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May 2, 2022

Mr. Jeremy Dommu
U.S. Department of Energy
Office of Energy Efficiency and Renewable Energy
Building Technologies Office, EE-5B
1000 Independence Avenue SW
Washington, DC 20585

Docket Number: EERE-2020-BT-STD-0007
RIN: 1904-AE63

Dear Mr. Dommu:

This letter comprises the comments of the Pacific Gas and Electric Company (PG&E), San Diego Gas and Electric (SDG&E), and Southern California Edison (SCE) in response to the United States (U.S.) Department of Energy (DOE) Preliminary Technical Support Document (PTSD) on Energy Conservation Standards for Electric Motors.

The signatories of this letter, collectively referred to herein as the California Investor-Owned Utilities (CA IOUs), represent some of the largest utility companies in the Western U.S., serving over 32 million customers. As energy companies, we understand the potential of appliance efficiency standards to cut costs and reduce consumption while maintaining or increasing consumer utility of products. We have a responsibility to our customers to advocate for standards that accurately reflect the climate and conditions of our respective service areas.

We appreciate the opportunity to provide the following comments on the preliminary analysis conducted by DOE for purposes of evaluating energy conservation standards for electric motors. We applaud DOE's proposal to expand the scope of the electric motors regulation and suggest different approaches for different electric motor categories proposed for addition to the scope. We continue to affirm the importance of part-load rating metrics for synchronous and inverter-only motors and note that significant energy savings opportunity exists for electric motor regulations which encourage substitution of induction motors with synchronous and inverter-only products.

Electric motors consume approximately 53 percent of world electric energy, and the CA IOUs anticipate that DOE's proposed electric motor regulation will achieve significant, technically feasible, and economically justified national energy savings throughout the commercial and industrial sectors.

The attached report contains supporting data, in-depth analysis, and recommendations on key aspects of the PTSD. A brief summary of CA IOU comments is presented here:

- **Comment 1:** The CA IOUs applaud DOE for including Totally Enclosed Air Over (TEAO) motors in the PTSD and recommend different approaches for moving forward with inverter-only and synchronous electric motors; small, non-small electric motors (SNEMs) and submersible motors.

- For air-over enclosures that otherwise meet the description of a currently regulated “medium” electric motor (AO-MEM), we support finalizing the test procedure rulemaking and establishing energy conservation standards consistent with current energy conservation standards for total enclosed, fan cooled (TEFC) electric motors.
 - For inverter-only and synchronous electric motors, we agree with DOE’s determination to include these motors in the same equipment classes as currently regulated induction motors. We recommend convening an Appliance Standards and Rulemaking Federal Advisory Committee (ASRAC) Working Group to finalize a test procedure and part-load metric for these motors before finalizing a test procedure and energy conservation standards rulemaking.
 - For SNEMs, we also recommend exploring stakeholder interest in convening an ASRAC Working Group to clearly define the scope of an SNEM regulation before moving forward with an energy conservation standard rulemaking.
 - For submersible motors, we encourage DOE to remove submersible electric motors from the current electric motor test procedure rulemaking and collaborate with industry stakeholders in developing a test procedure for this motor category.
- **Comment 2:** The CA IOUs strongly encourage DOE to adopt the use of a metric that is representative of part-load performance for inverter-only and synchronous electric motors.

In the PTSD, DOE based its preliminary analysis for electric motors on a nominal full-load efficiency metric.¹

The CA IOUs provide data in support of the use of a part-load metric for inverter-only and synchronous electric motor applications. This data shows that full load is not an accurate measure of how motors and motor applications operate in the field:

- Comments submitted to the 2021 Test Procedure NOPR by various industry stakeholders affirmed that full-load metrics are not representative of part-load performance for variable torque and speed applications and can result in inaccurate motor selection outcomes for end users with these applications.
 - Analysis of a dataset of electric motor applications from industrial and agricultural facilities in California, as well as a national dataset of commercial buildings, demonstrates that most of these systems operate at part-load.
 - A dataset of 60 commercial and industrial construction projects, including new construction and renovation projects, indicated that most electric motors running fans are oversized and therefore operate at part load. The Northwest Energy Efficiency Alliance (NEEA) observed that electric motors running pumps are on average oversized by 120 percent compared to the pump power at design point.
- **Comment 3:** The CA IOUs support DOE’s determination to analyze synchronous and inverter-only electric motors in the same equipment classes as induction motors.

The CA IOUs provide supporting data to show that synchronous and inverter-only electric motor are designed, marketed, capable, and are being used to replace induction motors:

- Manufacturer reference tables that promote the direct replacement of currently regulated induction motors with synchronous and inverter-only motors.
- Data showing synchronous motor performance exceeding a best-in-class copper cage induction motor paired with a commercially available VFD. This corroborates the PTSD savings estimates for synchronous electric motors.

¹ Tables ES.3.3.3, ES.3.3.4 and ES.3.3.5 of PTSD

- Summary of case studies docketed in response to DOE’s NOPR on Electric Motor Test Procedure published in December 2021, that demonstrate the use of synchronous and inverter-only motors in applications where National Electrical Manufacturers Association (NEMA) Design B motors are typically used.
- **Comment 4:** The CA IOUs strongly suggest that DOE update the maximum technology feasible for electric motors to include, at a minimum, the commercially available technology with the highest efficiency.

The CA IOUs provide data for commercially available electric motors, as well as built and tested prototypes, that exceed the max-tech performance assumption in the current PTSD of IE4.

- **Comment 5:** The CA IOUs encourage DOE to extend maximum application lifetime for NEMA Designs A, B, and C electric motors beyond 30 years in the life-cycle cost analysis.
 - The CA IOUs support DOE’s method of estimating application lifetimes based on mechanical lifetimes and annual operating hours, such that heavily used motors are replaced sooner than motors with lower annual operating hours.
 - We show that the survival application lifetime for NEMA Design A, B, and C electric motors used in the LCC analysis is not representative of a large number of units in some categories.
 - For NEMA Design A, B, and C motors, DOE’s approach produces weighted average application lifetimes of 27 years for 6 to 100 hp motors and 40 years for 101 to 500 hp motors in the industrial sector, and averages of 28 to 29 years for 51 to 500 hp motors in the commercial sector.
 - DOE’s imposition of a 30-year maximum application lifetime in the LCC analysis truncates the application survival curve for 62 to 65 percent for representative units at 150 and 250 hp.
 - We provide data to support a longer maximum application lifetime than 30 years for NEMA Design A, B and C electric motors.

The CA IOUs also provide supplemental cost data for permanent magnet synchronous motors and copper cage induction motors for a range of sizes in Appendix B.

In conclusion, we would like to reiterate our support for DOE's PTSD on Electric Motor Energy Conservation Standards. We thank DOE for the opportunity to be involved in this process.

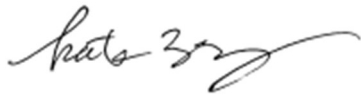
Sincerely,



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Detailed CA IOU Comments on DOE PTSD on Energy Conservation Standards for Electric Motors

Table of Contents

Comment 1: The CA IOUs applaud DOE for including Totally Enclosed Air Over (TEAO) motors in the PTSD and recommend different approaches for moving forward with inverter-only and synchronous electric motors; SNEMs and submersible motors.....	7
Comment 2: The CA IOUs strongly encourage DOE to adopt the use of a metric that is representative of part-load performance for inverter-only and synchronous electric motors.....	9
Section 2.1. Comments submitted to the 2021 Test Procedure NOPR by various industry stakeholders affirmed that full-load metrics are not representative of part-load performance for variable torque and speed applications and can result in inaccurate motor selection outcomes for end users with these applications.....	9
Section 2.2. Analysis of a dataset of electric motor applications from industrial and agricultural facilities in California; as well as a national dataset of commercial buildings, demonstrates that most of these systems operate at part load.....	10
Section 2.2.1. Load profiles for electric motor applications in industrial and agricultural facilities in California.....	10
Section 2.2.2. Load profiles for electric motor applications in national commercial facilities.....	11
Section 2.3. Most fan and pump electric motors are oversized and therefore operate at part load.	13
Section 2.3.1. Fan oversizing	13
Section 2.3.2. Pump oversizing.....	14
Comment 3: The CA IOUs support DOE’s determination to analyze synchronous and inverter-only electric motors in the same equipment classes as induction motors.	15
Section 3.1 Manufacturer reference tables promote direct replacement of currently regulated induction motors with synchronous and inverter-only electric motors.	15
Section 3.2. The CA IOUs provide data on synchronous motor performance exceeding a best-in-class copper cage induction motor paired with a commercially available VFD that corroborates the PTSD savings estimates for synchronous electric motors.....	18
Comment 4: The CA IOUs suggest that DOE update the maximum technology feasible for electric motors to at a minimum include the commercially available technology with the highest efficiency.	19
Comment 5: The CA IOUs encourage DOE to extend maximum application lifetime for NEMA Designs A, B, and C electric motors beyond 30 years in the life-cycle cost analysis.	21
Section 5.1. The CA IOUs show that the survival application lifetime for NEMA Design A, B and C electric motors used in the LCC analysis is not representative of a large number of units in some categories.	21
Section 5.2 The CA IOUs provide data to support a longer maximum application lifetime than 30 years for NEMA Design A, B and C electric motors.....	23
Appendix A: Addressing Totally Enclosed Air Over (TEAO) Motors in this Rulemaking	25
Appendix B: Supplemental Cost Data	26
Appendix C: Comparison of operating characteristics of synchronous and inverter-only electric motors with induction motors	27
Appendix D: Summary of case studies where currently regulated induction motors have been replaced with inverter-only or synchronous electric motors	31
Appendix E: Commercially available motors for consideration in max-tech analysis	33

Comment 1: The CA IOUs applaud DOE for including Totally Enclosed Air Over (TEAO) motors in the PTSD and recommend different approaches for moving forward with inverter-only and synchronous electric motors; SNEMs and submersible motors.

As discussed in depth in our comments in response to DOE's Notice of Proposed Rulemaking and request for comment regarding the Test Procedure for Electric Motors published on December 17, 2021 (2021 Test Procedure NOPR),² we applaud DOE's proposal to expand the scope of its electric motor regulation. However, we recommend different paths forward for the following motor categories: air-over enclosures that otherwise meet the description of a currently regulated "medium" electric motor (AO-MEMs) defined in this PTSD; inverter-only and synchronous electric motors; small non-small electric motors (SNEMs) and submersible electric motors.

AO-MEMs

As discussed in depth in our comments in response to the 2021 Test Procedure NOPR, AO-MEMs are quite similar in internal design and efficiency to currently-regulated TEFC (totally enclosed, fan cooled) electric motors and can be tested reliably with repeatable results according to National Electrical Manufacturers Association (NEMA) Part 34 Method 2.³ As such, we fully support finalizing the test procedure rulemaking and establishing energy conservation standards for AO-MEMs consistent with current energy conservation standards for TEFC motors. We suggest that DOE use test data from NEMA Part 34 Method 2 for representative units of AO-MEMs to identify any cases where different energy conservation standards for AO-MEMs and TEFC motors may be warranted.

Inverter-only and synchronous electric motors

We agree with DOE's determination to include inverter-only and synchronous motors in the same equipment classes as induction motors. In our experience, synchronous and inverter-only electric motors are designed to be, marketed to be, capable of being, and are being used as direct substitutes for induction motors currently regulated by DOE. We also shared supporting data in our comments to the 2021 Test Procedure NOPR that concur with the findings of this PTSD that there is limited benefit from further tightening of efficiency requirements for currently regulated single speed electric motors, while synchronous and inverter-only motors operate at higher efficiency levels.

However, as we noted in our response to the 2021 Test Procedure NOPR, we recommend convening an ASRAC Working Group to finalize a test procedure and part-load metric for synchronous and inverter-only electric motors before finalizing a test procedure and energy conservation standard rulemaking for induction motor/inverter-only/synchronous motor product classes.

SNEMs

As noted in our response to the 2021 Test Procedure NOPR, we strongly support DOE's long-standing precedent of regulating electric motors used as components of covered products or equipment. However, we recommend a careful and considered approach to extending this precedent to SNEMs. Given the many complex issues that have been documented on the docket for the 2021 Test Procedure NOPR related to scope expansion to SNEMs, we recommend that DOE explore stakeholder interest in convening an

² 2022-02-28 Comment response to the published Notice of proposed rulemaking and request for comment. This document is available here: <https://www.regulations.gov/comment/EERE-2020-BT-TP-0011-0031>

³ Test results for 3 hp 2, 4 and 6 pole TEAO motors and a 7.5 hp 4 pole TEAO motor are shown in Appendix A.

ASRAC Working Group to clearly define the scope of a SNEM regulation before moving forward with an energy conservation standard rulemaking for these motors.

Submersible motors

We understand that industry is developing a test procedure for submersible motors. We encourage DOE to remove submersible motors from the current electric motor test procedure rulemaking and collaborate with industry stakeholders in developing a test procedure that addresses the unique challenges of these motors. Once an industry test procedure for submersible motors is available, then we encourage DOE to open a test procedure rulemaking to address these motors.

Comment 2: The CA IOUs strongly encourage DOE to adopt the use of a metric that is representative of part-load performance for inverter-only and synchronous electric motors.

The 2021 Test Procedure NOPR proposed to use a nominal full-load efficiency metric for all electric motors included in the proposed scope expansion.⁴ DOE indicated that variable-speed technologies (i.e., motors driven by variable frequency drives, or VFDs) are included within the proposed scope of the electric motors test procedure.⁵ DOE added that although the 2021 Test Procedure NOPR proposed to use full-load efficiency metrics, the energy use analysis would be based on motor operating load conditions in the field (i.e., including part-load operation).

In response to the 2021 Test Procedure NOPR, the CA IOUs commented that part-load operational performance of inverter-only motors with a VFD can significantly exceed performance of currently-regulated induction motors over most ranges of load and speed, and that synchronous electric motors demonstrate particularly excellent part-load efficiency under low-load conditions.⁶ Further, the relationship of full-load performance compared to performance at various part-load operating regions of torque and speed is not consistent across different motor types.

This PTSD provides efficiency levels expressed in nominal full-load efficiency for various motor types.⁷ Below, we provide additional data in support of the use of a part-load metric for inverter-only and synchronous electric motor applications summarized as follows:

- Comments submitted to the 2021 Test Procedure NOPR by various industry stakeholders affirmed that full-load metrics are not representative of part-load performance for variable torque and speed applications and can result in inaccurate motor selection outcomes for end users with these applications.
- Analysis of a dataset of electric motor applications from industrial, and agricultural facilities in California; as well as a national dataset of commercial buildings, demonstrates that most of these systems operate at part load.
- A dataset of 60 commercial and industrial construction projects, including new construction and renovation projects, indicated that most electric motors running fans are oversized and therefore operate at part load. The Northwest Energy Efficiency Alliance (NEEA) observed that electric motors running pumps are on average oversized by 120 percent compared to the pump power at design point.

Section 2.1. Comments submitted to the 2021 Test Procedure NOPR by various industry stakeholders affirmed that full-load metrics are not representative of part-load performance for variable torque and speed applications and can result in inaccurate motor selection outcomes for end users with these applications.

In our comments on DOE's 2021 Test Procedure NOPR, we presented a variable speed application example to demonstrate limitations of using a metric based on performance at full-speed-at-rated-torque to compare different motor types in a motor selection process.⁸ Another commenter provided additional

⁴ 86 FR 71710, 71743-71745

⁵ 86 FR 71710, 71726-71727

⁶ 2022-02-28 Joint comment response to the published Notice of proposed rulemaking and request for comment, Electric Motors_NOPR_02_22_Final Submission. This document is available here: <https://www.regulations.gov/comment/EERE-2020-BT-TP-0011-0032>

⁷ Table ES.3.3.3, ES.3.3.4, and ES.3.3.5

⁸ Selection options included in this example are inverter-only motor designs and induction motor/VFD systems.

application examples that compared efficiencies between three motors sold by a motor manufacturer with the same configuration. Similarly, the motor with the highest efficiency (selection choice) changes based on the operating torque and speed.⁹

Various other commenters concurred that a full-load metric is not representative of part-load operation for inverter-only and synchronous electric motors.¹⁰

Section 2.2. Analysis of a dataset of electric motor applications from industrial and agricultural facilities in California; as well as a national dataset of commercial buildings, demonstrates that most of these systems operate at part load.

Section 2.2.1. Load profiles for electric motor applications in industrial and agricultural facilities in California

As part of annual evaluations of energy efficiency programs in California, the California Public Utility Commission (CPUC) collects project-specific data including end-use operational data, AMI (Advanced Metering Infrastructure) data, and energy savings models used to derive gross savings impacts for projects included in evaluation samples. We analyzed the CPUC project-specific data for two sets of samples (2019 data from agricultural sites and 2014 to 2015 data for industrial sites) to evaluate load profiles for electric motor applications.

The type and characteristics of the data available varies widely from project to project based on specific equipment involved in energy efficiency upgrades. Most projects have interval data for various parameters (e.g., amps, volts, power factor, power, flow, speed, etc.) either at the equipment level (e.g., fans, pumps, blowers, air compressors, various mechanical equipment or process loads, etc.) or site level (AMI data). Frequency of this data varies from 3-second intervals to monthly intervals and the duration of data varies from spot readings to multi-year tracking of interval trends.

To clean the data, we looked for projects with load trends that could be used to generate load profiles for a full year (i.e., 8760 hours). This process removed data collected for most commercial loads (due to seasonality of operations) but yielded a considerable amount of data on industrial and agricultural loads that were analyzed for this study.

Figure 1 shows load profiles developed based on data collected for various motor applications (air compressors, blowers, pumps) used in industrial and agricultural facilities.

⁹ 2022-02-28 Comment response to the published Notice of proposed rulemaking and request for comment, pages 3-4. This document is available here: <https://www.regulations.gov/comment/EERE-2020-BT-TP-0011-0031>

¹⁰ Commenters who concurred that a full-load metric is not representative of part-load operation for inverter-only and synchronous electric motors:

AHRI/AHAM, page 2, <https://www.regulations.gov/comment/EERE-2020-BT-TP-0011-0036>

NEEA, page 6, <https://www.regulations.gov/comment/EERE-2020-BT-TP-0011-0037>

ASAP/ACEEE/NRDC/NYSERDA, page 6, <https://www.regulations.gov/comment/EERE-2020-BT-TP-0011-0027>

Regal Rexnord, page 1, <https://www.regulations.gov/comment/EERE-2020-BT-TP-0011-0028>

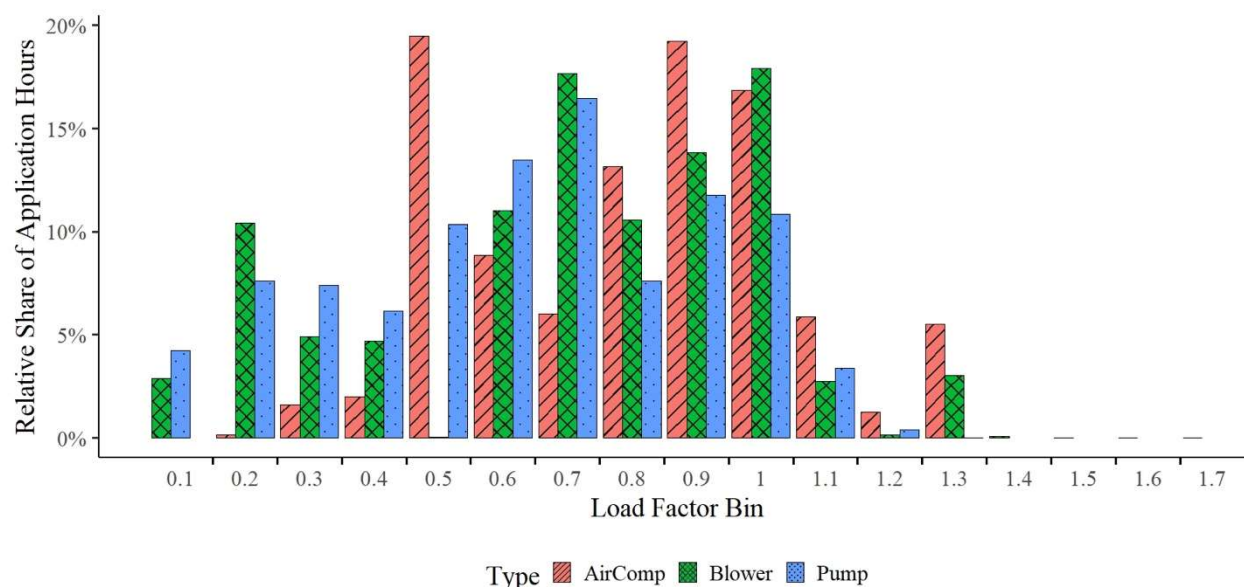


Figure 1: Load profiles for industrial and agricultural motor applications in California

Source: CA IOU analysis of CPUC project-specific data collected for California energy efficiency program evaluations

Although load profiles vary by motor application, all industrial and agricultural motor applications operated at part-load for a significant amount of time.

Section 2.2.2. Load profiles for electric motor applications in national commercial facilities

The NREL (National Renewable Energy Laboratory) ComStock database¹¹ is a national load profile database developed from calibrated simulation models of prototypical commercial buildings.¹² We use this dataset to produce load profiles for motor applications (e.g., HVAC and refrigeration systems) in commercial buildings.

We accessed the ComStock database of load profiles through its web portal¹³ and downloaded load data for national commercial motor applications.¹⁴ We then identified the peak 15-minute consumption for each application and developed a time series of load factors expressed as the ratio of the 15-minute application consumption to the annual peak 15-minute consumption. We divided the 15-minute load factors by the motor application oversizing factor to develop a national database of motor application (e.g., HVAC fan, pump, refrigeration, and heat rejection) load profiles adjusted for motor oversizing. Figure 2 (below) shows the fraction of annual hours for each load factor bin for the HVAC fan, pump, refrigeration, and heat rejection applications in commercial buildings.¹⁵

¹¹ NREL (National Renewable Energy Laboratory) ComStock database is available here: <https://comstock.nrel.gov/page/about>

¹² The prototypes represent 15 commercial building types with a wide variety of HVAC system types. Each prototype/HVAC system type combination is modeled using long term average weather data to provide annual end-use energy consumption estimates on a 15-minute interval. The results of each simulation run are expanded to the statewide level using building population weighting factors to provide an estimate of the statewide end use consumption across all building types and locations.

¹³ NREL (National Renewable Energy Laboratory) ComStock database is available here: <https://comstock.nrel.gov/select-dataset>

¹⁴ Please contact rlvine@energy-solution.com for access to this data on behalf of the CA IOUs.

¹⁵ Note that we removed part load ratios for heat rejection end use in the 0.0 to 0.1 bin, since these loads are assumed to represent non-fan energy consumption (e.g., cooling tower pumps and sump heaters) during very low heat rejection loads.

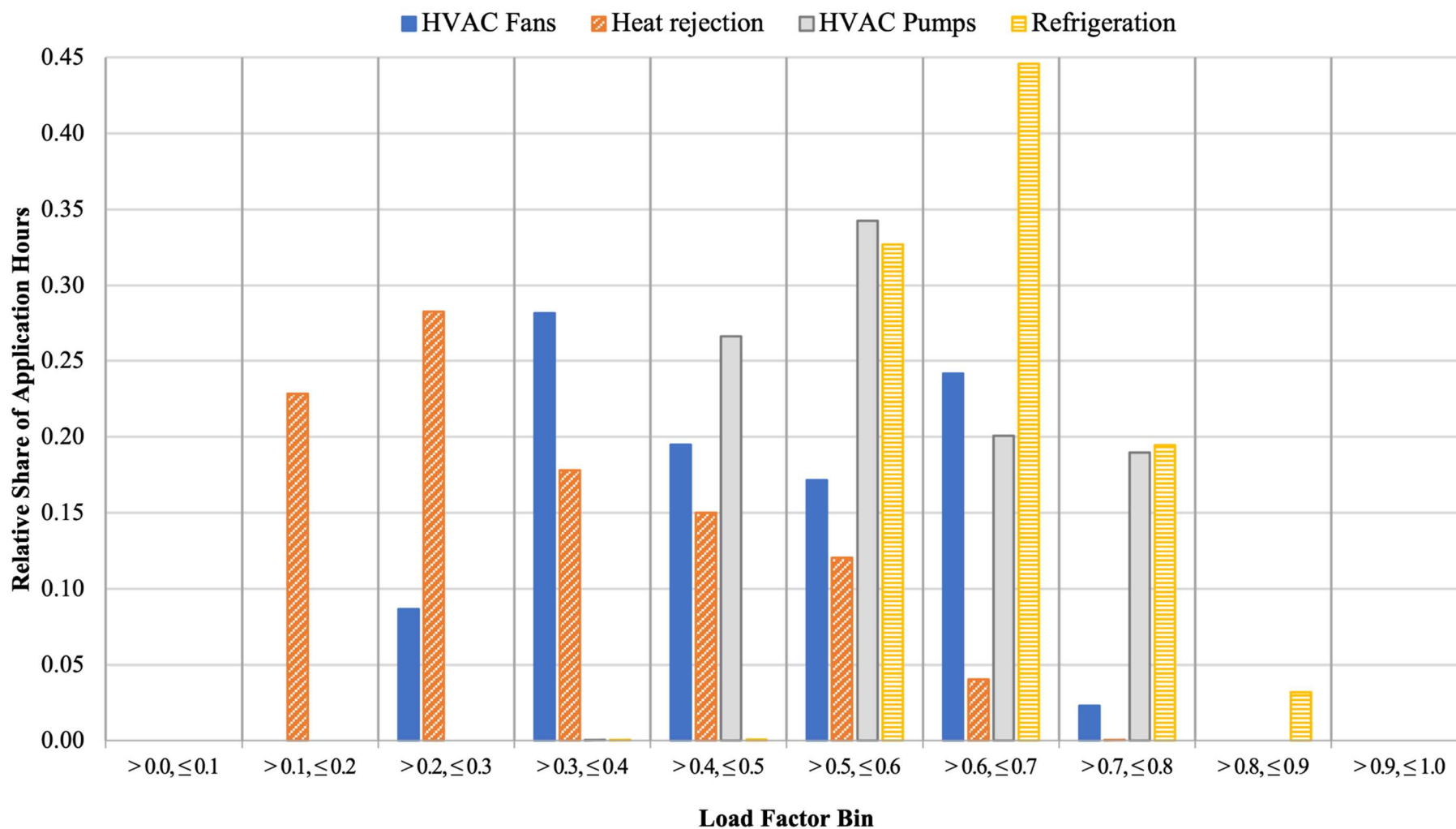


Figure 2: Load factors for national commercial motor applications

Source: CA IOU analysis of NREL ComStock commercial load data

Although load profiles vary by motor application, all commercial motor applications included in this analysis operate at part-load for a significant amount of time.

In summary, our analysis demonstrates that electric motor applications from industrial and agricultural facilities in California, and national commercial buildings operate at part load.

Section 2.3. Most fan and pump electric motors are oversized and therefore operate at part load.

Fan and pump electric motors are often oversized¹⁶ for various reasons, such as purchasing the next largest motor size available above the design specification; the addition of a safety factor when sizing a motor where the load is unknown or uncertain; to build-in capability to accommodate future increases in production; or to ensure the motor has ample power to handle load fluctuations. Oversizing results in fan and pump motors operating at less than full-load capacity for the majority of operation. Below we present data which shows the frequency of fan and pump oversizing.

Section 2.3.1. Fan oversizing

We analyzed 60 commercial and industrial projects, including new construction and renovation projects, in the ConstructConnect database.^{17,18} These projects included data on motor size and rated fan shaft horsepower at the design condition for 475 motors. Figure 3 shows percentage of motor oversizing by fan size.

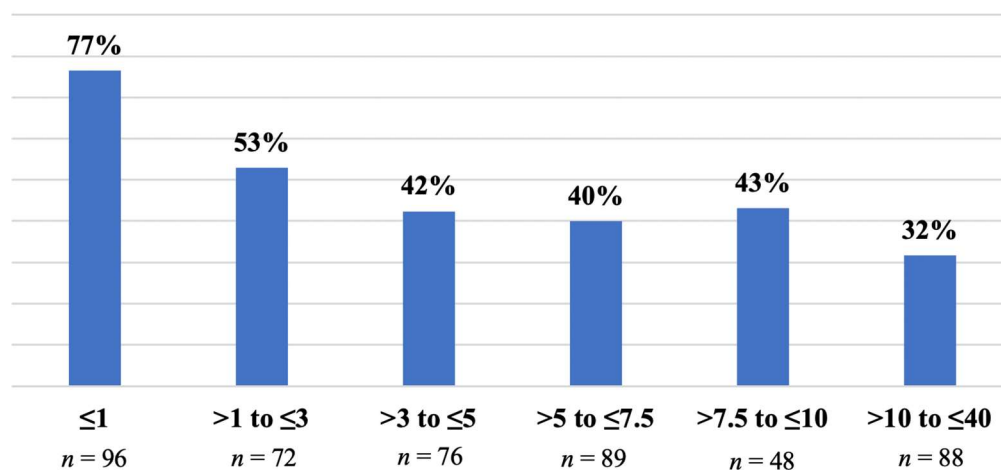


Figure 3: Percentage of oversized motors by fan size (brake horsepower)

Source: CA IOU analysis of 2022 ConstructConnect data

Note: *n* is the number of motors in each group

This analysis indicates that fans used in commercial and industrial buildings are often paired with motors that are more powerful than required to operate the fan at the design point, with some indication that the frequency of oversizing is higher for smaller motors. Oversizing results in fan motors operating at less than full-load capacity for the majority of operation.

¹⁶ Oversizing happens when the motor size is greater than the fan design brake horsepower. For example, if a 6.5 fan brake horsepower is paired with a 10-horsepower motor, the motor is oversized by 53.8 percent ($=10/6.5-1$).

¹⁷ ConstructConnect includes data for more than 600,000 non-residential projects in the U.S. and Canada. The ConstructConnect database is available here: <https://www.constructconnect.com>

¹⁸ Please contact rlevine@energy-solution.com for access to this data on behalf of the CA IOUs.

Section 2.3.2. Pump oversizing

According to a study performed by NEEA,¹⁹ pump motors on average across all motor horsepower values are oversized approximately 120 percent compared to the pump power at design point. We reanalyzed the data from this study to understand the distribution of motor oversizing by motor horsepower, as shown in Figure 4.

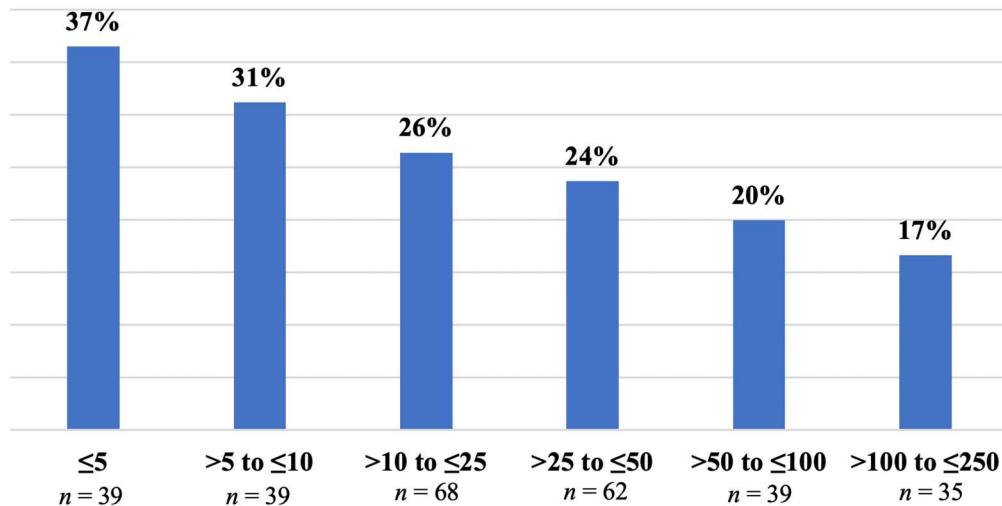


Figure 4: Percentage of oversized motors by pump motor size

Source: CA IOU analysis of 2019 NEEA data

Note: *n* is the number of motors in each group

This analysis indicates that pumps used in commercial and industrial buildings are often paired with motors that are more powerful than required to operate the pump at the design point, with some indication that the frequency of oversizing is higher for smaller motors. Oversizing results in pump motors operating at less than full-load capacity for the majority of operation.

In summary, based on the data described above, we strongly encourage DOE to adopt the use of a metric that is representative of part-load performance for inverter-only and synchronous electric motors.

¹⁹ Extended Motor Products Savings Validation Research on Clean Water Pumps and Circulators, prepared by Cadeo Group for NEEA, August 29, 2019.

Comment 3: The CA IOUs support DOE’s determination to analyze synchronous and inverter-only electric motors in the same equipment classes as induction motors.

DOE has tentatively determined that synchronous electric motors are generally capable of reaching the same or greater efficiency levels as induction motors, and tentatively planned to analyze them jointly with induction motors of similar output power, speed range, and torque/speed characteristic.²⁰ Similarly, DOE has tentatively determined that inverter-only induction motors do not warrant a separate product class from induction motors. In the PTSD, DOE requested comments regarding the tentative determination not to analyze synchronous electric motors and inverter-only electric motors in a separate equipment class from induction motors.

In the PTSD Shipment Analysis,²¹ DOE considered the possibility that some consumers will choose to purchase a synchronous electric motor rather than a more efficient NEMA Design A or B electric motor. Additionally, the PTSD National Impact Analysis (NIA)²² recognized NEMA Design A and B electric motor substitution by synchronous electric motors. In the PTSD, DOE requested comments regarding the tentative determination not to analyze synchronous electric motors in a separate equipment class from induction motors on the basis that they are able to reach the same efficiency levels.

The CA IOUs support DOE’s determination to include synchronous and inverter-only electric motors in the same equipment classes as induction motors. In our experience, synchronous and inverter-only electric motors are designed, marketed, capable of, and are being used as direct substitutes for induction motors currently regulated by DOE. In response to the December 2021 Test Procedure NOPR, we docketed a summary of case studies representing numerous industry sectors and motor applications where synchronous motors have successfully substituted for currently-regulated induction motors combined with VFDs.²³ Below, we summarize manufacturers’ technical data demonstrating drop-in replacement of currently-regulated induction motors with synchronous and/or inverter-only electric motors.²⁴ We also provide data to support the PTSD finding that synchronous motors have higher efficiency levels than induction motors.

Section 3.1 Manufacturer reference tables promote direct replacement of currently regulated induction motors with synchronous and inverter-only electric motors.

We reviewed the catalogs of manufacturers of synchronous and inverter-only electric motors and identified several examples promoting direct replacement of currently regulated induction motors with synchronous and inverter-only electric motors. The manufacturers offer products that have the same frame size, mounting, and shaft size, allowing for direct drop-in replacement, with a focus on variable speed applications with integrated speed controls including common applications such as blowers, fans, pumps, compressors, extruders, conveyors, mixers, wire drawing, and machine drives, as shown in Table 1.

²⁰ Section 2.3.1.3 of PTSD, EMs Not Analyzed in Preliminary Analysis

²¹ Section ES.3.7 Shipments Analysis of PTSD

²² Section ES.3.8 National Impact Analysis of PTSD

²³ A summary of the case studies docketed is included in Appendix D. Full document is available here: 2022-02-28 Joint comment response to the published Notice of proposed rulemaking and request for comment, Electric Motors NOPR_02_22_Final Submission. <https://www.regulations.gov/comment/EERE-2020-BT-TP-0011-0032>.

²⁴ See Appendix C for a summary of operating characteristics of synchronous and inverter-only electric motors compared to currently regulated induction motors

Table 1: Summary of Currently Available Synchronous and Inverter-only Motors Suitable for Replacement of Induction Motors

Mfg.	Model	Type	Size compatibility	Applications		Notes
				Centrifugal loads	Constant Torque Loads	
OEM A	Model a ¹	Synchronous Reluctance	Frame size 160	Yes	Yes	Smaller frame size than standard induction motor
OEM A	Model b ²	PM Synchronous	Same frame sizes as standard induction motor		Yes	Replaces induction motor and gearboxes in low-speed applications (220 to 600 RPM). Requires a frequency converter.
OEM A	Model c ³	IE5 Synchronous Reluctance	Same frame sizes as standard induction motor	Yes	Yes	
OEM A	Model d ⁴	IE5 PM Synchronous Reluctance	Available in standard sizes for drop-in replacement.	Yes		Integrated motor drive for plug and play applications. Requires VSD.
OEM B	Model a ⁵	FASR - ferrite assisted synchronous reluctance.	Frame sizes 140, 180, 210.	Yes		With or without integrated drive.
OEM B	Model a with Integrated Drive ⁶	PM PWM AC drive	Frame sizes 143, 145, 182,184.	Yes		
OEM C	Model a ⁷	PM assist Synchronous Reluctance	Frame sizes 132 to 355. IEC standard dimensions. Interchangeable with standard induction motors. Available in interchangeable and compact versions.	Yes	Yes	
OEM D	Model a ⁸	Synchronous Reluctance	Frame size 80/112 ... 225. Compatible with standard motor platform.	Yes	Yes	
OEM E	Model a ⁹	Switched reluctance	Frame sizes 56, 143, 145, 182, 184, 213, 215, 254, 256. Drop-in replacements for existing NEMA frame motors.	Yes		Requires use of external motor controller.

Sources:

1. <https://new.abb.com/motors-generators/iec-low-voltage-motors/process-performance-motors/synchronous-reluctance-motors>
2. <https://new.abb.com/motors-generators/iec-low-voltage-motors/process-performance-motors/permanent-magnet-motors>
3. <https://global.abb/topic/synrm-drive-package/en/product-information>
4. <https://new.abb.com/motors-generators/nema-low-voltage-ac-motors/variable-speed-ac/ec-titanium-integrated-motor-drive>
5. <https://www.baldor.com/brands/baldor-reliance/products/ac-motors/variable-speed-ac/ec-titanium-motors>
6. <https://www.baldor.com/mvc/DownloadCenter/Files/9AKK107591>
7. <https://acim.nidec.com/motors/leroy-somer/products/synchronous-reluctance-permanent-magnet-motors>
8. https://cache.industry.siemens.com/dl/files/277/109757277/att_949456/v1/simotics-synchronous-reluctance-drive-system-en-2018.pdf
9. <https://turntide.com/technology/optimal-efficient-equipment/>

Notes: PM – Permanent Magnet, PWM – pulse width modulated, IEC – International Electrotechnical Commission. IE5 according to IEC 60034-30-2.

Section 3.2. The CA IOUs provide data on synchronous motor performance exceeding a best-in-class copper cage induction motor paired with a commercially available VFD that corroborates the PTSD savings estimates for synchronous electric motors.

We reviewed the PTSD’s NIA²⁵ for estimating national savings at the max-tech level (Trial Standard Level 4, or TSL 4).²⁶ Table 2 shows a summary of estimated percent of savings over the base case for both NEMA Design A and B electric motors and NEMA Design A and B electric motor substitutes (i.e., permanent magnet synchronous motors).

Table 2: Percent of savings over base case consumption for TSL 4 for NEMA Design A and B electric motors

	AB 1-5 hp	AB 6-20 hp	AB 21- 50 hp	AB 51- 100 hp
NEMA Design A and B electric motors	2.6%	1.7%	1.7%	1.1%
NEMA Design A and B electric motor substitutes	14.5%	11.8%	11.8%	7.2%

Source: CA IOU analysis of PTSD NIA analysis for NEMA Design A and B Motors

As shown in Table 2 for 1 hp to 100 hp motors, DOE estimates the average savings potential for more efficient NEMA Design A and B electric motors to be approximately two percent over the base case, whereas synchronous motors have an estimated average of 11 percent savings over the same base case.

We anticipate that the TSD savings estimates for NEMA Design A and B electric motor substitutes are conservative. In contrast to the TSD comparison of synchronous electric motors with base case induction motor performance, we calculated percent savings for permanent magnet synchronous motors over best-in-class induction motors (i.e., copper cage induction motors) paired with a commercially available VFD for two different sizes (5 hp and 20 hp) using data gathered at Advanced Energy in a study by Deutsches Kupferinstitut.²⁷ Table 3 shows that the synchronous motor performance even exceeds the performance of a best-in-class copper rotor induction motor with VFD by 3.8 percent and 2.3 percent for 5 hp and 20 hp motors, respectively.

Table 3: Percent of savings for synchronous motor over copper cage induction motor with a VFD

	5hp	20hp
Average system efficiency for copper cage induction motor with a VFD	86.4%	91.0%
Average system efficiency for synchronous motor	82.6%	88.7%
Percent of savings	3.8%	2.3%

Source: CA IOU analysis of data from a study by Deutsches Kupferinstitut

In summary, we support DOE’s determination to analyze synchronous and inverter-only electric motors in the same equipment classes as induction motors and agree with the PTSD finding that synchronous motors have higher efficiency levels than induction motors.

²⁵ 2022-03-04 Preliminary National Impact Analysis AO-EM Spreadsheets, PTSD supporting and related material. March 6, 2022.

²⁶ TSL 4 represents the max-tech level for all equipment class groups

²⁷ Stefan Fassbinder, Richard deFay, Comparative Efficiency Measurements on Permanent Magnet Synchronous Motors and Cast Copper Cage Induction Motors

Comment 4: The CA IOUs suggest that DOE update the maximum technology feasible for electric motors to at a minimum include the commercially available technology with the highest efficiency.

The CA IOUs suggest that DOE update the max-tech feasible for electric motors from the current assumption of IE4 performance. In Table 4 below, and detailed in Appendix E, we list motors that are currently available on the market and that exceed the IE5 specification. We also list prototype motors that exceed IE6 specifications for some sizes and applications, see Table 5. Given the demonstrated existence of commercially available motors, as well as prototypes, that exceed the current max-tech level, we recommend that DOE update the current max-tech efficiency levels to at a minimum include the highest commercially available efficiency technology.

Table 4: Commercially and Near Commercially available motors that exceed IE4 level

Motor	Type	Characteristics	Efficiency ²⁸
Adventec Maxeff ^a	PMSM	High power factor design. 1 – 200 hp	> IE5
Zeus ^b	PMSM	Radial flux with modular low core material design. 15 – 1000 hp	>IE7
Ziehl-Abegg ^c	Electronically commutated external rotor	Designed for axial fan applications. 0.1 – 6 kW	~IE5
Pulnikov EC ^d	PMSM	Standard mounting and axle height. 0.04 kW to 30kW. Not in production	IE6-IE9 (depending on hp)
NovaMax ^e	PMSM	Conical rotor and stator design. 0.75 – 20 hp.	>IE5

Sources:

- a. <https://adventechinc.com/wp-content/uploads/2021/05/Maxeff-vs-Standard-motor-comparison-1.pdf>
- b. <https://zeusmotor.com/>
- c. <https://www.ziehl-abegg.com/en/products/ac-external-rotor-motors#overview>
- d. <http://pulnikovec.com/pmsm-series/>
- e. <https://www.regalrexnord.com/Brands/Marathon-Motors/Products/NovaMAX-EC-Permanent-Magnet-Motor>

The prototype motor projects listed in Table 5 take advantage of the superior magnetic properties of amorphous metal and nanocrystalline materials. For example, Hitachi has announced a motor based on an amorphous metal stator that meets IE5 performance.²⁹ Smaller size (less than 10 kW) prototype motors have been the focus of the development efforts. The advanced materials provide the opportunity to also develop new manufacturing methods that will facilitate commercialization. For example, amorphous metals have been used in volume production of power transformers and can provide efficiency improvements at lower cost.

²⁸ IEC efficiency levels IE1-5 for inverter only motor efficiency are defined according to IEC 60034-30-2. Levels more efficient than IE5 are conceptual and are estimated by reducing the previous IE efficiency level losses by 20 percent at each incrementally higher level. For example: IE6 is 20 percent lower losses than IE5.

²⁹ <https://www.hitachi.com/rd/news/press/2014/0709.html>

Table 5: Worldwide Research Projects Addressing Permanent Magnet Improvements

Country	Project
Japan	MagHEM ^a , ESICMM ^b
U.S.	REACT ^c , Strategic and Critical Materials Program ^d
Europe	REFREEPERMAG ^e , NANOPYME ^f , MAG-DRIVE ^g , ROMEO ^h , PerEMot

Sources:

a. <http://maghem.jp/english/index.html>

b. <https://elements-strategy.jp/en/about/base>

c. <https://arpa-e.energy.gov/technologies/programs/react>

d. <https://www.whitehouse.gov/wp-content/uploads/2021/06/100-day-supply-chain-review-report.pdf>

e. <https://cordis.europa.eu/project/id/280670/reporting>

f. <https://cordis.europa.eu/article/id/165081-solutions-to-permanent-magnet-problem>

g. <https://cordis.europa.eu/project/id/605348/reporting>

h. <https://cordis.europa.eu/project/id/309729/reporting>

In Figure 5, we summarize efficiency levels achieved by the commercially available motors and motor prototypes described compared to current and future efficiency specifications. The motor prototype efficiencies shown in Figure 5 are based on actual built and tested prototype motors.

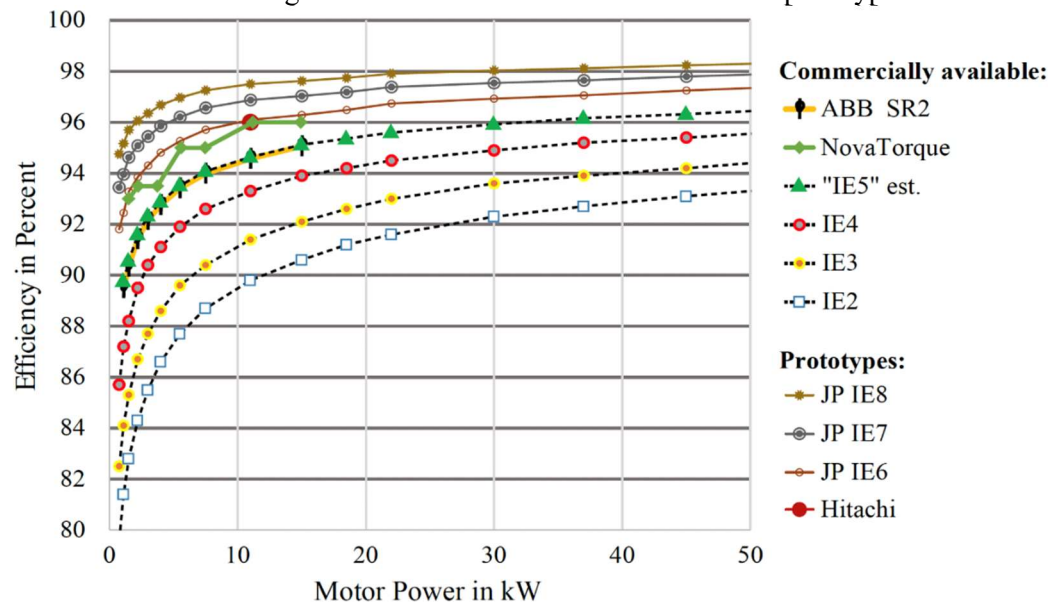


Figure 5: Motor Efficiencies of Commercially Available and Prototype Motors for Consideration as max-tech.

Source: John Petro, Magnetics and Motor Design Consultant: "Advanced Magnetics: The Key to Higher Energy Efficiency", Santa Clara, February 2017. https://ewh.ieee.org/r6/scv/mag/MtgSum/Meeting2017_02_presentation.pdf. John cited examples of commercial and prototype products with IE5 performance available from ABB, Hitachi, and NovaTorque. There is an expected 20 percent loss reduction per each energy class beyond IE5 level.

Comment 5: The CA IOUs encourage DOE to extend maximum application lifetime for NEMA Designs A, B, and C electric motors beyond 30 years in the life-cycle cost analysis.

DOE estimated the application lifetimes of electric motors in years by developing Weibull distributions based on mechanical lifetimes in years and annual operating hours of electric motors. Based on this approach, electric motors that operate longer are likely to be retired sooner. DOE considered that electric motors of less than or equal to 75 hp are most likely to be embedded in a piece of equipment (i.e., an application). For such applications, DOE developed Weibull distributions of application lifetimes expressed in years and compared the mechanical lifetime with the product lifetime. DOE then assumed that the electric motor would be retired at the earlier of the two ages. For the application lifetimes in the life cycle cost (LCC) analysis, DOE assumed a maximum application lifetime of 30 years.³⁰

We support DOE's general approach for estimating application lifetimes for electric motors. Below we provide additional data to support increasing the maximum application lifetime beyond 30 years for NEMA Designs A, B, and C electric motors. We also note that there is precedent for using maximum application lifetimes greater than 30 years. For example, in DOE's Technical Support Document for Distribution Transformer Energy Conservation Standards published in August 2021,³¹ DOE used a Weibull distribution to maintain an average lifetime of 32 years, based on a report by Oak Ridge National Laboratory that indicated that the average life of liquid-immersed distribution transformers is 32 years with a maximum lifetime of 60 years.³²

Section 5.1. The CA IOUs show that the survival application lifetime for NEMA Design A, B and C electric motors used in the LCC analysis is not representative of a large number of units in some categories.

The CA IOUs support DOE's approach for developing application lifetimes in years using the ratio of mechanical lifetimes to application operating hours. According to this analysis,³³ the weighted average lifetimes across applications for NEMA Design A, B, and C electric motors in the industrial sector are 27 years and 40 years for 6 to 100 hp motors and 101 to 500 hp motors, respectively. For the commercial sector, weighted average lifetimes across applications are 28 to 29 years for 51 to 500 hp motors. Therefore, the assumption of 30 years as the maximum motor application lifetime used in the LCC analysis in this PTSD³⁴ is not representative of the survival application lifetime for several categories of NEMA Design A, B, and C motors.

To show the impact of assuming a 30-year maximum motor application lifetime, we analyzed application lifetimes for some electric motor categories in the DOE-provided LCC spreadsheet. Table 6 shows the impact of assuming a 30-year maximum application lifetime for the sample of 10,000 applications for 150 hp NEMA Design A and B electric motors.

³⁰ 2022-03-04 Preliminary Life-Cycle Cost Regulated-EM Spreadsheets, SUPPORTING & RELATED MATERIAL under DOE's PTSD. March 6, 2022.

³¹ <https://downloads.regulations.gov/EERE-2019-BT-STD-0018-0022/content.pdf>

³² Barnes. Determination Analysis of Energy Conservation Standards for Distribution Transformers. ORNL-6847. 1996.

³³ DOE TSD Section 8.3.4 Equipment Lifetime, Table 8.3.4 Motor Lifetime by Horsepower Range and Sector for NEMA Design A and B, NEMA Design C

³⁴ DOE TSD Section 8.3.4 Equipment Lifetime page 8-22

Table 6: Application lifetime in years for 150 hp NEMA Design A and B electric motor (4 poles, enclosed)

Application	Sector	Percent having lifetime <30 years	Percent having lifetime = 30 years	Percent having lifetime >30 years
Air Compressor	Commercial	11%	89%	0%
Air Compressor	Industrial	24%	76%	0%
Fan	Commercial	52%	48%	0%
Fan	Industrial	43%	57%	0%
Material Handling	Commercial	87%	13%	0%
Material Handling	Industrial	31%	69%	0%
Material Processing	Commercial	2%	98%	0%
Material Processing	Industrial	23%	77%	0%
Other	Commercial	33%	67%	0%
Other	Industrial	15%	85%	0%
Pump	Agriculture	99%	1%	0%
Pump	Commercial	59%	41%	0%
Pump	Industrial	39%	61%	0%
Refrigeration Compressor	Commercial	40%	60%	0%
Refrigeration Compressor	Industrial	33%	67%	0%
All	All	36%	64%	0%

Source: CA IOU analysis of data provided in DOE's preliminary LCC spreadsheet for electric motors

As shown in the table above, based on the DOE LCC sample, 36 percent of electric motors in this category have a lifetime shorter than 30 years, 64 percent are assigned the maximum application lifetime of 30 years, and none have a lifetime of longer than 30 years.

Figure 6**Figure** shows the application survival curve for all electric motors in this category included in the LCC spreadsheet. This figure shows that the survival curve does not adequately represent more than 60 percent of the units in this category.

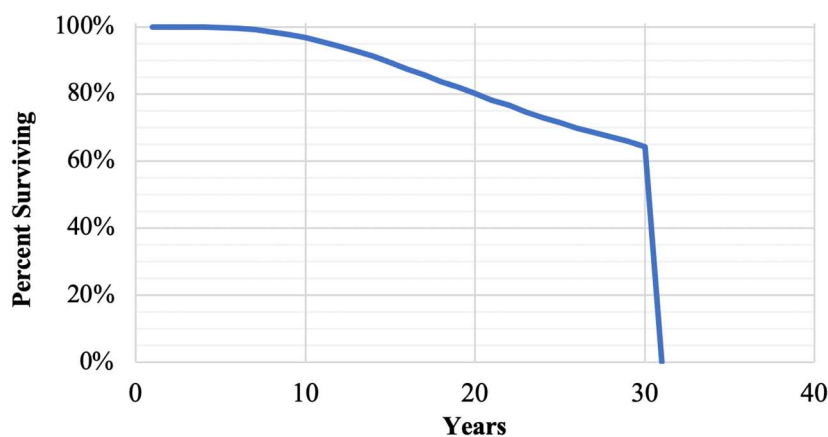


Figure 6: Application survival curve in years for 150 hp NEMA Design A and B electric motor (4 poles, enclosed)

Source: CA IOU analysis of data provided in DOE's preliminary Life-Cycle Cost spreadsheet for electric motors

We find similar results for two other electric motor categories. For 250 hp NEMA Design A and B (4-poles, enclosed), 62 percent of the applications are assigned an application lifetime of 30 years. For 150 hp NEMA Design C (4-poles, enclosed), 65 percent of the applications are assigned an application lifetime of 30 years.

For NEMA A, B, and C electric motor categories with horsepower less than 100 hp, extending the maximum application lifetime from 30 years to 50 years would affect less than one percent of the 10,000 samples for each category.

Note that this comment does not apply to Fire Pumps as the PTSD does not assume a 30-year maximum application lifetime for this category.

Section 5.2 The CA IOUs provide data to support a longer maximum application lifetime than 30 years for NEMA Design A, B and C electric motors.

Below we provide data to show that maximum application lifetimes are longer for larger electric motors, with some of these motors surviving to at least 50 years.

- **Industrial and Commercial Motor System Market Assessment (MSMA) Report.**³⁵
According to this study, about two to three percent of all commercial and industrial motors are older than 30 years. In addition to this, about 63 percent of industrial and 50 percent of commercial motors did not have legible nameplates. According to the study, most of these motors are older motors (e.g., age greater than 10 years). An analysis of MSMA data found that 5.4 percent of all motors with legible nameplates are older than 30 years.

Analyzing the MSMA data shows that 3.4 percent of motors rated 101 to 500 hp with legible nameplates have survived greater than or equal to 50 years. 54.6 percent of motors in this category have illegible nameplates. Conservatively, assuming that motors with legible and illegible nameplates survive at the same rate, then 3.4 percent of motors in this category are likely greater than or equal to 50 years. Similarly, 3.1 percent of motors rated 501 to 1000 hp with legible nameplates have survived greater than or equal to 50 years and 43.9 percent have illegible nameplates. For smaller motors rated 1 to 200 hp with legible nameplates, 4.8 percent have survived greater than or equal to 30 years, 0.2 percent have survived greater than or equal to 50 years, and 53.0 percent have illegible nameplates.

- **Swiss motor efficiency EASY program - Lessons learned from four years of the Swiss EASY audit and incentive program.**³⁶
According to this study, 56 percent of 4,142 motors included in the study are older than the operating life expectancy. Motor systems included in this study have been in operation for 20, 30, or even more than 40 years.

³⁵ Prakash Rao, Paul Sheaffer, Yuting Chen, Miriam Goldberg, Benjamin Jones, Jeff Crop, and Jordan Hester, U.S. Industrial and Commercial Motor System Market Assessment Report. Volume 1: Assessment Report. LBNL-2001382. January, 2021. (See “Motor Age” pages 67-68).

³⁶ Rolf Tieben, Rita Werle, Conrad U. Brunner. Impact Energy Inc., EASY- Lessons learned from four years of the Swiss EASY audit and incentive program. 2015.

- **Energy-Efficient Motor Systems: A Handbook on Technology, Program, and Policy Opportunities.**³⁷

This book refers to a 1995 survey of motor repair shops (Schueler, Leistner, and Douglass 1994) to show that the average electric motor life can be greater than 30 years for motors larger than 50 hp. Given the age of this study, we only include it because its finding is consistent with the more recent studies above.

In summary, we strongly suggest that DOE extend maximum application lifetime beyond 30 years for NEMA Designs A, B, and C electric motors in the LCC analysis.

³⁷ Steven Nadel, R. Neal Elliott, Michael Shepard, Steve Greenberg, Gail Katz, and T. de Almeida. American Council of Energy-Efficient Economy. Energy-Efficient Motor Systems: A Handbook on Technology, Program, and Policy Opportunities. 2002.

Appendix A: Addressing Totally Enclosed Air Over (TEAO) Motors in this Rulemaking

The CA IOUs urge DOE to address Totally Enclosed Air Over (TEAO) motors in this rulemaking. TEAO motors are quite similar in internal design and efficiency to TEFC motors and can be tested reliably with repeatable results. The CA IOUs initiated a motor test project in 2022 to explore the repeatability issue. We examined the variation in paired losses from a NEMA Part 34 Method 2 measurement and paired repeated efficiency measurements of the same motor. Test results for 3 hp 2, 4, and 6 pole TEAO motors and a 7.5 hp 4 pole TEAO motor are shown in Figure 1A.

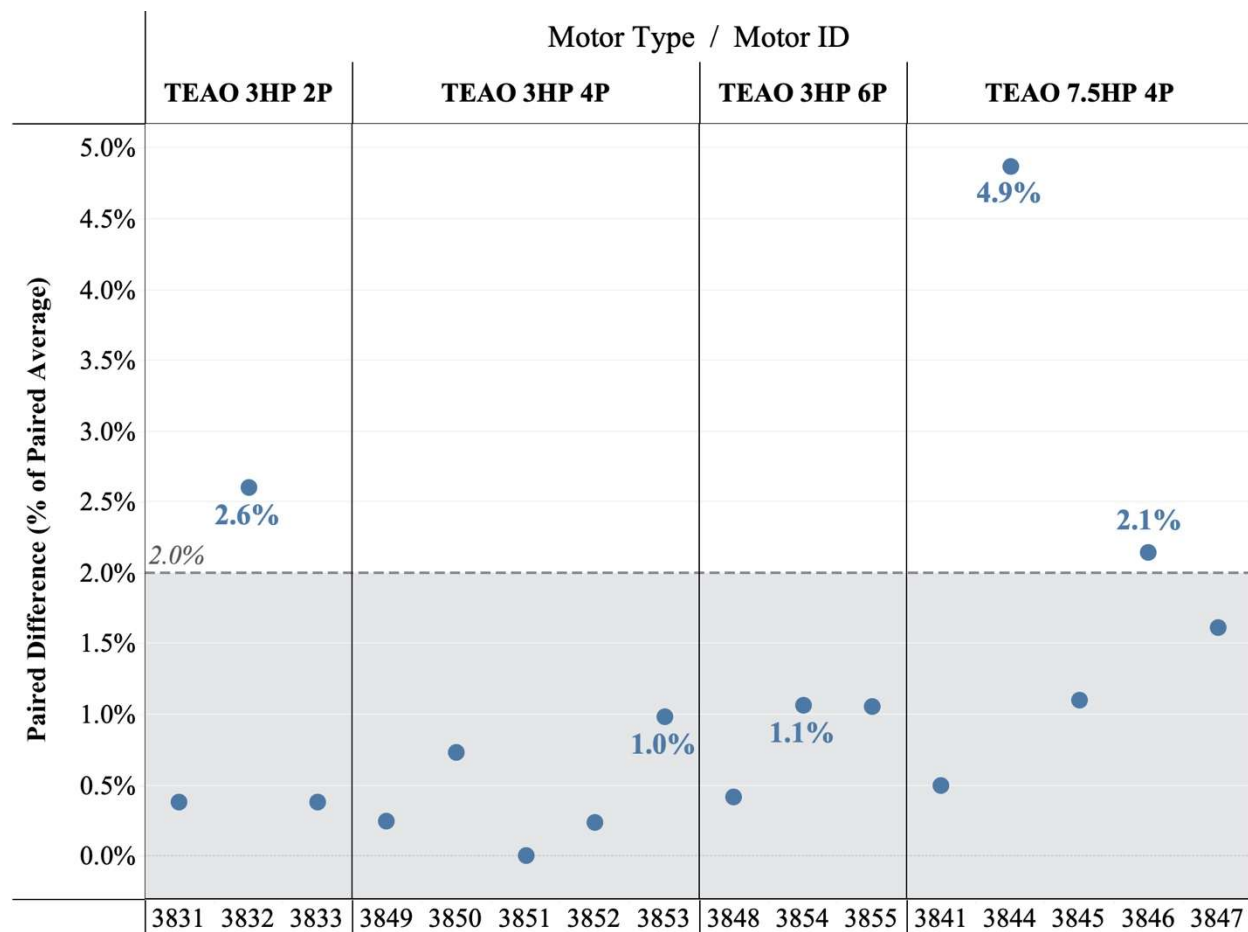


Figure 1A: Repeatability of TEAO Motor Efficiency Tests

Source: CA IOU analysis of CA IOU TEAO motor test project, 2022.

The variation in the estimate of the motor losses is generally less than plus or minus two percent, demonstrating the repeatability of the test procedure.

Appendix B: Supplemental Cost Data

Below in Table 1B, we provide cost data for permanent magnet synchronous motors and copper cage induction motors for a range of sizes.

Table 1B: Cost data for permanent magnet synchronous motors and copper cage induction motors

P_{2N}	Motor No.	Price	Lead time
5.0 hp	Copper rotor motor	\$ 399.85	Few days
	Sync. PM motor 3	\$ 1,432.32	10 days
	Sync. PM motor 4	\$ 1,029.23	14 weeks
	Sync. PM motor 5	\$ 1,587.51	18 weeks
7.5 hp	Copper rotor motor	\$ 565.85	
	Sync. PM motor 12	—	
	Sync. PM motor 14	\$ 1,097.95	
	Sync. PM motor 15	\$ 893.15	
10.0 hp	Copper rotor motor	\$ 866.71	Few days
	Sync. PM motor 21	\$ 4,414.95	10 days
	Sync. PM motor 24	\$ 1,415.02	8 weeks
	Sync. PM motor 23	\$ 1,823.29	14 weeks
20.0 hp	Copper rotor motor	\$ 1,372.48	Few days
	Sync. PM motor 31	\$ 5,427.58	1–16 weeks
	Sync. PM motor 34	\$ 2,035.47	
	Sync. PM motor 35	—	

Source: Stefan Fassbinder, Richard deFay, Comparative Efficiency Measurements on Permanent Magnet Synchronous Motors and Cast Copper Cage Induction Motors

Appendix C: Comparison of operating characteristics of synchronous and inverter-only electric motors with induction motors

Tables 1C and 2C compare operating characteristics for eight types of synchronous and inverter-only electric motors, compared to currently regulated NEMA Type B induction motors, and highlight the strengths and weaknesses of synchronous and inverter-only electric motors as substitutes for currently regulated induction motors, including manufacturers' published technical information describing direct replacement opportunities for induction motors by synchronous and inverter-only electric motors.

Table 1C: Characteristics of Induction Motors and Line Start Synchronous Motor Substitutes

Abbreviation	SCIM	CuIM	LSPM	LSSynRM
Full Name	Squirrel Cage Induction Motors. NEMA Type B.	Copper Rotor Induction Motors	Line Start Permanent Magnet SyncMotors	Line Start Synchronous Reluctance Motors
Motor category	Induction	Induction	Synchronous	Synchronous
HP range	Full	<20 HP for cast rotor. No size restriction for copper bars	1-10 HP ^h	0.75 –150
Efficiency	IE3/NEMA Premium	IE4	IE4	IE4
Electrical Characteristics	Baseline. Inrush current 5-6x full-load current. ^{n, p}	Higher Inrush Current than SCIM. a Starter may be helpful. ^g	May start backwards. Voltage imbalance or load jerks may require restart. ^a	Motor operates as induction during startup, synchronous at full speed.
Operating Speed	Baseline	Faster than SCIM due to lower slip	Synchronous, significantly faster than SCIM. ^{a, d}	Synchronous, significantly faster than SCIM.
Startup Torque	1.2-1.5x rated torque. ^{n, p}	Lower than SCIM.	7-17x rated torque. ^a	3-4x rated torque
Mechanical Serviceability	Baseline	Similar to SCIM	Requires special tools to access bearings. ^a	Very durable motor. Significant high temp capability. ^v
Replacement Issues	Baseline	Lower starting torque may present some issues; same with increased speed.	Synchronous speed may present application issues. Not ideal for frequent starts. High inertia loads, over 20-30x rotor inertia can lock rotor. ^{a, d}	Applications where load inertia is not particularly high and where high starting torque is not required. Synchronous speed may present application issues
Notes			Most suitable for fan/pump/compressor. ^w	Most suitable for fan/pump/compressor.

Table 2C: Variable Speed Motor Characteristics

Abbreviation	SCIM + VSD	PMSM	SynRm	SwRm
Full Name	Induction Motor with VSD	Permanent Magnet Synchronous Motors	Synchronous Reluctance Motors	Switched Reluctance Motors
HP range	Full	Full	5.5-315 kW. (ABB-IEC Frame).	<20 HP (Turntide) ^h ; 30-335 hp, ^u .
Efficiency	Baseline (IE3).	IE4-5.	IE4-5. ⁿ	IE4
Efficiency over speed range	Drops off at low speeds. Very good overspeed efficiency.	Excellent throughout operating range. Loss of efficiency at overspeed. ⁿ	Smaller speed operating window. Loss of efficiency at overspeed. ⁿ .	Good efficiency throughout operating range. ^{f,j,k,l,m} .
Electrical Characteristics	Baseline. Good Power Factor. ⁿ	Can run on similar inverter drive as SCIM. Excellent power factor. ⁿ	Can run on similar inverter drive as SCIM. Low power factor. ^c	Very low power factor. m,g Custom control hardware required. ⁱ
Operating Speed	Baseline.	Same operating range as SCIM. ⁿ	Reduced operating speed range, especially in over-speed range. ^q	Capable of extremely low and extremely high operating speeds. ^f
Startup Torque	Baseline.	Controlled by inverter; excellent starting torque. ^{f,n}	Controlled by inverter; capable of higher starting torque than SCIM. ^f	Extremely high torque, far exceeds SCIM. ^f
Mechanical Serviceability	Baseline.	Requires special tools to access bearings. ^a	Very durable motor. Significant high temp capability. ^v	Extremely durable motor. Requires training to service. ^{f,n} .
Replacement Issues	Baseline.	High ambient conditions vs demagnetization risk. ^a	Existing inverter may need upsizing. Overspeed capability may be an issue in some applications. ^q	Outside of power factor issues, should replicate most operating conditions. Possible noise concerns. ⁿ .
Notes				Torque ripple, was an early issue. m. 90% reduction via algorithm changes. ^s

Tables 1C and 2C notes:

- a. Danfoss. http://files.danfoss.com/download/Drives/DEDDPB404A502_Motor_Technology_LR.pdf
- b. Anibal de Almeida. http://www.motorsummit.ch/sites/default/files/2018-11/MS18_290_Anibal_de_Almeida_Presentation.pdf
- c. Burak et., al., EEMODS 2017: Design and Implementation of a line Start PM Synchronous Motor and Synchronous Reluctance Motor and performance comparison with induction motor. [http://publications.jrc.ec.europa.eu/repository/bitstream/JRC110714/eemods_2017_proceedings_v11\(1\).pdf](http://publications.jrc.ec.europa.eu/repository/bitstream/JRC110714/eemods_2017_proceedings_v11(1).pdf), page 346
- d. S. Kolomeitsev, L. Finkle, EEMODS 2017, High Starting Torque LSPM Motor for wide range of Industrial Applications. Page 475.
- e. P. Donolo et al, EEMODS 2017, Comparative analysis of the effects of voltage unbalance on the performance of IE4 electric motors.
- f. Turntide (aka Software Motor Company) https://turntide.com/wp-content/uploads/2020/07/Turntide-Motor-Comparison-Study_v2.pdf
- g. R. Tiwari, A. K. Bhardwaj, "Analysis of Induction Motor with Die Cast Rotor," International Journal of Innovative Research in Electrical, Electronics, Instrumentation, and Control Engineering, Vol 2. Issue 6, June 2014.
- h. Energy Efficiency Emerging Technology (E3T) Program, "Line Start Permanent Magnet Motors," BPA and Washington State Univ. <http://e3tnw.org/ItemDetail.aspx?id=434>. Accessed 4/20/2022.
- i. <https://turntide.com/wp-content/uploads/2020/12/Turntide-DataSheet-V03-15HP.121420.pdf>
- j. <https://turntide.com/learning-center/>
- k. <https://turntide.com/wp-content/uploads/2020/12/Turntide-DataSheet-V03-7.5-10HP.121420.pdf>
- l. https://turntide.com/wp-content/uploads/2020/07/Turntide-Motor-Comparison-Study_v2.pdf
- m. <https://turntide.com/wp-content/uploads/2020/12/Turntide-DataSheet-V02-5HP.121420.pdf>
- n. https://www.infineon.com/dgdl/Infineon-motorcontrol_handbook-AdditionalTechnicalInformation-v01_00-EN.pdf?fileId=5546d4626bb628d7016be6a9aa637e69
- o. <https://www.baldor.com/mvc/DownloadCenter/Files/9AKK107303>
- p. <https://www.baldor.com/~media/files/brands/baldor-reliance/resources%20and%20support/specguide.ashx>
- q. https://library.e.abb.com/public/9864acc1853bb0b4c1257de4002e153c/EN_SynRM_Brochure_3AUA00000120962_RevE.pdf
- r. https://www.orf.od.nih.gov/TechnicalResources/Documents/Technical%20Bulletins/20TB/Overspeed%20Motors%20May%202020%20-%20Technical%20Bulletin_508.pdf
- s. <https://www.ansys.com/blog/reduce-torque-ripple-switched-reluctance-motor-electric-vehicles>
- t. <https://www.mdpi.com/1996-1073/11/11/3215>
- u. https://www.energy.gov/sites/prod/files/2014/04/f15/amo_motors_handbook_web.pdf
- v. <https://new.abb.com/news/detail/69416/a-more-sustainable-future-for-wood-drying>
- w. https://www.aceee.org/files/proceedings/2017/data/polopoly_fs/1.3687876.1501159054!/fileserver/file/790264/filename/0036_0053_000044.pdf

Appendix D: Summary of case studies where currently regulated induction motors have been replaced with inverter-only or synchronous electric motors

The applicability of advanced motors as high efficiency replacement of induction motors has been demonstrated through case studies of successful projects. A document describing 13 case studies was docketed in response to the 2021 Test Procedure NOPR.³⁸ Below in Tables 1D and Table 2D, we summarize a small sample of these case studies to demonstrate the wide application of advanced motors across the commercial and industrial sectors.

Table 1D: Commercial Application Case Studies

Sector	Commercial	Commercial	Commercial	Commercial
Application	HVAC Fans	Pumping	Refrigeration Fans	Refrigeration Fans
Description	HVAC unit supply fan motors	Highrise Commercial Water Booster Pump	Walk in cooler evaporator fans	Refrigeration Condenser fans
New Technology	Switched Reluctance Motors (SRM)	Permanent Magnet Motors (PMM)	Permanent Magnet Synchronous Motors (PMSM)	High rotor pole switched reluctance (HRSR)
Existing Equipment	Induction motor	27-year-old pumps 1987 vintage	Among the 18 motors being retrofitted, only two are PSC motors, and the rest are SP motors	Induction
Motor Power	10 hp, 5 hp, 3 hp	20 - 30 hp	38 - 50 W	1.5 hp
Operating Hours	Not listed	24 hours/day, 7 days per week	24 hours/day, 7 days per week	24 hours/day, 7 days per week
Application	HVAC	Water booster system for multi-floor building	Evaporator Fan Motors in Walk-in Coolers and Freezers in small convenience stores; restaurant	Condenser fans
Industry	Retail grocery	Commercial Office Skyscraper – Domestic Water Loop	Commercial refrigeration	Grocery refrigeration
Location(s)	California, U.S.	Seattle, WA	Illinois (Multiple)	Colorado, U.S.
Year	2019	2015	2019	2017

³⁸ 2022-02-28 Joint comment response to the published Notice of proposed rulemaking and request for comment, Electric Motors NOPR_02_22_Final Submission, pages 28-31. This document is available here: <https://www.regulations.gov/comment/EERE-2020-BT-TP-0011-0032>

Table 2D: Industrial Application Case Studies

Sector	Industrial	Industrial	Industrial	Industrial	Industrial	Industrial	Industrial
Application	Compressor	Fans	Pumping	Aeration	Conveyor	Extruder	Extruder
Description	Industrial refrigeration compressor	Process Ventilation at Feed Mill	Drinking water pumping station	Wastewater Treatment Aeration Blowers	Power Plant Boiler Fuel Conveyor, Hoist and Hi Pressure Pump	Constant torque extruder	Plastic pipe extruder drive
New Technology	Synchronous Reluctance Motors (SynRM)	Synchronous Reluctance Motors (SynRM)	Synchronous Reluctance Motors (SynRM)	Permanent Magnet Synchronous Motors (PMSM)	Switched Reluctance Motors (SRM)	Synchronous Reluctance Motors (SynRM)	Synchronous Reluctance Motors (SynRM)
Existing Equipment	Not listed	Conventional 75 kW induction motor	Not listed - design build project	Conventional induction motor - turbo blower	N/A -- not provided.	Existing extruder motors were 20 years old and increasingly obsolete	182 kW DC motor
Motor Power	72 kW	37 kW	250 kW	200 HP (149 kW)	75-250 HP	25 kW	200 kW w/ drive
Operating Hours	24 hours / day, 7 days per week	24 hours per day, 5+ days per week	24 hours / day, 7 days per week	24 hours / day, 7 days per week	Not listed	Not listed	Not listed
Application	Refrigeration Plant	Process Ventilation	Potable Water Supply	Wastewater Treatment Aeration Blowers	Conveyor	PVC-U manufacturing	Extruder
Industry	Industrial Food Processing	Agriculture	Municipal	WWTP	Power	Industrial	Manufacturing - plastics
Location(s)	Melbourne, Australia	Sursee, Herzogenbuchsee St. Margrethen Switzerland	Nieuwdorp, Netherlands	Renton, Washington	North Yorkshire, UK	Nottingham, UK	Derbyshire, UK
Year	2020	2015	2017	2013	2013	Not listed	2019

Appendix E: Commercially available motors for consideration in max-tech analysis

Advantec Maxeff

The Advantec Maxeff motor is a permanent magnet AC (PMAC) motor providing efficiency exceeding IE4 and IE5 specifications. The motor design eliminates reactive (KVAR) at any load level, producing leading VAR at load levels less than full load and unity power factor at full load, which effectively helps to correct grid power factor. Below, we compare the efficiency of the Maxeff motor to the IE3, IE4, and IE5 efficiency specifications in Figure 1E.

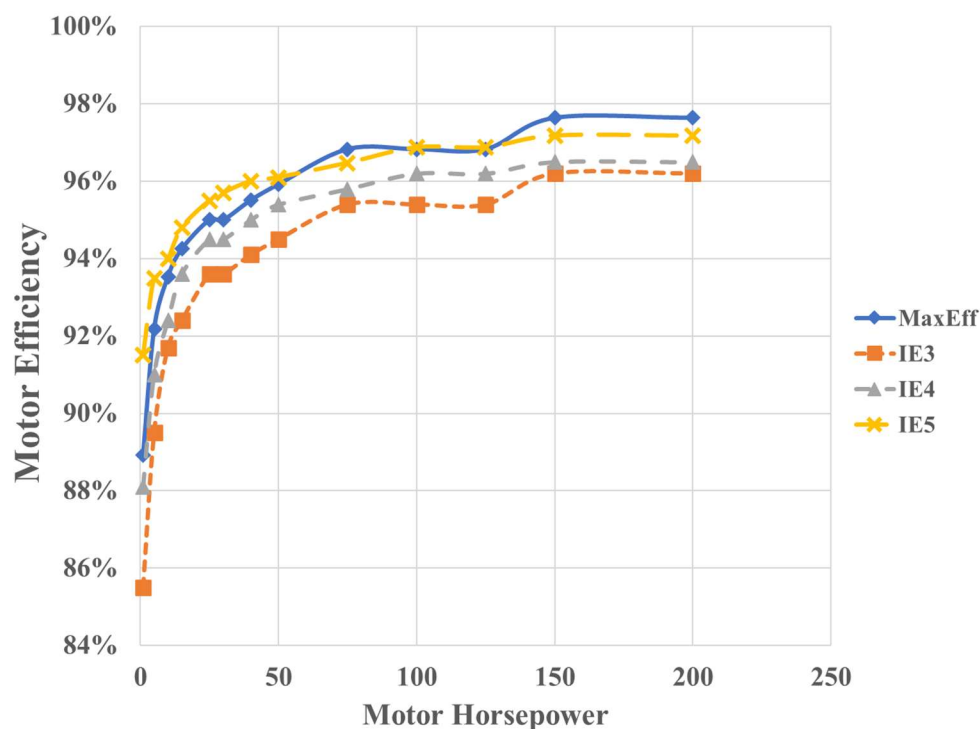


Figure 1E: Maxeff™ Efficiency Compared to IE3-IE5 Specifications.

Source: CA IOU analysis of manufacturer's performance data

ZEUS

The ZEUS motor is a radial flux surface PMAC motor which is configured for 3-phase, sinusoidal current supply from variable frequency pulse-width-modulated, voltage-source inverters.³⁹ It has modular design of both stator and rotor components and uses less than half the copper and less than half the core material of equivalent IMs. It is a 12-pole, 18 slot, concentrated coil, fractional-slot machine, with 0.5 slots per pole per phase, with a certified efficient rating equivalent to IE7. ZEUS industrial motors 15 to 30 hp continuous are TENV. ZEUS motors from 40 to 250 hp continuous are TEFC. ZEUS's traction motors (125, 250, 500, and 1,000 peak hp) are water/glycol-cooled, requiring an external heat rejection device.

³⁹ <https://www.adventechinc.com/>

A 15 hp 1800 RPM prototype motor was tested at 96.1 percent efficiency with VFD losses included, as shown in Figure 2E below.⁴⁰ The motor efficiency is compared to an IE3 NEMA Premium Induction motor. Removing the VFD losses, the motor efficiency is 96.9 percent, exceeding the estimated IE7 rating of 96.7 percent.

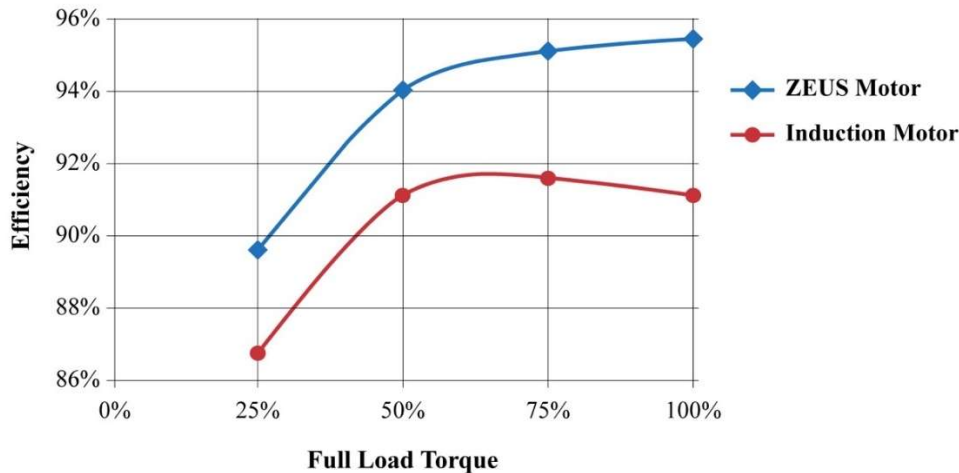


Figure 2E: 15 hp ZEUS PMAC motor compared to IE3 Specifications.

Source: Klontz, K. "Permanent Magnet Motor with Tested Efficiency Beyond Ultra-Premium/ IE5 Levels," Proc. ACEEE 2017 Summer Study on Energy Efficiency in Industry.

Ziehl-Abegg EC Blue motor

The Ziehl-Abegg EC Blue motor is an electronically commutated (EC) external rotor motor. The external rotor design is commonly used to drive axial fans. The motor is available in sizes ranging from 0.1 to 6 kW. EC Blue motors achieve an efficiency level of up to 93 percent, exceeding the IE4 efficiency class. The efficiency of a 5.7 kW EC Blue motor compared to an IE4 motor is shown in Figure 3E.

⁴⁰

https://www.aceee.org/files/proceedings/2017/data/polopoly_fs/1.3687894.1501159070!/fileserver/file/790273/filename/0036_0053_000048.pdf

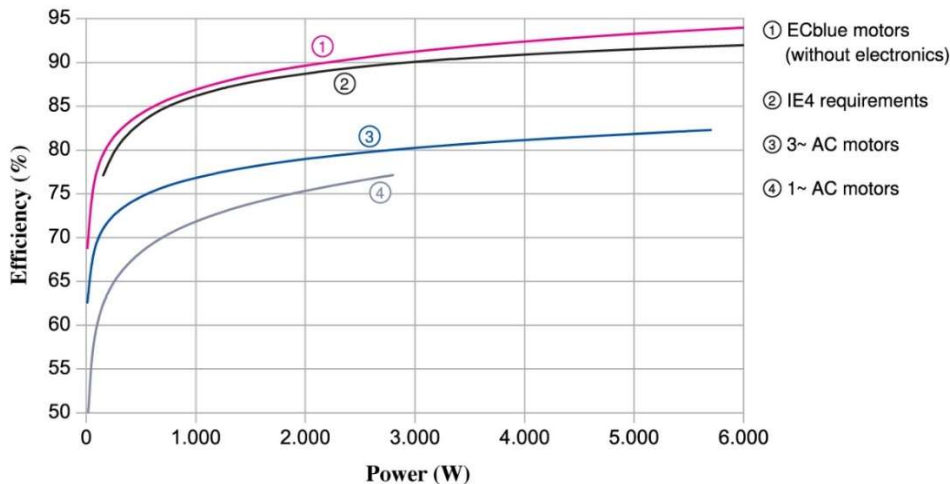


Figure 3E: Ziehl-Abegg EC Blue External Rotor Motor compared to IE4 Specifications

Source: https://www.ziehl-abegg.com/fileadmin/Downloadcenter_NEW/00_englisch%28EN%29_MASTER/X02_Catalogues/Catalogue-ECblue-High-efficiency-motors.pdf p. 8.

PulnikovEC

PulnikovEC Electromechanics has designed a series of advanced PMSM with outputs ranging from 0.04 kW to 30kW at rotating speeds of 1500, 3000, and 6000 RPM.⁴¹ Motors of the PMSM series are designed to comply with the same standards as conventional asynchronous motors:

1. Standard power supply;
2. standard axis height;
3. standard mounting;
4. standard output power;
5. standard rotation speed;
6. suitable for standard vector control (same as for synchronous or asynchronous motors).

The efficiency of these motors meets IE9 levels at sizes between 0.04 and 0.18 kW; IE8 levels at sizes between 0.25 and 0.75 kW; IE7 levels at sizes between 1.1 and 2.2 kW; and IE6 levels at sizes between 3.0 and 15.0 kW. PulnikovEC has developed the designs, but the motors are not currently in production.

NovaMax

The NovaMax (formerly NovaTorque) motor is a PMAC variable speed motor manufactured by Marathon Motors.⁴² The motor is available in sizes ranging from 0.75 to 20 hp and speeds ranging from 600 to 3600 RPM. The rotor in the NovaTorque motor design consists of a pair of conical hubs mounted on opposite ends of the motor shaft. The rotor hubs use an interior permanent magnet (IPM) arrangement. The surface area available for magnetic flux transmission is maximized by giving the motor's stators and rotor hubs matching conical shapes. The unique rotor design provides a high efficiency motor exceeding IE5 specifications (see Figure 4E).

⁴¹ <http://pulnikovvec.com/>

⁴² <https://www.regalrexnord.com/Brands/Marathon-Motors/Products/NovaMAX-EC-Permanent-Magnet-Motor>

NovaTorque Axial Motor with Conical Air Gap

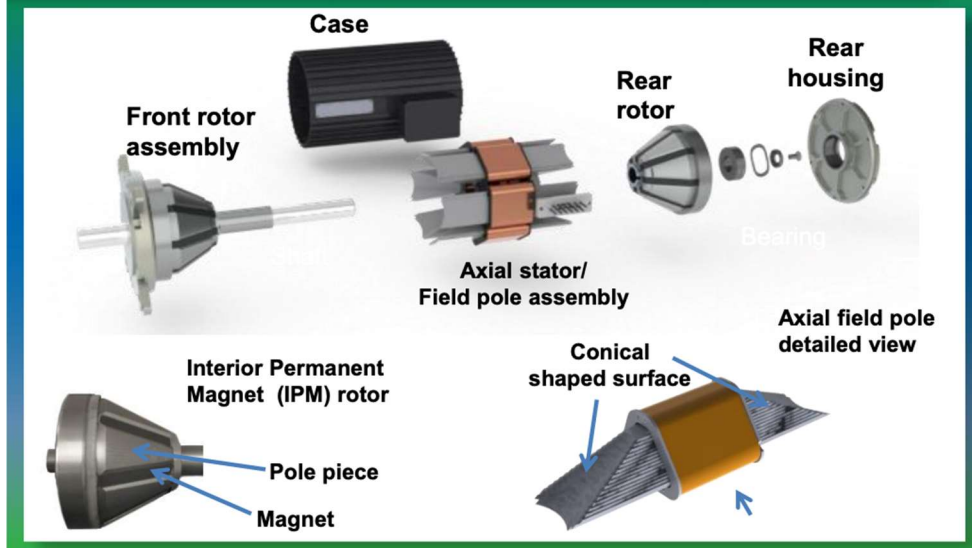


Figure 4E: NovaMax (NovaTorque) Axial Motor Design

Source: <https://www.smud.org/-/media/Documents/Business-Solutions-and-Rebates/novatorque-final-report.ashx>

Below in Figure 5E, we present the NovaMax motor efficiency at various motor sizes along with the respective IE3, IE4, and IE5 efficiency specifications.

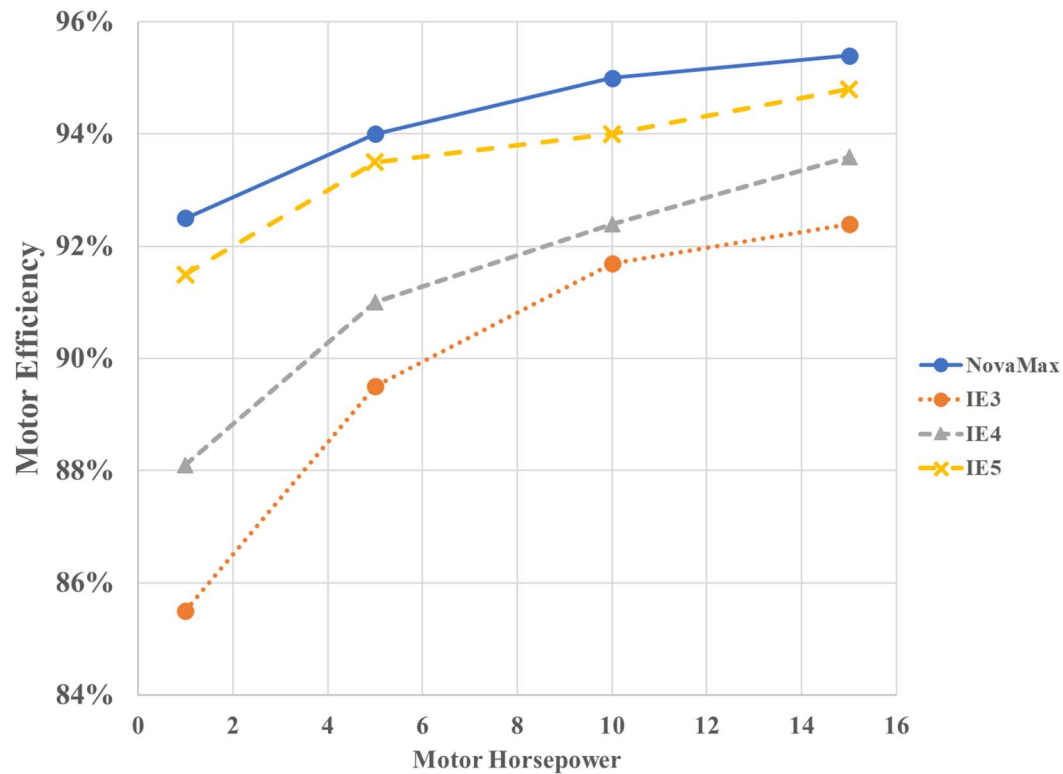


Figure 5E: NovaMax Motor Efficiency compared to IE4 and IE5 Specifications

Source: CA IOU analysis of manufacturer's data. Efficiency of NovaMax motor is available at <https://www.regalrexnord.com/-/media/Files/Literature/Marathon-Motors-Literature/MCB17025E-SB0051E-Marathon-Motors-NovaMax-Brochure-r4.pdf?la=en&hash=01A39A8214B088A477A3E09016583583> p. 1.