficiency motors represent a significant potential for cost savings in most applications, the savings opportunities they present are more than mere theory. The following stories illustrate several real-world cases where premium efficiency motors yielded a significant increase in value to the businesses that utilized them (Refs. 16–20).

General Electric Supply. General Electric is one of the founders of the electrical industry in the United States, and has been in the electric motor business for over 100 years. GE Supply, a subsidiary of General Electric, began distributing electric motors in the 1920s. GE Supply has noticed that as the customer base for electric motors becomes smaller, the competition among distributors to increase or maintain motor sales becomes increasingly fierce. Premium efficiency motors allow GE Supply to provide its customers with a value-added alternative to conventional motors, despite the marketplace being traditionally price-driven.

Crown Pacific Lumber Company. Crown Pacific conducted an ener-

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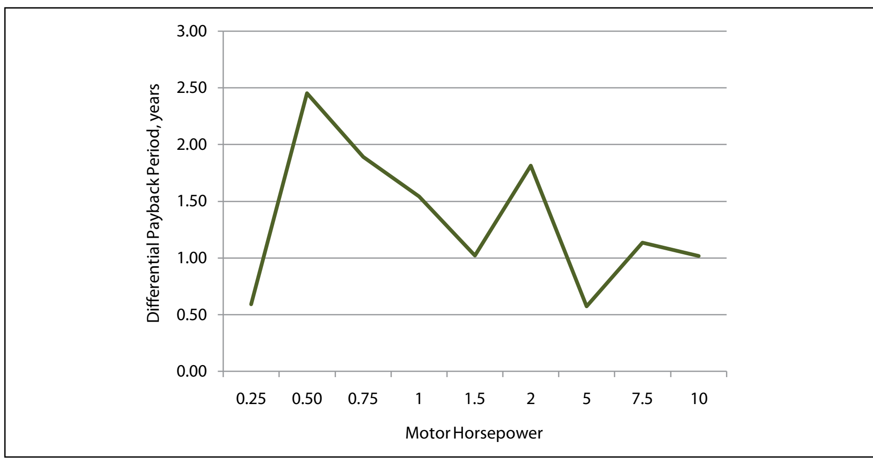

Figure 2—Calculated differential payback period by motor horsepower, based on average purchase price from distributor.

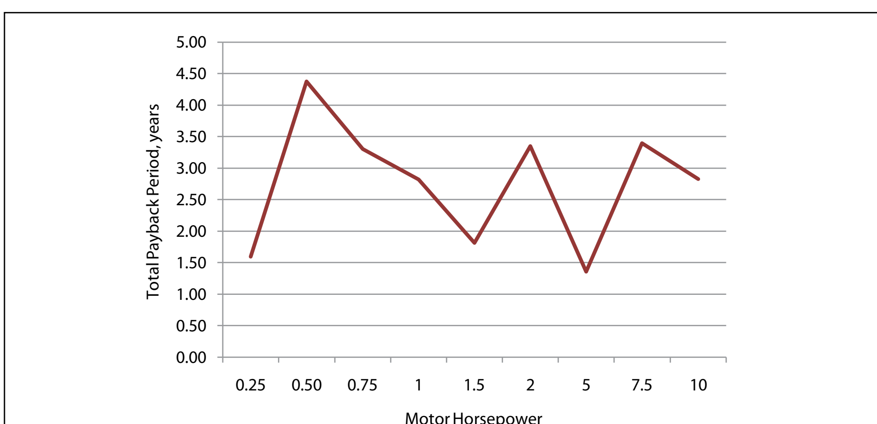

Figure 3—Calculated total payback period by motor horsepower, based on average purchase price from distributor.

NOTE: Figure 2 shows the amount of time required for the motor to pay back the difference in purchase price between itself and its standard efficiency counterpart; Figure 3 shows the amount of time required for a premium efficiency motor to pay back the entirety of its initial purchase price. Generally speaking, premium efficiency motors should be considered when a standard efficiency motor is due for rewinding or replacement, or when designing new machines or processes. Savings may also be realized by replacing standard efficiency motors that have already been rewound, are oversized or are under loaded. Premium efficiency motors are best able to return significant cost savings to the user when the motor's annual operation exceeds 2,000 hours (Ref. 15).

gy survey of over 300 motors at the Gilchrist mill near La Pine, Oregon in 2000 and early 2001. Two standard efficiency motors, which were operating the mill's air compressors, were discovered to cost over $49,000 per year to operate. Subsequent investigation revealed that these motors were operating at a nominal efficiency of just 89%. One of these motors was replaced with a premium efficiency equivalent, which saved Crown Pacific $3,400 per year in operating costs and over 100,000 kWh of electricity. The payback period for this motor swap was 1.8 years.

Weyerhaeuser Company. With over 50,000 electric motors in operation company-wide—or approximately 81% of the company's electrical load—finding the most efficient motor possible became crucial to the $20 billion company. However, they also needed an efficient motor that reduced unplanned downtime and maintenance costs. A multidisciplinary team led by Weyerhaeuser senior scientist John Holmquist selected the Reliance 841 XL Premium Efficiency motor as the company's go-to motor for its applications. Replacing the larger motors at its North American Paper Corporation facility in Longview, Washington—which produces enough newsprint to reach to the moon and back every two weeks—saw a significant cut in the plant's average monthly power bill of $4 million. These savings, combined with incentives and rebates from local utility companies, produced payback periods for the premium efficiency motors in less than one year.

Hydraulic Institute. The Hydraulic Institute (HI) has provided industry standards, education and information exchange to the pumping industry for over 85 years. Recently, HI has been engaged in an ongoing endeavor to develop new industry standards for optimized pump designs and reductions in life cycle costs, and premium efficiency motors have been the key to this effort. Because pumps are used in such a wide variety of industrial processes—chemical, oil and gas, forestry and irrigation, among others—HI recognized the enormous savings potential inherent in optimized system design, and premium efficiency motors were the cornerstone of their plan. HI's 200-page guide, "Pump Life Cycle Costs: A Guide to LCC Analysis for Pumping Systems," brought premium efficiency motors to the forefront of the pump industry, and has received high praise for providing guidelines to reduce the operating costs of each element of a pump system.

International Paper. The International Paper plant in Courtland, Alabama was experiencing vibration and cavitation issues with a white water pump that had been installed in the facility in the 1970s. The pump's high vibration levels—0.6 to 0.7 inches per second—led to bearing failures, packing defects, misalignment and increased maintenance costs due to impeller damage. This gave the pump motor a mean time between failures of nine months. Traditional solutions, including laser leveling, precision blade balancing of the impeller, wear plates and new pump casings, did nothing to alleviate the problem. The company finally turned to the root cause failure analysis (RCFA) process. RCFA focused the company's attention to specific failure mode analyses, leading to the discovery of cavitation damage on the low-pressure side of the impeller, denoting a suction issue. The plant ultimately decided to install a new pump designed to run at a lower speed than the original, and the new pump was to be powered by a premium efficiency motor.

Using a premium efficiency TEFC motor, the plant saw almost immediate results. The new pump motor's operating temperature dropped by 75°F, reducing the thermal growth misalignment from 0.006 to 0.001 and vastly improving motor life. Motor bearing temperatures decreased by 30°F, improving lubricant life and performance. The reduced energy consumption created more reliability for control valves, allowing valves that had been run at 20–30% open to now be run 50–70% open. In the five years since the premium efficiency motor has been installed, the pump has not needed any maintenance work whatsoever.

Conclusion

Premium efficiency motors allow for a realization of significant cost savings, and will often pay for themselves many times over during their useful life. Their advantages of reduced energy consumption—even at zero load—higher rotation speeds at a given voltage and prolonged operating life should weigh heavily on the minds of businesses faced with the possibility of replacing their standard efficiency motors with premium efficiency alternatives. Although slightly more expensive than standard motors, it has been demonstrated that a premium efficiency motor will pay back the difference in acquisition cost via energy savings quickly, oftentimes in less than two years. In some instances, the motor's savings would pay for the entire acquisition cost of the motor in 18 months or less. This is, of course, neglecting the additional cost savings presented by utility companies in the form of discounts and rebates for using premium efficiency motors.

Premium efficiency motors, however, are not a panacea for all problems. Because of the reduced field slip, certain applications—such as centrifugal loads (compressors, fans, etc.)—will see an energy consumption equal to the cube of the application's rotational speed. Thus, increasing the rotational speed of the motor without the use of reduction gearing or variable-frequency drives in these applications may cause energy usage to increase with a premium efficiency motor. However, proper facility planning and correct motor specification for a given application will maximize the cost savings potential of using a premium efficiency motor.

The greatest difference in efficiency between motor classes was found to be for one-quarter- and 1.5-horsepower motors (19% and 10%, respectively). But this efficiency differential does not necessarily translate into the greatest cost savings, as the five-horsepower motor was found to have shorter payback periods than the 1.5-horsepower motor, despite the five-horsepower motor's lower efficiency differential. Likewise, it was determined payback periods were not linear with respect to motor horsepower. The premium efficiency motors with the greatest economic return to the user were found to be the one-quarter- and five-horsepower variants. Each of these not only had the shortest differential payback (0.59 and 0.54 years, respectively), but also the shortest total payback (1.59 and 1.36 years, respectively). Yearly cost savings in total dollars were found to be directly related to output horsepower, though the five-horsepower motor is again an outlier in this regard. Research showed that the five-horsepower premium efficiency motor yielded an annual dollar savings nearly on par with the 10-horsepower motor. Therefore, efforts to increase plant efficiency via reductions in operating costs should focus primarily on replacing one-quarter- and five-horsepower motors with premium efficiency variants. The five-horsepower motor is of particular importance in this regard, as it is very common in a large variety of industrial applications.

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Guillermo "Willie" Costa *has been with L.A.-based Mechanical Belts & Drives for the past seven years, leading most of the company's Lean Six Sigma and marketing initiatives. He has designed a number of the fabrication tools and equipment used at the company—mostly jobsite-related—cutting templates and tables. He also ran Mechanical Belts & Drives' returns and repairs operations for two years. He presently attends Cal Poly Pomona, studying aerospace engineering, and has done two internships for NASA and some contract design work of his own.*