PEET Workshops 2021

Electric Motors: 7 October 2021

- Attached is the discussion document prepared for the 4E PEET discussions on Electric Motors.
- Participation in the online forum is limited to 4E Member countries, although each Member is allowed multiple participants.
- **All participants will need to register** in advance to attend. Please register on the 4E Members site here:

https://www.iea-4e.org/events/members-peet/peet-workshops-2021-electric-motors/

- Once you have registered, meeting details and the Agenda will be forwarded to you.

Country/region	**7 October Start times**
New Zealand	23.30
Australia	21.30
Japan/Korea	19.30
China (Beijing)	18.30
EU	12.30
UK	11.30
Nth America (East)	6.30

The following questions arise from the discussion document on electric motors produced by Paul Waide and may be worthy of further consideration:

Potential discussion topics

Q1. The following AC motor types are now covered in the IE efficiency classification by either IEC TS 60034-30-2:2016 or IEC 60034-30-1: 2014 (or NEMA MG1):

- VSD integrated motor
- Rotor-wound 3 phase AC induction motors
- Synchronous motors
- 3-phase AC induction motors with a rated capacity from 0.12kW to 1000 kW with 2, 4. 6 or 8 poles

so shouldn't they be fully included in rating plate/energy label and/or MEPS/TR requirements?

Q2. Currently Canada/China/ USA have MEPS for some types of single phase motors and the European economies do for all types. Is there any reason not to set MEPS/rating plate or label requirements for single phase motors generally?

Q3. Currently China is the only 4E member to regulate the efficiency of DC motors (two specific types) – is more work needed to assess the potential of DC motor efficiency declarations and MEPS/TR requirements and related standardisation needs?

Q4. Is there any reason not to include Explosion proof and/or Brake motors in 3-phase AC induction motor MEPS/TR requirements?

Q5. Is IE2 the appropriate level for AC motors with integrated VSDs?

Q6. Is IE2 the appropriate level for single-phase induction motors?

Background document to PEET 2021 discussion of electric motors

September 2021

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PEET efficiency trends analysis 2021

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Disclaimer

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Glossary

Duty (for motors) the statement of the load(s) to which a motor is subjected, including, if applicable, starting, electric braking, no-load and rest and de-energised periods, and including their durations and sequence in time

Duty type (for motors) a continuous, short time or periodic duty, comprising one or more loads remaining constant for the duration specified, or a non-periodic duty in which load, and speed vary within the permissible operating range

fractional hp motors motors rated at < 1 horsepower (i.e. < 0.75 kW)

Full load (for motors) the load that causes a motor to operate at its rating

IEA International Energy Agency

IE class the 'International Efficiency' classification of motors and other components of a motor system defined by the respective IEC Standards

IEC International Electrotechnical Commission

integral hp motors motors rated at 1 horsepower or greater (i.e. >= 0.75 kW)

ISO International Organization for Standardization

Load (for motors) all the values of the electrical and mechanical quantities that signify the demand made on a rotating machine by an electrical circuit or a mechanism at a given instant

MEPS minimum energy performance standard

NA not available (or applicable)

NEMA North American Manufacturers' Association

PEET Product Energy Efficiency Trends project

Rating the set of rated values and operating conditions

Rated value a quantity value assigned, generally by a manufacturer, for a specified operating condition

Rated output the value of the output included in the rating. For a motor it means the mechanical power available at the motor shaft under rated operating conditions. It is expressed in kilo-Watts (kW) in countries following the metric system, and in horsepower (hp) in other countries

Single-speed motor a motor rated for 50 Hz and/or 60 Hz on-line operation

TR Top Runner

VSD variable speed drive

1. Introduction

This report presents 2021 findings of the IEA 4E Product Energy Efficiency Trends (PEET) project. This work follows upon previous PEET projects but applies a different methodological approach as follows. For the PEET 2021 work a survey was sent to each 4E member economy to request information on:

- changes made to product energy efficiency regulations and test procedures in the period of July 2020 to June 2021
- pending changes to product energy efficiency regulations and test procedures in the period of July 2021 and beyond

Note, in order to ensure a consistent approach when discussing application of policy measures and test/methodological standards the convention applied in this report is to reference them based on when they enter into effect and not when they are first issued.

Based on the findings received and processed in July 2021 it was decided to conduct in-depth investigations into the developments in energy efficiency regulations and test procedures applicable to the following four product groups:

- Electric motors
- Televisions (and when relevant) electronic displays
- Domestic refrigeration appliances
- Room air conditioners

which constituted the set of products where the greatest changes in 4E economy regulations had occurred or were pending within the periods in question.

The analysis presented in this report addresses each of these products in turn and is being developed according to the following indicative timetable.

Proposed Date (webinar)	Topic/scope	Draft Report	Final Report
4-8 October	Electric Motors	09-Sep	30-Sep
18-22 October	Televisions	17-Sep	04-Oct
15-19 November	ExCo week		
29 Nov-3 Dec	Domestic Refrigeration Appliances	08-Nov	22-Nov
13-17 Dec	RAC	22-Nov	06-Dec

For each product the analysis presents:

- A summary of the of the existing regulations in place per 4E economy and the recent or pending changes
- A comparison of the scope of the regulations in 4E economies
- A comparison of the efficiency levels applied in the 4E economies.

For the comparison of efficiency levels normalisation methods are applied (either as per previous PEET work or amended/updated as explained in each case)

Whenever relevant a synthesis of necessary information on test procedures and/or product types is provided but only to the extent that it facilitates the above analyses and their communication.

The intention of this work is not to produce a definitive account or public facing report but to foster and facilitate a common basis for discussion of the issues addressed among 4E members. This report will not be published and is solely for 4E member's use. It is also a living document being added to per the schedule outlined above.

This specific report presents background information to inform the discussion on electric motors.

2. Findings for electric motors

This section discusses the status of 4E policy measures (MEPS/Top Runner/labelling) for electric motors including recent or pending changes. In doing so it considers and compares the policy measures in terms of:

- the type of regulation (MEPS/Top Runner, Energy Labels/Rating plates)
- the principal type of motors addressed
- the characteristics of the principal motor types which are within or without of scope
- the level of ambition of the policy requirements.

For the purposes of this exercise the following principal motor types are considered[1]:

- integral horsepower[2] polyphase AC induction motors
- fractional horsepower[3] polyphase AC induction motors
- single phase AC induction motors
- AC motors with an integrated variable speed drive (VSD)
- DC motor types.

These distinctions are used because they correspond to the main motor types that are treated within 4E economy regulations which in-turn map to the most important types of motors found in the market; and, consequently, that have the greatest energy savings potential from the adoption of energy saving regulations. However, it should be remembered that there are other, less important, motor types that are currently not subject to energy efficiency regulations in 4E economies. Often motor energy efficiency policy measures are related to the existence of replicable standards for measurement and the rating & classification of energy efficiency. Thus, the discussion considers test procedure and standardisation developments when relevant to the policy development and comparison discussion. The remainder of the report is structured as follows:

- Section 3 provides a summary of electric motor types and major standards
- Section 4 summarises the status of the regulations in the 4E economies
- Section 5 compares the scope of the motor regulations in place for each of the principal motor types
- Section 6 reports findings on the comparison of the ambition of the motor regulations in force (or that are pending).

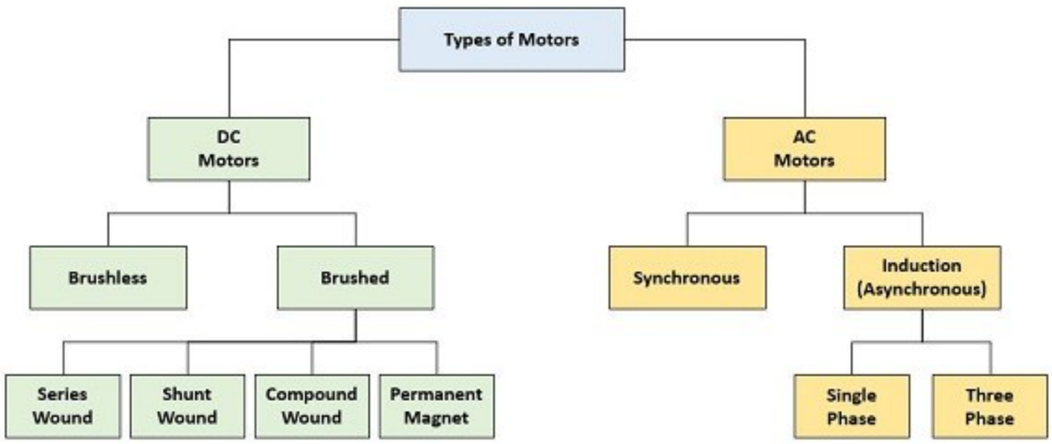
[1] See section 2.1 *Approach to motor groupings used in this report* for the rationale
[2] Integral horsepower motors have a rated capacity of >1 hp i.e. of >= 0.75 kW
[3] Fractional horsepower motors have a rated capacity of <1 hp i.e. of < 0.75 kW

3. Summary of electric motor types and major standards

Before exploring the developments in motor energy efficiency regulations its useful to consider the major types of electric motors and how they can be grouped for comparison of regulatory measures. Readers familiar with these distinctions can skip this section but it is presented as important background to the discussion of regulatory scope presented in section 5.

The main families of electric motors are shown in Figure 1. They can be split into AC and DC motors, of which AC motors can then be classified into Synchronous and Asynchronous types, of which the latter can be split into single-phase and three (poly)-phase types. DC motors can be split into Brushless and Brushed types for which there are then 4 main sub-types. AC induction (asynchronous) motors dominate overall motor electricity consumption and hence have naturally been the prime focus of energy efficiency policy developments. Within the main 3-phase AC induction motor category distinctions can be made based on a number of characteristics (discussed when relevant in the review of policy scope section below) but the main distinction in terminology used is whether they are of a rated capacity below 1 horsepower (hp) and hence are called fractional hp motors, or are 1 hp or above and hence are called integral hp motors.

Figure 1: Types of electric motors



Appendix A presents summaries of these motor types and the technical distinctions between them.

Approach to motor type groupings applied in this report

In order facilitate comparative review a pragmatic approach is taken in this report to motor-type groupings which aim to relate the technologies and their key characteristics to the regulatory scope groupings that are currently applied. Thus, the following grouping are used:

- polyphase AC squirrel cage induction motors, principally distinguished into the following sub-sets
    - fractional hp motors (<0.75 kW)
    - integral hp motors from 0.75 kW to 150 kW
    - integral hp motors from >150 kW to 183 kW
    - integral hp motors from >183 kW to 375 (or 373) kW

    - integral hp motors from > 375 (or 373) to 1000 kW
    - in addition, a sub-type of Explosion proof motors
- motors with integrated VSDs
- single-phase AC induction motors
- DC motors

If relevant additional distinctions are used for sub-types of the above groupings. The above classifications arise because of the major distinctions in scope of the existing 4E regulations, although sometimes there are necessary overlaps (e.g. the 375 or 373kW boundary for polyphase integral hp AC induction motors above).

Note, asynchronous rotor-wound AC motors (i.e. slip-ring motors) are not considered further in the regulatory comparison exercise as no 4E economy has set efficiency regulations for this motor type (they are either explicitly excluded from the scope of the current AC induction motor regulations or they are implicitly excluded because they are not cage type motors as called for in the scope).

Note, synchronous AC motors are not considered further in the regulatory comparison exercise as no 4E economy has set efficiency regulations for this motor type (they are implicitly excluded from the scope of the current AC motor regulations as they are not induction motors).

Summary of developments on test and rating standards relevant to motor efficiency

Thanks to extensive international cooperation over an extended period an internationally compatible system of classifying the efficiency of electric motor systems has been developed. IEC standards are used in most of the world and in North America NEMA standards are used, however, this cooperative work has allowed a considerable degree of alignment to occur such that both standards bodies have developed a system for energy efficiency classification of electric motors in a manner that allows their levels to essentially be directly equated despite differences in prevalent power supply frequencies (e.g. 50Hz in many countries and 60Hz in North America & Korea and 60 or 50Hz in Japan depending on the region). The basic mapping is shown in Figure 2 although some minor differences exist.

Figure 2: Mapping between NEMA and IEC energy efficiency classes for motors

NEMA	IEC
Standard Efficiency	IE1
High Efficiency	IE2
Premium Efficiency	IE3
Super Premium	IE4
No Standards	IE5

Each band of efficiency = 10% less motor loss

For the approximate comparison of policy efficiency thresholds applied in this report the IEC's IE classification will be used. Most MEPS/TR and energy label grades used in 4E economies are now set directly at one or other of these class thresholds (once account is taken of the mapping between NEMA and IEC efficiency classes); however, occasionally this is not the case and in this event the policy thresholds are mapped to the lower IE class threshold (in keeping with the practice in the IEC and NEMA standards. In a few cases the applicable IE class to the MEPS/TR requirements can vary as a function of the rated capacity, the number of poles and the type of motor enclosure. For simplicity, the mapping will be based on the most prevalent 4-pole case and will report any changes in IE class related to capacity or enclosure type.

IEC efficiency standards

Standard IEC 60034-30-1 on efficiency classes of line-operated AC motors was published by the IEC in 2014. This standard defines four IE efficiency classes for single speed electric motors. Compared with its predecessor IEC/EN 60034-30: 2008 (now withdrawn), it significantly expands the range of products covered with the inclusion of 8-pole motors and introduces IE4 efficiency performance class for electric motors. Compared to its predecessor the standard also extended the rated capacity of motors covered down to a lower limit of 0.12kW (from the previous 0.75 lower limit) and to an upper limit of 1000 kW (from the previous value of 375 kW).

More recently, the technical standards have been updated per IEC/TS 60034-30-2[4], which are for variable speed AC motors not covered in the IEC/EN 60034-30-1 and apply to frequency converters only. They apply to synchronous and permanent magnet motors. The purpose of IEC/TS 60034-30-2 is to create a level playing field between established and new, innovative, motor technologies to enable fair competition and market development. Note, following discussion with the EMSA team it is understood that IEC/TS 60034-30-2 also covers both rotor-wound 3 phase AC induction motors and AC induction motors, thus both types can be rated under the IE classification using this standard.

NEMA efficiency standards

The NEMA MG-1 standard sets out the efficiency classes indicated in Figure 2. Currently NEMA has no defined standard available for the IE5 level, although some manufacturers in the North American market are marketing a VFD-driven motor-drive pair as “ultra-premium efficiency.” The same concept applies in which IE5-equivalent efficiency levels are achieved through variable speed drives at full and partial loads.

[4] IEC TS 60034-30-2:2016 *Rotating electrical machines - Part 30-2: Efficiency classes of variable speed AC motors (IE-code)* specifies efficiency classes for variable speed rotating electric machines not covered in IEC 60034-30-1. The classification only covers machines designed for operation with sinusoidal fundamental current that are not designed to be operated direct on-line (grid), for example permanent magnet synchronous machines with and without additional reluctance torque, sinusoidal reluctance synchronous machines and synchronous machines with DC field windings.

4. Summary of electric motor regulations in 4E economies

Tables 1 to 5 present an overview of which economies have MEPS or Top Runner (TR) requirements and/or energy labelling requirements for:

- integral horsepower polyphase AC induction motors
- fractional horsepower polyphase AC induction motors
- single-phase AC induction motors
- motors with integrated variable speed drives
- DC motor types.

As electric motors are almost exclusively sold on a business-to-business (B2B) basis energy labelling is not so relevant or common as for consumer facing products; however, it is relevant for rating plates (and product literature) to indicate the motors energy performance and thus 4E economies stipulate such requirements in their regulations.

From these tables it can be seen that:

- all 4E economies have MEPS for integral horsepower polyphase AC induction motors
- all but four 4E economies have MEPS for fractional horsepower polyphase AC induction motors
- Canada/USA and China have MEPS for single-phase AC induction motors while the European economies will from July 2023
- only European economies have (pending in July 2023) MEPS for AC motors with an integrated variable speed drive (VSD)
- only China has MEPS for DC motor types
- only China currently applies energy labels to electric motors (however, other economies have rating plate requirements).

Table 1: MEPS or Top Runner requirements in place for integral horsepower polyphase AC induction motors (>=1HP/0.75kW)

	MEPS/TR			Mandatory label		
	MEPS/TR	Changes July 2020-June 2021	Changes post June 2021	Mandatory label	Changes July 2020-June 2021	Changes post June 2021
Australia	✓					
NZ	✓		✓			
Canada	✓					
USA	✓					
China	✓	✓		✓	✓	
EU	✓		Jul-21 & Jul 23			
Switzerland	✓		Jul-21 & Jul 23			
UK	✓		Jul-21 & Jul 23			
Japan	✓					
Korea	✓					

Table 2: MEPS or Top Runner requirements in place for fractional horsepower polyphase AC induction motors (<1HP/0.75kW)

	MEPS/TR			Mandatory label		
	MEPS/TR	Changes July 2020-June 2021	Changes post June 2021	Mandatory label	Changes July 2020-June 2021	Changes post June 2021
Australia						
NZ						
Canada	✓					
USA	✓					
China		✓			✓	
EU			Jul-21			
Switzerland			Jul-21			
UK			Jul-21			
Japan						
Korea						

Table 3: MEPS or Top Runner requirements in place for single-phase AC induction motors

	MEPS/TR			Mandatory label		
	MEPS/TR	Changes July 2020-June 2021	Changes post June 2021	Mandatory label	Changes July 2020-June 2021	Changes post June 2021
Australia						
NZ						
Canada	✓					
USA	✓					
China		✓			✓	
EU			Jul-23			
Switzerland			Jul-23			
UK			Jul-23			
Japan						
Korea						

Table 4: MEPS or Top Runner requirements in place for motors with an integrated variable speed drive (VSD)

	MEPS/TR			Mandatory label		
	MEPS/TR	Changes July 2020-June 2021	Changes post June 2021	Mandatory label	Changes July 2020-June 2021	Changes post June 2021
Australia						
NZ						
Canada						
USA						
China						
EU			Jul-21			
Switzerland			Jul-21			
UK			Jul-21			
Japan						
Korea						

Table 5: MEPS or Top Runner requirements in place for DC or other motor types

	MEPS/TR			Mandatory label		
	MEPS/TR	Changes July 2020-June 2021	Changes post June 2021	Mandatory label	Changes July 2020-June 2021	Changes post June 2021
Australia						
NZ						
Canada						
USA						
China	✓	✓		✓	✓	
EU						
Switzerland						
UK						
Japan						
Korea						

Changes in the period of July 2020-June 2021

The following changes in MEPS (and energy efficiency grades used in energy labels) came into effect on 1st June 2021 for motors sold in China[5]:

- 3-phase AC asynchronous motors (from 0.12kW up to 1000kW) need to meet MEPS (at IE3 levels) and energy labelling requirements
- capacitor-start asynchronous motors between 120 and 3700W need to meet MEPS and energy labelling requirements
- capacitor-run asynchronous motors between 120 and 2200W need to meet MEPS and energy labelling requirements
- two-value capacitor asynchronous motors between 250 and 3700W need to meet MEPS and energy labelling requirements
- capacitor-run motors for air conditioner fans between 10 and 1100W need to meet MEPS and energy labelling requirements
- brushless DC motors for and air conditioner fan between 10 and 1100W need to meet MEPS and energy labelling requirements.

Pending changes after June 2021

The following changes in MEPS have or are set to occur in this period for motors sold in the EU/UK/Switzerland[6]:

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[5] GB 18613-2020: Minimum allowable values of energy efficiency and values of efficiency grades for motors http://std.samr.gov.cn/gb/search/gbDetailed?id=A70340E7DF578CC8E05397BE0A0A829B

[6] Commission Regulation (EU) 2019/1781 of 1 October 2019 laying down ecodesign requirements for electric motors and variable speed drives pursuant to Directive 2009/125/EC of the European Parliament and of the Council, amending Regulation (EC) No 641/2009 with regard to ecodesign requirements for glandless standalone circulators and glandless circulators integrated in products and repealing Commission Regulation (EC) No 640/2009 (Text with EEA relevance) https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2019.272.01.0074.01.ENG

- from 1 July 2021 integral horsepower 3-phase AC induction motors (from 0.75kW up to 1000kW) will need to attain IE3 MEPS levels
- from 1 July 2021 fractional horsepower (>0.12kW up to 0.75kW) 3-phase AC induction motors will need to attain IE2 levels
- from 1 July 2021, the power losses of variable speed drives rated for operating with motors with a rated output power equal to or above 0.12 kW and equal to or below 1 000 kW shall not exceed the maximum power losses corresponding to the IE2 efficiency level[7]
- from 1 July 2023 Ex eb increased safety motors with a rated output equal to or above 0.12 kW and equal to or below 1 000 kW, with 2, 4, 6 or 8 poles will need to attain IE2 levels
- from 1 July 2023 single-phase motors with a rated output equal to or above 0.12 kW will need to attain IE2 levels
- from 1 July 2023 the energy efficiency of three-phase motors which are not brake motors, Ex eb increased safety motors, or other explosion-protected motors, with a rated output equal to or above 75 kW and equal to or below 200 kW, with 2, 4, or 6 poles, shall correspond to at least the IE4 efficiency level.

The following changes in MEPS are set to occur in this period for motors sold New Zealand:

- from (an as yet unannounced date) integral horsepower 3-phase AC induction motors (from 0.73kW up to 185kW) will need to attain IE2 levels in line with Australian requirements[8].

The following changes in test procedures are set to occur in this period:

- from (an as yet unannounced date) the test procedure used in New Zealand applicable to integral horsepower 3-phase AC induction motors (from 0.73kW up to 185kW) will be changed to align with the Australian test method[9].

[7] The European economies requirements for motor with integrated VSDs are understood to use an efficiency classification aligned to that reported in IEC 60034-2-3:2020: Rotating electrical machines - Part 2-3: Specific test methods for determining losses and efficiency of converter-fed AC motors.

[8] https://www.eeca.govt.nz/regulations/equipment-energy-efficiency/about-the-e3-programme/products-under-e3/three-phase-electric-motors/

[9] Finding from the IEA 4E member survey for this project

5. Comparison of the scope of electric motor regulations in 4E economies

This section reviews the scope of motor MEPS/TR and labelling efficiency regulations in place in 4E economies and compares them across the 4E member jurisdictions for each of the principal motor types discussed in section 3.

Integral hp polyphase AC induction motors

All the 4E economies have MEPS applicable to 3- (or poly) phase AC induction motors with squirrel-cage rotors in the integral hp capacity range but none have MEPS applicable to 3-phase induction motors with wound-rotors (so called slip motors). Thus, that part of the 3-phase AC induction motor market is not regulated for energy efficiency.

Generally, the regulations apply to all single-speed electric induction motors that are manufactured in or imported into the country/region, and are either sold as standalone equipment or as a component of a motor-driven unit to the extent that they can be tested independently. However, there are important differences in scope that affect the proportion of the whole integral hp polyphase AC induction motor market that is affected by the regulations (aside from the universal exclusion of wound-rotor type motors mentioned above).

In general, these regulations do not apply to:

- Induction motors that are mechanically or electrically integrated into the motor-driven unit to the extent that these are incapable of independent operation even if a temporary end shield or a drive end bearing is fitted
- Motors rated for temperatures outside the specified ranges
- Motors specifically designed to operate wholly immersed in a liquid
- Multi-speed motors, torque motors
- Motors for special requirements of the driven machine beyond the requirements of the IEC 60034 series of standards (such as motors for heavy starting duty, special torque stiffness and/or breakdown torque characteristics, large number of start/stop cycles, very low rotor inertia)
- Motors for special characteristics of the grid supply beyond the requirements of the IEC 60034 series of standards (or NEMA equivalent) (such as motors with limited starting current, increased tolerances of voltage and/or frequency)

The other main aspects that affect the scope of applicability of the regulations are compared by 4E economy in Table 6.

Table 6 (Part1) shows the scope of requirements with regards to:

- the rated capacity
- the number of poles (note, cases of the number of poles specified between the minimum and maximum values will be increments of 2 e.g. if the minimum is 2 and the maximum is 8 then the poles specified in the regulations will be 2, 4, 6, and 8)
- whether the regulations only apply to fixed speed (ticked if then case)
- the rated duty cycles which are in scope (e.g. S1, S2, S3 under the IEC system) – see **Error! Reference source not found.**: Motor duty cycles under IEC 60034-15 (NEMA MG-1 specifies comparable cycles) for the distinctions

- the number of phases, the range of eligible voltage and the eligible frequency.

Table 6 (Part2) shows the scope of requirements with regards to:

- efficiency thresholds dependency on the type of motor enclosure
- whether the scope includes brake[10] motors
- whether the scope includes explosion proof motors[11]
- whether any frame constraints apply[12]
- whether TENV motors[13] are included
- whether any other motor types are included
- any other scope distinctions which are applied.

Table 6: Comparison of coverage of MEPS or Top Runner requirements for integral hp polyphase AC induction motor types as a function of motor characteristics (Part 1)

	Min power (kW)	Max Power (kW)	Min poles	Max Poles	Fixed speed	Duty type(s)	Phases	Eligible voltage (V)	Eligible frequency (Hz)
Australia	0.73	185	2	8	✓	S1 & S3	3	<=1100	50 or 50/60
NZ	0.73	185	2	8	✓	S1 & S3	3	<=1100	50 or 50/60
Canada	0.746	375	2	8	✓	MG1 or S1	Poly	<=600	60Hz or 50/60
USA	0.75	373	2	8	✓	MG1 or S1	Poly	<=600	60Hz or 50/60
China	0.75	1000	2	8	✓	S1?	3	<1000	50
EU	0.75	1000	2	8	✓	Continuous	3 or 1	50> to <=1000	50 or 50/60
Switzerland	0.75	1000	2	8	✓	Continuous	3 or 1	50> to <=1000	50 or 50/60
UK	0.75	1000	2	8	✓	Continuous	3 or 1	50> to <=1000	50 or 50/60
Japan	0.75	375	2	6	✓	S1 & S3	3	<=1000	50, 60 or 50/60
Korea	0.75	375	2 <= 200kW, 4 > 200kW	8 <= 200kW, 6 > 200kW	✓	S1 & S3	3	<=600	60

[10] 'brake motor' means a motor equipped with an electromechanical brake unit operating directly on the motor shaft without couplings;

[11] In IEC standards 'Ex eb increased safety motor' means a motor intended for use in explosive atmospheres and certified 'Ex eb'. A similar definition & classification applies in NEMA standards.

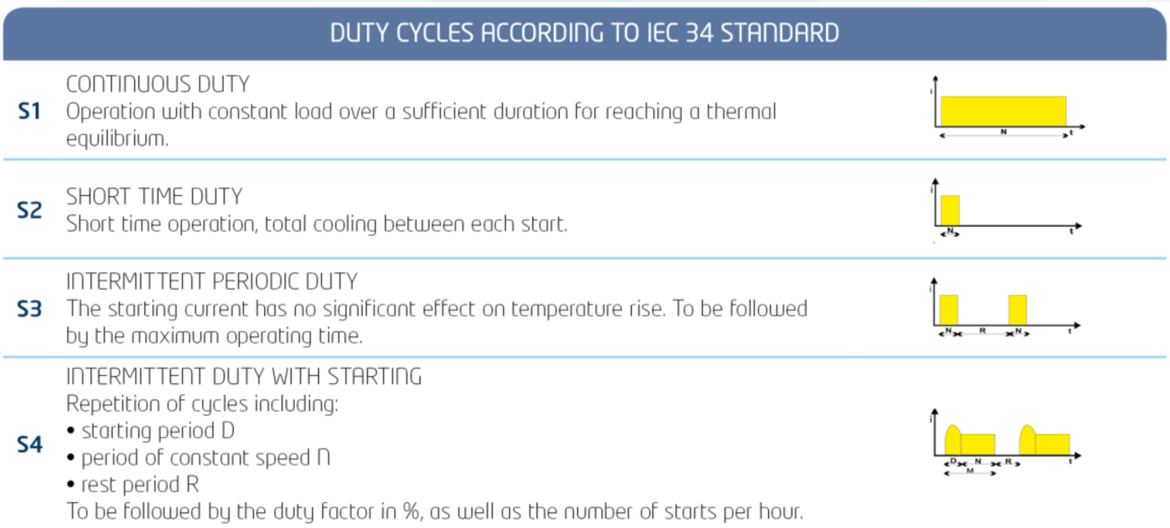
[12] E.g. according to IEC 60072-16 or equivalent NEMA frame sizes

[13] totally enclosed non-ventilated (TENV) motor' means a motor designed and specified to operate without a fan, and which dissipates heat predominantly through natural ventilation or radiation on the totally enclosed motor surface

Table 6: Comparison of coverage of MEPS or Top Runner requirements for integral hp polyphase AC induction motor types as a function of motor characteristics (Part 2)

	Thresholds dependency on Open/Closed?	Includes Brake motors?	Includes Explosion motors?	Frame type constraints	Includes TENV motors?	Other types included	Other distinctions
Australia	No	By default	By default	No	By default		
NZ	No	By default	By default	No	By default		
Canada	Yes	Yes	Yes	Yes		fire pump	NEMA A (2-8 poles), B (2-6 poles or 2-8), C (4-8 poles)
USA	Yes	Yes	Yes	Yes		fire pump	NEMA A (2-8 poles), B (2-6 poles or 2-8), C (4-8 poles)
China	No	By default	Yes	No	No		
EU	No	No	From 2023	No	No		
Switzerland	No	No	From 2023	No	No		
UK	No	No	From 2023	No	No		
Japan	No	By default	No	No	By default		
Korea	Semi enclosed type or totally enclosed type	Yes	Yes	Yes	No	Delta starting	

Figure 3: Motor duty cycles under IEC 60034-15 (NEMA MG-1 specifies comparable cycles)



Fractional hp polyphase AC induction motors

It is noteworthy that China first introduced MEPS and labelling requirements[14] for fractional hp motor that entered into force in 2020 while European economies first MEPS requirements entered into force

[14] http://std.samr.gov.cn/gb/search/gbDetailed?id=71F772D7E8DAD3A7E05397BE0A0AB82A

in July 2021[15]. In both cases they reflect the first revision of the previous AC polyphase induction motor requirements since the revision of the IEC 60034-30-1 standard in 2014 to include fractional hp motors, and hence presumably regulators took advantage of this to extend the scope of the regulations into the fractional hp capacity range. Four other 4E economies have not currently made the same scope extension of their energy efficiency requirements.

The US[16] and Canadian[17] regulations which have been in force since 2016 are constructed slightly differently as they are not applied as a single seamless product group across the full polyphase AC induction motor capacity range (i.e. including integral and fractional hp motors) but are distinguished as a separate motor category within a broader "small motors" regulation. Within that regulation the MEPS apply to "open" polyphase AC induction motors rated between 0.18 and 2.2 kW, of 2, 4 or 6 poles.

In contrast, the regulations applicable in China and the European economies also apply to 8 pole motors in this power range. The European regulations do not specify limitations of the nature of the motor enclosure whereas China's indicate they apply to enclosed fan-cooled types.

Single-phase AC induction motors

Canada and the USA specify MEPS for single-phase motors which are of the "capacitor-start capacitor-run" or "capacitor-start induction-run" type. MEPS apply in the capacity range of 0.18kW to 2.2kW. These apply to "open" motors.

As mentioned in section 4, China[18] has set MEPS and labelling requirements for the following types of single-phase motors:

- capacitor-start asynchronous motors between 120 and 3700W
- capacitor-run asynchronous motors between 120 and 2200W
- two-value capacitor asynchronous motors between 250 and 3700W
- capacitor-run motors for air conditioner fans between 10 and 1100W.

European 4E economies currently do not have MEPS in force for single-phase electric motors but they will enter into force at the IE2 level in 2023. Note, these MEPS apply to all single-phase motors with a rated capacity of greater than 0.12kW regardless of sub-type.

European regulations do not specify applicability constraints regarding the nature of the motor enclosure whereas China's indicate they apply to enclosed fan-cooled types.

Integrated VSD motors

No MEPS or labelling requirements are currently in force for integrated VSD motors in 4E economies but will enter into force in the European economies in July 2023. The European economy regulations apply to variable speed drives with 3 phases input that:

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[15] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2019.272.01.0074.01.ENG

[16] https://www.ecfr.gov/cgi-bin/retrieveECFR?gp=&SID=d1e87558e010ad735dbab5f8bad09f64&mc=true&n=pt10.3.431&r=PART&ty=HTML#sp10.3.431.x

[17] https://www.nrcan.gc.ca/energy-efficiency/energy-efficiency-regulations/guide-canadas-energy-efficiency-regulations/small-electric-motors/21826

[18] GB 18613-2020: Minimum allowable values of energy efficiency and values of efficiency grades for motors http://std.samr.gov.cn/gb/search/gbDetailed?id=A70340E7DF578CC8E05397BE0A0A829B

(i) are rated for operating with one motor[19], within the 0.12 kW-1 000 kW motor rated output range

(ii) have a rated voltage above 100 V and up to and including 1 000 V AC

(iii) have only one AC voltage output.

Within these regulations 'variable speed drive' (VSD) means an electronic power converter that continuously adapts the electrical power supplied to a single motor to control the motor's mechanical power output according to the torque-speed characteristic of the load driven by the motor, by adjusting the power supply to a variable frequency and voltage supplied to the motor. It includes all electronics connected between the mains and the motor including extensions such as protection devices, transformers and auxiliaries.

DC motors

In the case of DC motors China has MEPS and efficiency grade (labelling) requirements in place for:

- permanent magnetic synchronous DC motors[20]
- brushless DC motors (10W~1100W) for air conditioner fans.

No other 4E economy has currently set motor efficiency requirements for DC motors.

Comparison of coverage across all motor types

Table 7 below shows a comparison of the scope of coverage MEPS or Top Runner requirements by types of motor across the 4E economies.

Table 7: Comparison of coverage of MEPS or Top Runner requirements by motor types

	polyphase AC squirrel cage induction motors								
	Fractional hp <0.75 kW	0.75-150 kW	150-183 kW	183-375(3) kW	375(3)-1000 kW	Explosion proof	Integrated VSD	Single-phase AC	DC
Australia		✓	✓			✓			
NZ		dtbc	dtbc			✓			
Canada	✓	✓	✓	✓		✓		✓	
USA	✓	✓	✓	✓		✓		✓	
China	✓	✓	✓	✓	✓	✓		✓	✓
EU	✓	✓	✓	✓	✓	2023	✓	2023	
Switzerland	✓	✓	✓	✓	✓	2023	✓	2023	
UK	✓	✓	✓	✓	✓	2023	✓	2023	
Japan		✓	✓	✓					
Korea		✓	✓	✓		✓			

Notes:

- dtbc = pending but date to be confirmed
- Canadian and US MEPS for polyphase AC induction motors in the capacity range 186-373kW. For NEMA Design A or B or IEC Design N motors they apply for 2 and 4 pole motors across the entire power range, for 6 pole motors up to 261 kW and for 8 pole motors up to 186 kW. For NEMA Design C and IEC Design H they apply up to 150 kW for 4, 6, or 8 pole configurations. In addition, fire pump motors are regulated in the range 0.75kW to 373(5) kW.

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[19] Of the following type: induction electric motors without brushes, commutators, slip rings or electrical connections to the rotor, rated for operation on a 50 Hz, 60 Hz or 50/60 Hz sinusoidal voltage, that:
(i) have two, four, six or eight poles;
(ii) have a rated voltage UN above 50 V and up to and including 1 000 V
(iii) have a rated power output PN from 0,12 kW up to and including 1 000 kW
(iv) are rated on the basis of continuous duty operation; and
(v) are rated for direct on-line operation.

[20] GB 30253-2013: Permanent magnet synchronous motor energy efficiency limit value and energy efficiency grade, of 2013-12-18, coming into effect on 2014-09-01
http://std.samr.gov.cn/gb/search/gbDetailed?id=71F772D7E902D3A7E05397BE0A0AB82A

- Canadian and US MEPS for single-phase AC motors are set specifically for capacitor-start capacitor-run and capacitor start induction run motor types
- China's requirements for single-phase AC motors are distinguished into 3 types with applicable rated capacities of as low as (0.12kW to 3.7kW for capacitor-start asynchronous motors or for two-value capacitor asynchronous motors) or (0.12kW to2.2kW for capacitor-run asynchronous motors)
- European MEPS requirements from 2023 for integrated VSDs are for motors rated above 0.12 kW and equal to or below 1000 kW.

Significance of differences in regulatory scope

Inherently regulations with wider scope will affect more motors and thereby lead to greater energy savings thus the extent of the scope of regulations is a key factor influencing the achievable impacts. This report does not attempt to quantify this but some results (an illustration from the EU) are reported in the sub-section on *Significance of differences in level of efficiency thresholds* in section 6.

In the case of polyphase integral hp AC induction motors the following point can be made. Extending the scope of applicability with regards to: the rated capacity range; eligible number of poles; eligible rated duty cycles; type of specialised sub-categories included (e.g. explosion proof, brake, fire pump, delta starting, etc.); frame types included; and enclosure & cooling/ventilation types included will bring in more eligible motors and increase the achievable savings (all other factors being equal).

Similarly, the advent of standards for IE classes applicable to VSD integrated motors allows this product group to be brought into scope.

For single-phase AC induction motors requirements can either be set for specific sub-types within specified power ranges (as done in Canada, USA and China) or collectively for all such motors (as is coming into effect in European economies), but clearly setting a broader scope will enable greater savings to be achieved (all other factors being equal).

In principle, the same true for DC motors (noting that currently China is the only 4E economy to specify requirements for DC motors and then only for two sub-types). As DC motors are mostly used in OEM products which in turn may be subject to MEPS and labelling the rationale for applying MEPS and labelling dedicated to them may be weaker than in the case for other motor types, nonetheless there could be a case to assess this as well as to consider/monitor market developments to ensure that technology preference shifts do not open up gaps in regulatory coverage where no policy measure apply.

The case of other AC motor types that are not currently regulated in 4E economies may also be worthy of further investigation. This analysis has identified that currently neither 3-phase wound-rotor motors nor synchronous motors are subject to MEPS or labelling in 4E economies.

6. Comparison of efficiency thresholds of electric motor regulations in 4E economies

This section reports the efficiency thresholds of motor MEPS/TR and labelling efficiency regulations in place in 4E economies and compares them across the 4E member jurisdictions for each of the principal motor types discussed in section 3.

For each of the regulations in place the applicable efficiency thresholds were compared to the corresponding IE class and the findings are reported in Table 8. Most often the efficiency thresholds used in the regulation are specified precisely at a given IE class (or NEMA equivalent) but sometimes they are not (in which case they could be slightly above the minimum for the class) or cross classes depending on the precise point a motor resides within the applicable rated capacity range.

Table 8: Comparison of MEPS or Top Runner efficiency levels per the IE efficiency class

	polyphase AC squirrel cage induction motors								
	Fractional hp <0.75 kW	0.75-150 kW	150-183 kW	183-375(3) kW	375/3-1000 kW	Explosion proof	Integrated VSD	Single-phase AC	DC
Australia		IE2	IE2						
NZ		IE2 (in tbc)	IE2 (in tbc)						
Canada	IE3	IE3	IE3(IE2)	IE3(IE2)		IE3 or IE2		IE3 or IE2	
USA	IE3	IE3	IE3(IE2)	IE3(IE2)		IE3 or IE2		IE3 or IE2	
China	IE3	IE3	IE3	IE3	IE3	IE3		IE0 or IE1	NA
EU	IE3	IE3 (4 in 2023)	IE3 (4 in 2023)	IE3 (4 in 2023)	IE3	IE2 (2023)	IE2	IE2 (2023)	
Switzerland	IE3	IE3 (4 in 2023)	IE3 (4 in 2023)	IE3 (4 in 2023)	IE3	IE2 (2023)	IE2	IE2 (2023)	
UK	IE3	IE3 (4 in 2023)	IE3 (4 in 2023)	IE3 (4 in 2023)	IE3	IE2 (2023)	IE2	IE2 (2023)	
Japan		IE3	IE3	IE3					
Korea		IE3	IE3	IE3		IE3			

Notes:

- China's requirements for single-phase AC motors are distinguished into 3 types with applicable rated capacities of as low as (0.12kW to 3.7kW for capacitor-start asynchronous motors or for two-value capacitor asynchronous motors) or (0.12kW to2.2kW for capacitor-run asynchronous motors)
- European economy IE4 requirements from 2023 are for motors rated above 75 kW and equal to or below 200 kW only
- European economy IE2 requirements from 2023 for integrated VSDs are for motors rated above 0.12 kW and equal to or below 1000 kW
- European economy IE2 requirements from 2023 for single-phase AC motors apply to such motors of any rated capacity above 0.12 kW
- Canadian and US MEPS for polyphase AC squirrel cage induction motors in the 0.75 to 373(5) kW range distinguish between NEMA Design A & B (per IEC Design N) and NEMA Design C (per IEC Design H). For the NEMA A+B types the MEPS are mostly set at IE3 but some parts (depending on whether the motor is Open or Closed, the no. of poles and the capacity) may be IE2 and some just above the IE3 threshold. Note the scope of requirements varies depending on the no. of poles so 8 poles motors are only in scope up to 186 kW, 6 poles up to 261 kW and 4 or 2 poles the entire capacity range. NEMA Design C motors are only subject to MEPS in the 0.75kW to 150kW capacity range and for 4, 6 or 8 pole motors. These also have MEPS mostly at the IE3 level or just below (IE2) depending on the enclosure, no. of poles & capacity. In addition, fire pump motors are regulated in the range 0.75kW to 373(5) kW.

Polyphase AC induction motors

From Table 8 it can be seen that:

- all 4E economies with fractional polyphase AC induction motor MEPS/TR have set them at the IE3 level

- for integral hp polyphase AC induction motors in the 0.75-150 kW range current MEPS/TR requirements in force are all at the IE3 level except for in Australia and those imminently pending in New Zealand which are IE2
- for integral hp polyphase AC induction motors in the >150-183 kW range current MEPS/TR requirements in force are all at the IE3 level except for IE2 in Australia, Canada, the USA and those imminently pending in New Zealand
- the same is true of polyphase AC induction motors in the >183 - 375(3) kW range except that Australian and NZ MEPS do not apply to this capacity range
- for polyphase AC induction motors in the >375 to 1000 kW range all economies with MEPS/TR have set them at the IE3 level.

Note, from 2023 European economies will adopt IE4 levels for 3-phase AC induction motors in the capacity range of 75kW to 200kW.

In the specific case of explosion proof polyphase AC induction motors MEPS are set at the IE3 level in China (0.75-1000kW capacity range) and Korea (0.75-375kW range). In Canada and the USA MEPS for these motors are at the IE3 level in the 0.75-150kW range and at (or just above) the IE2 level for the >150 to 373 kW range. Explosion proof motors are not currently subject to MEPS in European 4E economies but will come into force in 2023 at the IE2 level.

Integrated VSD motors

No 4E economy currently has MEPS/TR requirements in force for motors with integrated VSDs but from 2023 European economies will require IE2 levels to be met for such motors in the capacity range of 0.12kW to 1000kW.

Single-phase AC motors

European 4E economies currently do not have MEPS in force for single-phase electric motors but they will enter into force at the IE2 level in 2023. Note, these MEPS apply to all single-phase motors with a rated capacity of greater than 0.12kW regardless of sub-type.

Canada and the USA specify MEPS for single-phase motors which are of the “capacitor-start capacitor-run” or “capacitor-start induction-run” type. MEPS apply in the capacity range of 0.18kW to 2.2kW and are at the IE3 level up to 1.5kW or IE2 (or slightly above) at higher rated capacities.

Mapping China’s single-phase motors requirements to the IE levels shows that:

- capacitor-start asynchronous motors (120 to 3700W) are set between at IE1 or IE0 (i.e. sub IE1) but are mostly at IE0. The energy label Grade 1 is at IE1 or IE0 (depends on the capacity but the energy efficiency thresholds do not align with the boundaries of the IE classes)
- capacitor-run asynchronous motors (120 to 2200W) have MEPS mostly set at IE1 with some IE0; the energy label Grade 1 = IE3
- two-value capacitor asynchronous motors (250 to 3700W) have MEPS set at IE1 while the energy label Grade 1 = IE3
- capacitor-run motors for air conditioner fans (10 to 1100W) have MEPS set at IE1 (or IE0) while the energy label Grade 1 = IE2.

DC motors

Only China has specified MEPS/TR requirements for DC motors and these are concerned with:

- permanent magnet synchronous motors and came into effect in 2014[21].
- brushless DC motors for and air conditioner fan between 10 and 1100W.

See the regulations for the efficiency levels as the IE rating system does not apply.

Significance of differences in level of efficiency thresholds

In approximate terms each improvement in IE class corresponds to motors being required to achieve 10% less losses, thus a jump in MEPS from IE2 to IE3 would prevent motors with a 10% higher set of losses from being sold, while jumping from IE2 to IE4 would prevent motors with a 19% higher set of losses from being sold (i.e. from 0.9 x 0.9 = 0.81). The actual energy savings that would result from this will depend on:

- the proportion of motors that would be sold at any IE class level before and after the MEPS/TR requirements come into effect
- the magnitude of business-as-usual energy losses of the affected part of the motor stock subject to MEPS/TR
- the magnitude of loss reductions due to the policy requirement.

The impact of these factors will vary depending on the prevalent circumstances in each economy concerned. However, currently, in all 4E economies the proportion of total motor stock energy consumed by polyphase AC induction motors and or motors with integrated VSDs will significantly exceed that used by DC motors or single-phase motors despite the latter two categories still being very significant, and in the case of DC motors, of potentially growing importance.

Findings from the EU Impact assessment

As an input to the revision of the EU motor Ecodesign regulations an ex-ante impact assessment[22] was conducted that analysed the projected impact of both the scope extensions and the increase in ambition. Table 9 below shows the estimated contribution of each motor type to the total energy savings in 2030 in the ECO3 scenario. It can be seen from the table that about 59% of the impact is estimated to stem from the scope extensions while 41% is from the increase in ambition (for 3-phase motors within the 0.75 to 375kW capacity range).

[21] GB 30253-2013 *Permanent magnet synchronous motor energy efficiency limit value and energy efficiency grade* http://std.samr.gov.cn/gb/search/gbDetailed?id=71F772D7E902D3A7E05397BE0A0AB82A

[22] https://www.vhk.nl/downloads/Reports/2019/IA_report-swd_2019_0343.pdf

Table 9: EU Ecodesign regulatory Impact Assessment findings: Contribution of each sub-category of motor to the total savings in the ECO3 scenario

Contribution of each sub-category of motor (TWh)	2030	%
3-phase 0.75-375 kW	5.8	41%
Small 1 phase motors 0.12-0.75 kW	0.9	7%
Small 3-phase motors 0.12-0.75 kW	1.4	10%
Single phase induction motors > 0.75 kW	2.5	17%
Large 3-phase induction motors 375-1000 kW	1.7	12%
Explosion proof motors 0.75-375 kW	1.2	8%
Brake motors 0.75-375 kW	0.7	5%
8-pole motors 0.75-375 kW	0.1	0.5%
Total	**14.3**	**100%**

Clearly, this is just one case and the relative savings to be expected from a scope extension (and or an increase in ambition) is dependent on the starting point of the existing regulatory framework, the stock levels, average efficiency and usage of the motors in a given economy. Nonetheless, this analysis suggests that despite the move to IE4 levels for a significant proportion of the integral hp polyphase AC motors (from IE3 or IE2 if sold with an integrated VSD) greater savings are attributable to extending the scope with:

- 24% from the inclusion of measures applicable to single-phase motors
- 13% from the inclusion of explosion proof and brake motors
- 10% from the extension of scope to include fractional hp motors
- 0.5% from the inclusion of 8-pole polyphase integral hp motors.

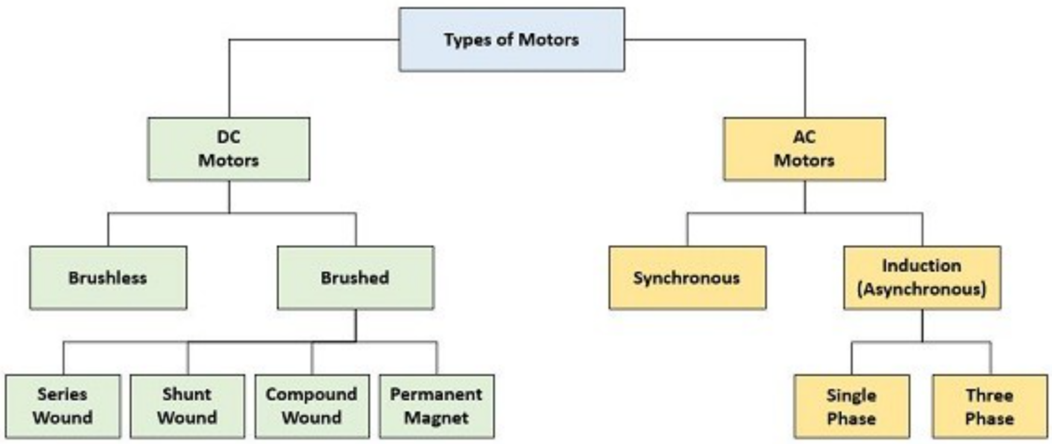
This is against a preceding regulatory framework wherein polyphase AC induction motors in the range 0.75 to 375 kW had to attain IE3 if sold independently or IE2 if sold with an integrated VSD, but where the other motor types cited in the table were not regulated.

Appendix A

When considering developments in motor energy efficiency regulations its useful to consider the major types of electric motors and how they can be grouped for comparison of regulatory measures. Readers familiar with these distinctions can skip this section but it is presented as important background to the discussion of regulatory scope presented in section 4.

The main families of electric motors are shown in Figure A-1. They can be split into AC and DC motors, of which AC motors can then be classified into Synchronous and Asynchronous types, of which the latter can be split into single-phase and three (poly)-phase types. DC motors can be split into Brushless and Brushed types for which there are then 4 main sub-types. AC induction (asynchronous) motors dominate overall motor electricity consumption and hence have naturally been the prime focus of energy efficiency policy developments. Within the main 3-phase AC induction motor category distinctions can be made based on a number of characteristics (discussed when relevant in the review of policy scope section below) but the main distinction in terminology used is whether they are of a rated capacity below 1 horsepower (hp) and hence are called fractional hp motors, or are 1 hp or above and hence are called integral hp motors.

Figure A-1: Types of electric motors



AC motors

AC motors are highly flexible in many features including speed control (VSD - Variable Speed Drives) and have a much larger installed base (in terms of total rated capacity, not numbers) compared to DC motors, some of the key advantages are:

- Low power demand on start
- Controlled acceleration
- Adjustable operational speed
- Controlled starting current
- Adjustable torque limit
- Reduced power line disturbances

The current trend for VSDs is to add more features and programmable logic control (PLC) functionality, which add advantages but require greater technical expertise during maintenance.

Types of AC motor include:

Induction (Asynchronous)

This type of motor uses electromagnetic induction from the magnetic field of the stator winding to produce an electric current in the rotor and hence Torque. These are the most common type of AC motor and are important to industry due to their load capacity, with Single-Phase induction motors being used mainly for smaller loads, for example in household appliances whereas, Three-Phase induction motors are used more in industrial applications including compressors, pumps, conveyor systems and lifting gear. Three-phase induction motors are by far the most important class of electric motor in terms of overall energy consumption and are available is capacities ranging from a fraction of a kW up to 1000 kW. In principle they come in two types:

- squirrel cage type
- wound rotor type (also referred to as "slip ring motors")

Squirrel cage types are the most versatile and cost-effective for most applications and hence are the most commonly used general-purpose motor. Wound rotor induction motors are used in applications which require smooth start and adjustable speed. Some of the applications of this motor type include cranes, mills, hoists, lifts (elevators) and conveyors. Wound rotor induction motors are also used in fans, blowers and mixers; and in large pumps in the water industry.

Synchronous

In this type of motor, the rotation of the rotor is synchronized with the frequency of the supply current and the speed remains constant under varying loads, so is ideal for driving equipment at a constant speed and are used in high precision positioning devices like robots, instrumentation, machines and process control.

Synchronous motors can be of the following types:

- Permanent magnetic (IPM or SPM types)
- Wound field
- Reluctance (Synchronous reluctance or Switched reluctance types).

Single phase motors

Unlike polyphase induction motors single-phase induction motors are not inherently self-starting and hence have to apply one of the various possible starting techniques to become self-starting motors. The method used results in the following types of single-phase induction motor (each using a different starting and/or run method):

- Split-phase induction motor
- Capacitor-start inductor motor
- Capacitor-start capacitor-run induction motor (the two-value capacitor method)
- Shaded-pole induction motor
- Permanent split capacitor motor or single value capacitor motor.

Applications of Split-Phase Induction Motors: these have low starting current and moderate starting torque. These motors are used in fans, blowers, centrifugal pumps, washing machines, grinders, lathes, air conditioning fans, etc. These motors are available in size ranging from 1/20 to 1/2 KW.

Applications of Capacitor-start induction motors and of Capacitor-start capacitor-run induction motors - both of these single-phase AC motor types have high starting torque; hence they are used in conveyors, grinders, air conditioners, compressors, etc. They are available up to 6 kW.

Applications of Shaded-pole induction motors: these are the oldest single-phase induction motor type. They have poor starting torque & the starting power factor is very low. Hence the motor gives low efficiency for higher power rating design. Consequently, this type of motor is only used for low power ratings in a range of 1/300 to 1/20 kW. Due to their low starting torques and reasonable cost, these motors are mostly employed in small instruments, hairdryers, toys, record players, small fans, electric clocks, etc.

Applications of Permanent split capacitor motor or single value capacitor motors: these have higher efficiency and pull-out torque. They are used in fans and blowers in heaters and air conditioners amongst other applications.

DC Motors

DC motors were the first type of motor widely used and the systems (motors and drive) initial costs tend to be typically less than AC systems for low power units. However, with a higher power, the overall maintenance costs increase and would need to be taken into consideration. The DC Motors speed can be controlled by varying the supply voltage, they are available in a wide range of voltages, the most popular types are 12 & 24V. DC Motor advantages being:

- Easy installation
- Speed control over a wide range
- Quick Starting, Stopping, Reversing and Acceleration
- High Starting Torque
- Linear speed-torque curve.

DC motors are widely used and can be found in small tools and appliances, through to electric vehicles, lifts & hoists.

The two common types are:

Brushed

These are the more traditional type of motor and are typically used in cost-sensitive applications, where the control system is relatively simple, such as in consumer applications and more basic industrial equipment, this motor type can be broken down as:

- Series Wound – This is where the field winding is connected in series with rotor winding and speed control is by varying the supply voltage, however, this type offers poor speed control and as the torque to the motor increase, then the speed falls. Applications include automotive, hoists, lifts and cranes as it has a high starting torque.
- Shunt Wound – This type has one voltage supply and the field winding is connected in parallel with the rotor winding and can deliver increased torque, without a reduction in speed by increasing the motor current. It has a medium level of starting torque with constant speed, so it's suitable for applications including lathes, vacuum cleaners, conveyors & grinders.

- Compound Wound – This is a cumulative of Series and Shunt, where the polarity of the shunt winding is such that it adds to the series fields. This type has a high starting torque and can run smoothly if the load varies slightly, it's used for driving compressors, variable-head centrifugal pumps, rotary presses, circular saws, shearing machines, elevators and continuous conveyors
- Permanent Magnet – As the name suggests rather than electromagnet a permanent magnet is used and are used in applications where precise control and low torque, such as in robotics, servo systems.

Brushless

Brushless motors alleviate some of the issues associated with the more common brushed motors (short life span for high use applications) and are mechanically much simpler in design (not having brushes). The motor controller uses Hall Effect sensors to detect the rotor's position, using this the controller can accurately control the motor via current in the rotor coils) to regulate the speed. The advantages of this technology is a long life, little maintenance and high efficiency (85-90%), whereas the disadvantages are higher initial costs and more complicated controllers. These types of motors are generally used in speed and positional control with applications where reliability and ruggedness are required, such as fans, pumps and compressors.

An example of brushless design is Stepper Motors, which are primarily used in open-loop position control, with uses from printers through to industrial applications such as high-speed pick and place equipment.

Brushless motors are also available with a feedback device which allows the control of the Speed, Torque and Position of the motor and the intelligent electronics control all three so, if more torque is required to accelerate quickly to a certain speed then more current is delivered, these are known as Brushless Servo Motors.

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