Impacts of Performance Factors on Savings from Motor Replacement and New Motor Programs

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This paper assesses the impact of motor loading, speed, and power factor on peak and energy savings from the substitution of efficient new motors for standard new motors. Efficient motors are compared to an average of standard motors from the five high-volume manufacturers, based on analysis of manufacturer's data. The results are weighted by size-of-motor and sales-by-size-class to provide an estimate of the aggregate impacts if a program reached the entire motor market. The reliability of the published data used to perform this analysis is assessed. Program implications are delineated.

The direction and magnitude of impacts varies greatly for individual motors, but patterns are fairly consistent among classes and sizes of motors. (1) On average, efficient motor savings are 11% greater at 60% loading than 100% loading. (2) For centrifugal loads where there is no adjustment to compensate for greater speed, the average efficient motor runs faster, losing 25% of savings. (3) Efficient motors, on average, have higher power factor and lower demand than standard motors. If there is no preexisting power factor compensation in the electric system, the demand decrease and power factor increase cause efficiency gains on the combined utility/customer transmission and distribution system equivalent to a 59% increase in the end-use savings. Energy savings are increased by an average of 50% during the on-peak hours and 39% during the off-peak hours. The power factor-related savings vary by utility, depending on typical marginal peak and energy transmission and distribution losses.

Introduction

This paper provides a summary of the basic approach and results of an analysis of how motor energy and demand savings are influenced by three critical performance variables: (1) motor loading, (2) operating speed, and (3) the effect of demand and power factor changes on T&D losses. We chose to examine these factors because they were some of the most important sources of uncertainty regarding estimates of savings from the motor segments of electric utility efficiency programs targeted at new construction and equipment replacement. Recent analyses have documented, on an anecdotal basis, how differences in motor speed caused by reduced motor slip in efficient motors, as compared to standard motors, can reduce or eliminate efficiency-related savings (E-Source 1993). This problem is most extreme for cube law (centrifugal) applications, where the motor is pushing against a fluid or air subject to a cubic resistance function, and where there is no control system which reduces motor speed, or hours to account for greater work at higher speed. Field research conducted by a major New England utility had indicated that none of motors installed on cube law loads in their programs had involved adjustments to equalize the speed with that of the old motor (Savage 1994). Motor loading and power factor were known by motor experts to have a measurable effect on savings, but we could not find a study which dealt with the issues in combination or on more than an incidental sample.

The availability of a comprehensive database of manufacturer-provided motor performance information (WSEO 1993), and a market study which included estimates of motor sales by type, speed, and size and brand (Easton 1992), made it feasible to study a population of motors which was at least crudely representative of sales in a region, and then readily analyze performance data on those motors. We decided to (1) assemble such a sample, (2) perform basic comparisons of performance characteristics of commonplace motors, (3) use the data with established engineering principles to estimate affects of these factors on savings, and then (4) perform a sales-weighted aggregation of the results to assess overall impact of each factor individually, and in combination, on sales in the market.

Defining the Baseline for Analysis

Based on program experience, we concluded that motors installed through equipment replacement and new building programs often replace motors of the same brand, because many dealers emphasize one brand for a certain range of applications. However, market research (Easton 1993) shows that some dealers carry multiple lines, so same-brand replacement may not always occur. The possibility of cross-brand replacement complicates definition of the baseline (or the point of comparison) for assessing motor savings.

The objective of a utility program should be to get the most efficient cost-effective motor possible in place in each application. To assess overall program success, the comparison to the "average" baseline is most appropriate, in that it is a consistent yardstick for measuring each efficient motor. This is also the most appropriate baseline for evaluation, in that it makes no specific judgement about what brand motor would have been selected without the program. This assumption also greatly simplifies evaluation by allowing for calculation of one baseline for all motors. Results presented in this paper use this technique.

However, from the perspective of a customer or a dealer participating in the program, the pertinent point of comparison for a qualifying motor is the single motor which would have been installed absent the program. To represent how some of the choices facing individual consumers might look, we performed same-brand comparisons with the same size, speed, and type of motor, in addition to comparing to an average baseline. For brevity, these results are not presented in this paper. While the relative performance of specific motors differed depending on the baseline, the overall magnitude and direction of the results were, in aggregate, similar.

Sample Selection

In this study, performance characteristics are compared for two categories of motors differentiated by their efficiency levels, "qualifying" motors and "standard" motors. "Qualifying" motors are all motors with efficiency levels which qualify for the conservation program of a major New England utility (NEPSCO 1993). These efficiency standards are among the highest (most efficient) among utility programs, and meet or exceed published NEMA standards for all motor categories. In defining "standard" motors, we included all motors which were not "qualifying."

Data from a study of the motor market in Southern New England (Easton 1992) was used to identify matched groups of motors intended to represent the highest volume "qualifying" and "standard" motors.

- The five manufacturers with the largest sales were identified.
- The motor type and nominal speed classifications with the highest sales were identified; 1800 RPM Totally Enclosed Fan Coil (TEFC), 3600 RPM TEFC, and 1800 RPM Open Drip Proof (ODP).
- A cross-section of motors speeds were chosen for study: 2, 3, 5, 7.5, 10, 50, and 100 horsepower motors. The size classes were not based strictly on the motors' sales volume. They were selected to represent a wide range of sizes, with higher representation of the smaller sizes. Both motor volume and potential aggregate savings are greatest in the smaller size classes (Easton 1992).

The resulting 21 motor classifications (three speed/types classifications multiplied by seven sizes) directly represent 63% of motors sold in Southern New England. Because the sizes cover a wide range, these motors are assumed to be fairly representative of the intermediate sizes not covered (e.g., 75 HP). Ideally, the plan was to sample one "qualifying" and one "standard" motor each from each combination of brand, speed/type, and size. This would result in a total of 5 x 3 x 7 = 105 qualifying and 105 standard motors. [1]

Individual motor performance data were obtained from a motor characteristics database (WSEO 1993). For a given nominal speed, size, and type (e. g., 1800 RPM, 25 horsepower, totally enclosed fan coil), dozens, and sometimes hundreds, of different motors are available. Many of these are "specialty" motors, intended to meet unusual torque or loading requirements, work in very dirty environments, operate at less common voltages, etc.

For each of the 105 nominal speed/size/type/brand combinations studied, we selected one individual motor each in the "qualifying" and "standard" categories. Where possible, we chose low-cost models with the most commonplace frame types for a given nominal speed, size, and type (e.g., 215T) because these are usually the highest volume motors. We chose motors with variants on the most common frame type (e.g., L215T), or specialized motors, only when there was no motor with the more common frame type available at a low price.

All of the five top-selling brands sell "qualifying" motors for some nominal speed/type/size combinations. However, for some brands, there was no efficient and/or standard motor for a specific nominal speed/type/size class. In these cases, we proceeded with fewer motors in the sample. For some sizes and classes, a manufacturer offered two low-cost, common-frame motors: one with a higher efficiency and the other with a higher power factor. In these cases, we averaged the performance characteristics for the two.

Overall, the analysis included 107 different "standard" and 88 "qualifying" motors. This is a very small fraction of the available motors, but is likely to include many of the most commonplace ones and have performance characteristics similar to many of the rest.

Data Analysis

Calculation of Differences between Qualifying and Standard Motors

For each size, type, nominal speed, and brand, we calculated the difference between the qualifying and standard motor in efficiency, power factor, and speed. We performed this calculation separately for 100% and then 60% motor loadings. 60% was chosen as a rounded version of 62%, an estimate of average motor loading in the subject utility's conservation programs from a prior empirical study (Hill 1994).2 As expected, we found that motor speed was faster for efficient motors, on average, raising the possibility of loss of savings for cube law applications.

First the qualifying motor was compared to the standard motor from the same brand. Then, separately, the qualifying motor was compared to the 5-brand average for standard motors. The data for 60% loading was obtained by interpolating linearly between the listings in the database for 75% and 50% loading. While this process is not precise, no data is available for a large population of motors at loadings between 50% and 75%.

The slip at 60% loading was calculated as slip at 100% loading x 60%. Although slip is not perfectly linear with loading, most experts believe that a linear approximation is close to correct (E-Source 1993).

Resulting changes in efficiency with motor size, differences in speed, and differences in power factor, were summarized by type of motor, size, and nominal speed. Horsepower-weighted averages were developed for all sizes, by type and nominal speed, and then, for all motors studied.

Calculation of Impacts on Savings

The impact of slip on the percent of load saved for cube law loads was calculated based on the following relationships. Changes in motor horsepower vary as the cube of motor speed. This is expressed by the equation:

$$BHP_1/BHP_2 = (RPM_1/RPM_2)^3$$

Where BHP is brake horsepower and RPM is speed, in revolutions per minute, and the subscripts refer to the efficient and standard motors. This basic equation (Fan Law 1) was then used to account for increases in speed due to the reduced slip of high-efficiency motors, and the consequent higher loadings on the motor (Trane). The relationship between brake horsepower and motor horsepower was accounted for by use of the following terms:

BHP = motor horsepower x fraction loaded

Note that the overall equation shown directly above does not account for system effects discussed in Endnote 3. These are thought to have a very small impact on the results.

The impact of power factor and demand differences was assessed next. The focus was the impact of these factors on resistive losses in the power transmission and distribution system. The impact of power factor improvement, demand drop due to efficiency increase, and demand increase due to increased slip, were factored together. Changes in electrical system power (kW) due to changes in electrical system losses (I^2R) were accounted for by the following equations (Roadstrum and Wolaver):

KW changes (I^2R) = kVA changes x electrical system losses

$$\blacktriangle kW_{I2R} = \blacktriangle kVA \times (\%\ \text{system losses}/100)$$

where kVA (apparent power) changes are characterized by:

$$\text{total } \blacktriangle kVA = (\blacktriangle kVA\ \text{efficiency}) + (\blacktriangle kVA\ \text{slip}) + (\blacktriangle kVA\ \text{power factor})$$

A key input into this calculation is the typical marginal transmission and distribution system losses from combined utility and customer systems. Utility system losses were estimated based on prior utility studies. These losses are 23% for peak, 18% for on-peak energy, and 13% for off-peak energy. On-peak is defined as the period from 8 AM to 9 PM Monday through Friday.

Typical in-facility losses were estimated by a building electrical system designer to be 5.75% for industrial facilities and 7.75% for commercial facilities. These were averaged for the system analysis.[4] The in-facility and utility system loss estimates were added together.

These calculations were integrated into a series of spreadsheets, first to calculate the additive effect of loading, speed, and power factor for each class of motor studied, and then for the sales-weighted averages.

Summary of Results

The results presented in this paper are pertinent only to the new and replacement motor markets, because we compared the qualifying motors to standard motors which were available for sale in 1993. We did not have data to compare to typical standard motors which are currently in use in the field. This would be appropriate for analyzing retrofit programs.

In each section of the following summary, results are presented for the comparison with the 5-brand baseline, because it is most pertinent for resource planning. Detailed results are presented in Tables 1 through 4. These tables compare savings with the indicated adjustments to a baseline savings estimate, which is computed as the rated efficiency at 100% load multiplied by the rated load (e.g., 60%). This baseline represents prior evaluation methods. Several key results are summarized below.

- Among all motors studied, average savings are about 11% higher at 60% load than at 100% load, ignoring the issues of differential speed and power factor. This difference was not consistent among motors and brands; some improved much more than others at part load.

- Among all motors studied, increased speed of efficient motors, relative to standard motors, reduces savings by an average 25%, if the motor serves a cube law load with no compensating control or speed adjustment. Within each class of motor, this difference was far greater for some motors than others. For a major utility in Southern New England, about 40% of motors affected by the utility's programs served cube law loads (HBRS 1993). These consist primarily of fans and pumps with no variable speed control or other feedback device (e. g., variable inlet vane) which shuts off, or slows, the motor if more work is done. The weighted average loss of savings is therefore 25% x 40% = 10%.

- On average, qualifying motors have a 1.3% higher rated power factor at 60% load than standard motors. Both the direction and magnitude of change in power factor between standard and qualifying motors varied greatly by brand within many classes.

- Transmission and Distribution savings associated with the power factor change and the overall change in demand from the motor add an average of 59% to coincident utility demand savings. The addition to on-peak energy savings was 50%. The addition to off-peak energy savings was 39%. Most of the demand and power factor-related added savings (77% of the added savings for peak, 73% for on-peak energy, and 64% for off-peak energy) are on the utility system, will not accrue to the customer, and will not reduce utility rate revenues. However, utility generation needs may be significantly reduced.

- When the three factors discussed above are combined for cube law loads, average coincident utility demand, on-peak energy, and off-peak energy savings are increased by an average of 32%, 25%, and 15%, respectively. For non-centrifugal loads and centrifugal loads with compensating controls or adjustments for speed (assuming that speed for these motors does not significantly impact energy use), savings are increased by an average of 77% for peak, 67% for on-peak energy, and 54% for off-peak energy. Assuming that 40% of motors serve centrifugal loads with no adjustment, the overall impact on program savings is an increase of 59% of coincident demand savings, 50% for on-peak energy savings, and 38% for off-peak energy savings.

- There are many qualifying motors which have high increases in speed, poor power factor, or both, compared to either same-brand or 5-brand average baselines. These factors can significantly degrade savings. These "worst offenders" may save little or nothing where adjustments are not made to motor speed or power factor. Unless corrections are made, these motors may not be appropriate for efficiency programs and may significantly decrease average savings.

Applications

Subject to the concerns expressed in the Caveats, Concerns, and Need For Refinement section, there are several potential implications of these data for program evaluation and delivery.

Evaluation

First, the results of this study can be used in evaluations to estimate typical program savings in a way which realistically reflects the factors assessed. Motor savings

Table 1. Combined Data on All Motors Studied (Combining the Results of Tables 2, 3, and 4)

Motor Size	% Efficiency Gain From Qualifying Motor											Combined Effects					
	@ 100% Load	@ 60% Load Unadjusted		@ 60% Load Adjusted		Motor @ 60% Load Slip and PF Adjusted						Including Slip Adjustment			Excluding Slip Adjustment		
	% Pt	% Pt	Chng	% Pt	Chng	% Efficiency Pts			Savings Change								
						(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
2	4.6	6.4	39%	5.1	-20%	10.3	9.4	8.5	102%	84%	67%	124%	105%	85%	181%	157%	132%
3	7.7	7.2	-6%	5.1	-29%	8.6	8.0	7.4	69%	57%	45%	12%	4%	-4%	58%	47%	36%
5	6.2	7.1	15%	5.0	-30%	7.2	6.8	6.5	44%	36%	30%	17%	10%	5%	66%	56%	49%
7.5	5.5	5.8	6%	3.8	-34%	7.2	6.7	6.1	89%	76%	61%	31%	22%	11%	100%	86%	70%
10	4.7	4.5	-4%	3.1	-31%	5.0	4.6	4.3	61%	48%	39%	6%	-2%	-9%	54%	42%	33%
50	3.6	4.6	28%	4.0	-13%	5.5	5.2	4.9	38%	30%	23%	53%	45%	36%	76%	66%	57%
100	3.2	3.9	22%	2.8	-28%	4.1	3.9	3.6	46%	39%	29%	28%	22%	13%	79%	70%	57%
Wt Avg	5.3	5.9	11%	4.4	-25%	7.0	6.6	6.1	59%	50%	39%	32%	25%	15%	77%	67%	54%

(1) = Peak (2) = Peak Energy Period (3) = Off-Peak Energy Period

Table 2. Results of Motors Analysis -- 5 Brand Average Baseline: 3600 RPM TEFC

Motor Size	% Efficiency Gain From Qualifying Motor											Combined Effects					
	@ 100% Load	@ 60% Load Unajusted		@ 60% Load Adjusted		Motor @ 60% Load Slip and PF Adjusted						Including Slip Adjustment			Excluding Slip Adjustment		
	% Pts	% Pts	Chng	% Pts	Chng	% Efficiency Pts			Savings Change								
						(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
2	6.0	6.1	2%	6.2	2%	7.6	7.4	7.1	23%	19%	15%	27%	23%	18%	25%	21%	16%
3	8.2	9.5	15%	8.5	-11%	16.3	14.9	13.6	92%	75%	60%	98%	81%	65%	121%	102%	84%
5	5.7	7.4	30%	5.9	-20%	11.2	10.2	9.4	90%	73%	59%	96%	79%	65%	146%	124%	107 %
7.5	6.6	8.3	25%	6.7	-19%	12.0	11.0	10.2	79%	64%	52%	80%	65%	53%	124%	105%	90%
10	5.0	6.2	23%	4.6	-26%	7.2	6.8	6.3	57%	48%	37%	43%	35%	25%	92%	81%	68%
50	4.2	5.5	30%	5.1	-7%	7.8	7.3	6.9	53%	43%	35%	85%	73%	64%	99%	87%	76%
100	3.3	4.4	33%	3.8	-14%	4.9	4.8	4.6	29%	26%	21%	48%	45%	39%	72%	68%	61%
Wt Avg	5.7	7.1	24%	6.0	-15%	10.1	9.4	8.7	68%	57%	45%	76%	64%	52%	109%	94%	80%

(1) = Peak (2) = Peak energy Period (3) = Off-Peak Energy Period

Table 3. Results of Motors Analysis -- 5 Brand Average Baseline: 1800 RPM TEFC

Motor Size	% Efficiency Gain From Qualifying Motor											Combined Effects					
	@ 100% Load	@ 60% Load Unajusted		@ 60% Load Adjusted		Motor @ 60% Load Slip and PF Adjusted						Including Slip Adjustment			Excluding Slip Adjustment		
	% Pts	% Pts	Chng	% Pts	Chng	% Efficiency Pts			Savings Change								
						(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
2	3.7	6.4	73%	4.8	-25%	11.1	10.0	8.9	131%	108%	85%	200%	170%	141%	300%	260%	221%
3	7.2	6.5	-10%	4.6	-29%	7.9	7.3	6.7	72%	59%	46%	10%	1%	-7%	55%	43%	31%
5	5.9	6.8	15%	4.8	-29%	5.9	5.7	5.5	23%	19%	15%	-0%	-4%	-7%	41%	36%	32%
7.5	4.7	4.9	5%	3.4	-31%	6.1	5.6	5.2	79%	65%	53%	30%	20%	11%	88%	73%	60%
10	4.3	3.9	-9%	3.4	-13%	5.4	5.0	4.7	59%	47%	38%	26%	16%	9%	44%	33%	25%
50	3.1	4.4	41%	3.9	-11%	5.0	4.8	4.6	28%	23%	18%	60%	54%	47%	81%	74%	66%
100	3.0	4.0	32%	2.9	-28%	4.0	3.8	3.6	38%	31%	24%	32%	26%	19%	83%	74%	64%
Wt Avg	4.8	5.4	12%	4.0	-26%	5.9	5.5	5.2	48%	38%	30%	22%	14%	8%	65%	54%	45%

(1) = Peak (2) = Peak Energy Period (3) = Off-Peak Energy Period

Table 4. Results of Motors Analysis -- 5 Brand Average Baseline: 1800 RPM ODP

Motor Size	% Efficiency Gain From Qualifying Motor											Combined Effects					
	@ 100% Load	@ 60% Load Unajusted		@ 60% Load Adjusted		Motor @ 60% Load Slip and PF Adjusted						Including Slip Adjustment			Excluding Slip Adjustment		
	% Pts	% Pts	Chng	% Pts	Chng	% Efficiency Pts			Savings Change								
						(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
2	5.7	6.4	12%	5.0	-22%	10.8	9.7	8.8	116%	94%	76%	88%	69%	53%	141%	116%	96%
3	8.3	7.8	-7%	5.6	-28%	7.6	7.2	6.9	36%	29%	23%	-9%	-14%	-17%	27%	20%	15%
5	6.8	7.6	11%	5.5	-28%	8.7	8.1	7.6	58%	47%	38%	27%	18%	11%	76%	63%	53%
7.5	6.6	6.5	-1%	4.4	-32%	8.8	8.0	7.3	100%	82%	66%	34%	22%	11%	98%	80%	64%
10	5.3	5.0	-6%	2.5	-50%	4.1	3.9	3.6	64%	56%	44%	-23%	-27%	-32%	54%	46%	35%
50	4.2	4.7	11%	3.7	-21%	5.5	5.2	4.9	49%	41%	32%	30%	23%	16%	65%	56%	47%
100	3.5	3.6	4%	2.6	-28%	4.7	4.3	4.0	81%	65%	54%	35%	24%	15%	87%	71%	59%
Wt Avg	5.9	6.1	3%	4.3	-30%	7.2	6.7	6.2	67%	56%	44%	21%	13%	5%	72%	60%	48%

(1) = Peak (2) = Peak Energy Period (3) = Off-Peak Energy Period

estimates for replacement and new building programs are often based on engineering estimates, using tracking systems to identify efficient motors installed and generic assumptions about "typical" standard motors. These estimates usually base savings on full-load efficiency differences. The better evaluations reduce savings due to part-loading of motors (Mass Electric 1993), but do not factor in the differences in efficiency gain at part load, impacts of motor speed, or power factor. Using the methods employed in this analysis, a utility can account for these factors on a systematic basis, either for a sample of all motors available (as was done in this study) or for the specific motors sold.

Program Implementation

Subject to resolution of power factor issues discussed in the next section, the methods employed in this study can be used to easily and meaningfully establish standards for motor qualification for programs which reflect the effect of loading, slip, and power factor on savings. However, before proceeding, utilities outside the Northeast may wish to develop their own data on motor sales for their service territories. Other utilities may also wish to replicate the study of motor loadings to see if the factors used in this paper are appropriate. For non-centrifugal loads, or centrifugal loads where there are compensating controls or adjustments for speed, the appropriate gauge for qualifying motors is power factor-adjusted efficiency at typical loadings (e.g., 60%). The appropriate gauge for centrifugal loads where there is no compensating adjustment is power factor-adjusted, slip-adjusted savings at typical loadings.

Use of these modified standards is likely to result in the inclusion of additional motors and exclusion of some motors currently eligible for the program. The net result of these steps will be significantly increased average real savings through inclusion of motors with high real savings and exclusion of motors with low real savings. In setting program eligibility standards, it continues to be important to ensure that there are qualifying motors which fit a wide variety of motor applications. This should not be a problem; it is likely that as many additional motors are qualified as are disqualified.

In addition to setting up better eligibility standards for programs, the analysis method (which, once worked out, is relatively simple) can be used by vendors and utility representatives to help customers select among program-eligible motors those motors which optimize savings to the customer, by maximizing power factor and matching speed from old and new motors. To assist in this, we have completed an additional set of analyses assessing the impacts on resistive losses on the customer distribution system only (excluding utility system losses). For customers who do not correct power factor, and are not penalized for power factor imbalances by the utility, their primary concern is losses on their side of the meter, as reflected in this alternative analysis. Customers who are concerned about the impact of low power factor on other systems in the building, or who are subject to utility rate penalties for low power factor, would be very eager to avoid low power factor motors.

The net result of better customer screening will be more savings and fewer customers who paid for illusory savings (and are consequently disappointed with utility customer assistance).

Caveats, Concerns, and Need for Refinement

There are additional issues which must be cleared up to reach firmer quantitative conclusions about the affects identified in this study.

1. The monetary value to the utility of energy savings from power factor reduction may be different from the value of other savings. Utilities can correct power factor on their system through hardware installed at the meter or in the substation. This has a cost, but it is not the same cost as for generation. Furthermore, some of the equipment investments have already been made, resulting in sunk costs which cannot be saved. However, utilities may sometimes correct power factor so far from the load in the transmission and distribution system that much of the losses on the transmission and distribution system still occur. Utilities also don't correct power factor to unity (E-Source 1993), often correct power factor in steps, and do not correct instantaneously. Thus, much of the savings indicated in this study may have full value to utilities. These issues merit further investigation.

2. The absolute value of both unadjusted and adjusted savings in this study may be biased slightly high, because the baseline is exclusively low-cost standard motors. There could be a some mid-efficiency motors in the baseline. To use the methods presented in this paper to estimate the absolute value of savings, these motors should be included. Based on a cursory review of the data on these motors, we would not expect this to change the magnitude or direction of the percent adjustments for loading, motor speed, and power factor shown in this paper.

3. It would be ideal to also factor in results for all motor manufacturers. This would be a huge task. We

feel that inclusion of the top five manufacturers gives this study reasonable representativeness.

4. Each of the top selling motor brands was equally weighted within each size and type category. Data were unavailable on sales-by-brand for specific types and sizes. This should have only a minor impact on the overall estimates.

5. Manufacturer's data on motor performance is approximate. For example, RPM may be rounded to the nearest five, and there are acceptable error bands for reported data which are of significant size relative to savings. The aggregation of data across many motor sizes, brands and types reduces the importance of this issue for the analysis presented in this memo. The consistent patterns of effect shown in the results support the contention that the results were not rendered meaningless by random error in manufacturer's data.

6. This data set reasonably represents the potential impact once the replacement and new motor programs begin to saturate most major markets. Utility program participants in any program year are only a part of the market. For now, these are the best data available. If data become available on the specific motors installed in a given year, this type of analysis can be used with such data to provide more precise estimates of impact from a specific program in a specific year.

7. While 60% loading is considered the approximate average for participants at the one utility cited, there is considerable variation around that average for individual motors, even at that utility. Given additional data (and for other utility programs), this estimate of the average may change. This is why the full analysis was run at 100% and 60% loadings; to provide a sensitivity analysis. At 100% loading:

- The 11% increase in savings for lower loadings does not occur.

- The negative impacts of slip increase by about 10/6.

- Power factor improves, on average, for qualifying motors as compared to standard motors, but by much less.

The net impact is that, at 100% load, the average qualifying motor on a cube law load may save a *smaller* percentage of load than nominal efficiencies indicate, whereas at 60% load, the motor saves a *much larger percentage* than nominal efficiencies indicate. On the other hand, cursory observation of the data indicates that, at lower loads, the negative impact of slip decreases further, and the improvement in power factor for qualifying motors increases further. This symmetry of effect around the 60% figure indicates that using the mean produces reasonably unbiased results.

8. This analysis does not account for some factors which may influence savings, such as the relative performance of dual voltage motors on each voltage, use of motors on voltages other than those specified, the efficiency of the motors with respect to voltage fluctuations, etc. By addressing the factors considered most important, we think that this analytic approach provides *better*, albeit imperfect, estimates of motor savings than existed before.

9. Dealer offerings are dynamic; this analysis will need to be updated periodically to retain its pertinence. There is already a revised version of the motor database used to produce this analysis. Now that the analytic tools have been developed, updating will be relatively simple.

10. Results may vary slightly for types of motors not included. However, the direction and magnitude of the results are relatively consistent for the three classes of motors studied. This indicates that this error may not be very large.

11. The impressive added savings due to improved power factor is highly dependent on what the typical *marginal* resistive losses are on the combined utility and customer transmission and distribution systems. This figure may vary significantly between utilities and buildings.

12. Future T&D efficiency improvements may reduce marginal losses and the resulting motor savings. However, T&D efficiency improvements are not necessarily more cost-effective than, or preferable to, improved motor power factor, and should not be assumed in the baseline for estimating savings from motors. In least-cost planning, the least expensive option should be considered first.

13. Motor selection is a complicated issue. Not all customers will be able to select the "best" motor from a power factor or speed perspective, because they need to make sure that other motor characteristics are suitable for a specific application (e.g., starting torque, tolerance of overload, frame type, etc.) However, utilities can still avoid paying for motors which don't save energy through consideration of these factors.

14. Power factor differences appear to be mixed in direction and magnitude with little pattern. Power factor impacts can change magnitude or sign depending on motor loadings. In developing this analysis, it was noted that the sign of power factor differences sometimes changed between 50% and 75% loading. For this reason, utilities or customers with significantly different average loadings from 60% should redo this analysis based on their typical loading.

Summary

This paper demonstrates that (1) motor savings as a percentage of load are, on average, higher at 60% load than at 100% load, (2) efficient motors serving centrifugal loads operating at 60% load lose about a quarter of their savings, on average, due to increased average speed of efficient motors if speed is not corrected, and (3) improved average power factor of efficient motors may significantly add to savings, depending on how power factor is adjusted elsewhere in the system. Another important conclusion is that these factors vary greatly among efficient motors, so more careful selection of motors (by both utility screening and customer selection) can significantly increase energy savings and reduce power factor-related performance problems.

With a small amount of additional research and tool development, the methods demonstrated in this paper can be used to improve motor program evaluation and the selection of motors in the field.

Acknowledgements

This paper was prepared with the financial support of the New England Electric System, and with the organizational support of the Conservation Law Foundation of New England. We also wish to thank the Washington State Energy Office for their excellent MotorMaster database, and Wayne Stebbins of Hoechst-Celanese and Jon Talbot of the RMH Group for their invaluable input during development of the line loss equations. Also, Gary Schroeder of E-Cube for his assistance in deriving various equations.

Endnotes

1. In addition to intermediate sizes of motors, the motors not included in this sample include 1200 RPM motors, 3600 RPM ODP motors, other brands, and very large and very small motors.

2. In calculating loadings from empirical data, the Savage study assumed constant efficiency at various loadings. Our database review indicated that, at 60% loadings, the qualifying motors are .1% more efficient on average than at 100% loadings. This would adjust the 62% factor upward by about one-tenth of one percent. Because this adjustment is so small, relative to the other uncertainties in the analysis, we did not include it in the calculations.

3. To the degree that fan and/or pump systems have some minimum static pressure (head) that they must overcome, the cube law equation tends to overestimate savings. While this can be a large impact for systems whose speed varies greatly (e.g., variable speed drives), the authors feel that this will be of small impact at the high end of the speed range. Since the high end of the speed range is where the changes due to slip are expressed (e. g., a change from 1735 to 1750 RPM), this should not be of major concern. There is a related issue of whether the motor efficiency curve parallels the system efficiency curve, since a large divergence could introduce significant error. Again, the authors do not see this as an issue of great concern. In both cases, while the reader should be aware of these simplifications in the analysis, any errors introduced are expected to be much smaller than uncertainties from other sources as discussed in the paper. Future analysis, however, may benefit from addressing these issues more fully.

4. The estimates were:

Line Losses:	Industrial 1 to 2%
	Commercial 3 to 4%
Transformer Losses:	Industrial 3.5 to 5%
	Commercial 3.5 to 5%

These were averaged to 6.75%.

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