A SURVEY OF EFFICIENCY LEVELS SPECIFIED FOR THREE-PHASE CAGE INDUCTION MOTORS

A study by and for the

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Introduction

The APEC Energy Standards Information System maintains a website — www.apec-esis.org — that lists current and proposed standards relating to energy efficiency requirements. The majority are connected with the measurement of energy performance or contain mandatory requirements for minimum energy performance or for energy performance labelling.

While a brief description of the standards is generally provided, full details can only be obtained by studying the individual standards. Where a particular topic is of interest or relevance to several different sets of investigators, duplication of effort may be avoided by the production of a general study, such as this survey.

This particular study on three-phase cage induction motors draws on material collected from the series of conferences on Energy Efficiency in Motors Driven Systems (EEMODS) organised by, among others, Dr Paolo Bertoldi and Professor Aníbal de Almeida as well as on the standards listed by APEC-ESIS. The study lists the efficiency requirements set by various mandatory Standards[1] and then gives graphical comparisons between them, taking account of the three complicating factors of different supply frequencies, different test procedures and the difference between weighted average and absolute minimum requirements.

No attempt is made to evaluate the economic costs and benefits of introducing any particular minimum energy performance standard for cage induction motors, although some notes are provided in Appendix A. Local circumstances will always need to be taken into consideration in such an exercise. However, it is probably fair to say that if a significant proportion of the global market adopts the same, stringent mandatory requirements, economies of scale will make that stringency level the most economic.

It is in the hope of assisting progress towards that situation that this survey is being produced.

[1] In this study, the term "Standard" is used in the sense of any document written with the aim of improving consistency. It thus may include regulations that contain technical requirements and industry specifications as well as documents published as Standards by national or international standards organisations.

1. Background

1.1 Purpose

Around seventy percent of electricity used in the industrial sector is utilised via electric motor drives. There are significant potential energy efficiency savings to be made in this area. A relatively small portion of those savings, but one that is straightforward to obtain, is from setting minimum efficiency requirements for the motors themselves.

The purpose of this study is to list the measures that are in place throughout the world and to make it easier to assess the options and feasibility of introducing a minimum energy performance standard (MEPS) for three-phase cage induction motors.

1.2 Origins of the study

The study was produced as a result of several of the APEC-ESIS project team receiving queries from more than one economy[2] interested in considering the introduction of minimum efficiency requirements for cage induction motors. The contents are believed correct at time or writing. However, it is possible that certain details have been overlooked, and APEC-ESIS cannot accept any responsibility for any inaccuracies or omissions.

Readers with particular knowledge of the measures in an economy are welcome to submit additional material for inclusion in future editions of this study.

1.3 Comparisons of efficiency requirements

Mandatory or voluntary requirements for the efficiency of three-phase cage induction motors have been in place in North America for some years. Other economies have introduced requirements more recently, have requirements planned, or are actively considering them at the time of writing. While the measure of energy performance for cage induction motors — namely efficiency — appears straightforward, there are some complications that make the comparison of the requirements in different economies not so straightforward as it appears.

One consideration is that two different basic Standards exist for the measurement of motor efficiency. In brief, the IEC 34-2 procedure uses assigned values for stray losses and for winding temperatures, while the approach of the North American IEEE 112 and the proposed IEC 61972 is to measure actual performance — an approach that is increasingly realistic with recent improvements in measurement instruments and techniques.

This difference was recognised by the authors of the Australian and New Zealand Standard AS/NZS 1359.5, and this Standard accordingly includes two sets of table, one set for each measurement standard. This feature means it is easier to compare the Australian and New Zealand requirements with others, and accordingly this study tends to use the Australian and New Zealand Standard as a benchmark.

1.4 Performance requirements

This study lists the performance requirements in different economies. The requirements may be voluntary or mandatory, and may be contained within a standard

[2] In this study, the term "economy" is used instead of "country" or "nation". This is because some economies such as the European Union, comprise more than one nation, and because in other instances a single nation may comprise more than one economy.

or within regulations. There may be a mix of mandatory and voluntary requirements. For example, the Australia and New Zealand performance standard — AS/NZS 1359.5 — defines two classes of motors: high efficiency and minimum efficiency. It is mandatory for motors to comply with the minimum efficiency levels. It is voluntary for motors to comply with the high efficiency levels, but only motors that do comply with the high efficiency levels may be described as “high efficiency”. For two and four pole motors, the classifications are based on European ones (eff 1 and eff 2, with eff 3 being non-complying) but extended to cover a wider range of rated outputs. However, in the European Union all efficiency levels are voluntary.

2. Factors that affect comparison

2.1 Standards for measuring motor efficiency

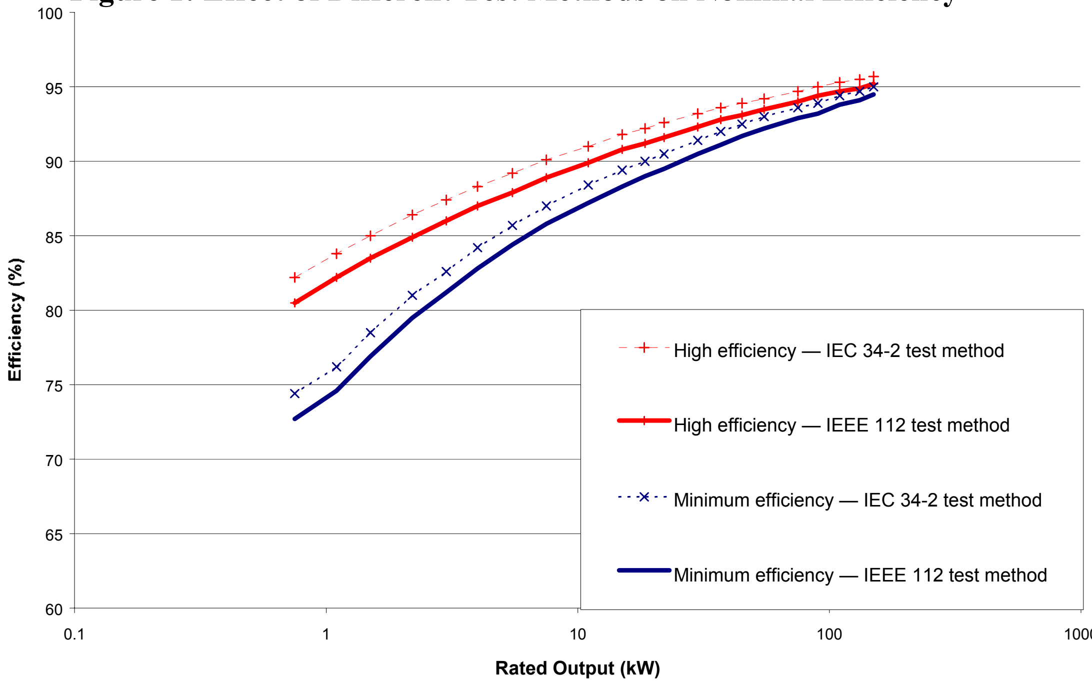
Up to 1996, there were two and a half basic standards. IEC 60034-2 and its derivatives — including AS 1359.102.1 — may be described as the European standard. It measures motor parameters and losses at standardised conditions and has a fixed value for stray loss. The North American IEEE 112, and its Canadian equivalent, measures actual performance, including measuring the stray losses, which requires specialised measuring equipment. The "half standard" referred to above is the Japanese one. This was similar to the IEC standard but ignored stray loss entirely, thereby making motors look more efficient.

Some national standards include minor variations to one or other of the two basic standards.

In 1996, at the *International Conference on Energy Efficiency Improvements in Electric Motors and Drives* in Lisbon, there was general agreement to rewrite the IEC standard to be compatible with the IEEE one, but with the option of having a high assigned value of stray losses. The IEC process did not make progress as swiftly as expected, and in consequence Australia and New Zealand produced their version (AS/NZS 1359.102.3) as a "prediction" of what the new IEC standard — IEC 61972 — would be. This standard is considered to be technically equivalent to IEEE 112.

In this study, unless a note to the contrary is given, efficiencies quoted are those obtained by testing to AS/NZS 1359.102.3 or one of its equivalents. Conversion between the two methods may occasionally be necessary. A rigorous method of doing so was devised when producing the Australian and New Zealand performance standard. This lists two sets of efficiency targets, one set for each method of test. The resulting tables may be used to provide simple conversion factors between the two test methods based on proportioning the losses.

Figure 1: Effect of Different Test Methods on Nominal Efficiency



The effect of the different measurement methods is shown in Figure 1, which is based on the tables in AS/NZS 1359.5.

Because the Australian/New Zealand Standard contains parallel requirements for both methods of test, it may be readily compared to all requirements in other economies. Therefore this study uses the Australian/New Zealand Standard as its reference point.

Mathematically, it is the losses of a motor that define its performance, and when comparing requirements, setting energy performance requirements or dealing with tolerances and measurement uncertainties it is often best to consider the losses. The conversion between (percentage) efficiency and (per unit) losses is:

$$Losses = \frac{100}{Efficiency} - 1$$ or, for a spreadsheet, =(100/[efficiency]) - 1 **(1)**

$$Efficiency = \frac{100}{1 + Losses}$$ or, for a spreadsheet, =100/([losses] + 1) **(2)**

2.2 Supply frequency

Both 50 Hz and 60 Hz are common supply frequencies.

This raises the question of whether the efficiency levels can be compared. For a given frame size, greater output can be obtained from a 60 Hz motor. As a rule of thumb, in any motor the torque available is directly dependent on the volume of the rotor. Power output from a given size of motor thus varies directly with speed. It is true that in practice that the coefficient of power output (i.e. power output per volume) increases as motors become larger, but it is also true that large motors exhibit lower starting and accelerating torques when expressed in terms of torque at rated output.

A motor that is designed for one frequency can work if connected to the other frequency, provided that the voltage is suitable. Generally, a 60 Hz motor may be run from a 50 Hz supply and vice versa providing the ratio of voltage to frequency is kept constant. The rated output is also approximately linear, but a motor that is operated at a frequency other than that for which it was designed will almost certainly exhibit a relative degradation of its efficiency. It is better to use a motor at the frequency for which it has been designed. If this is done, then it should be the case that a motor specifically designed for 50 Hz operation will have a very similar efficiency to a motor of the same power but specifically designed for 60 Hz operation.

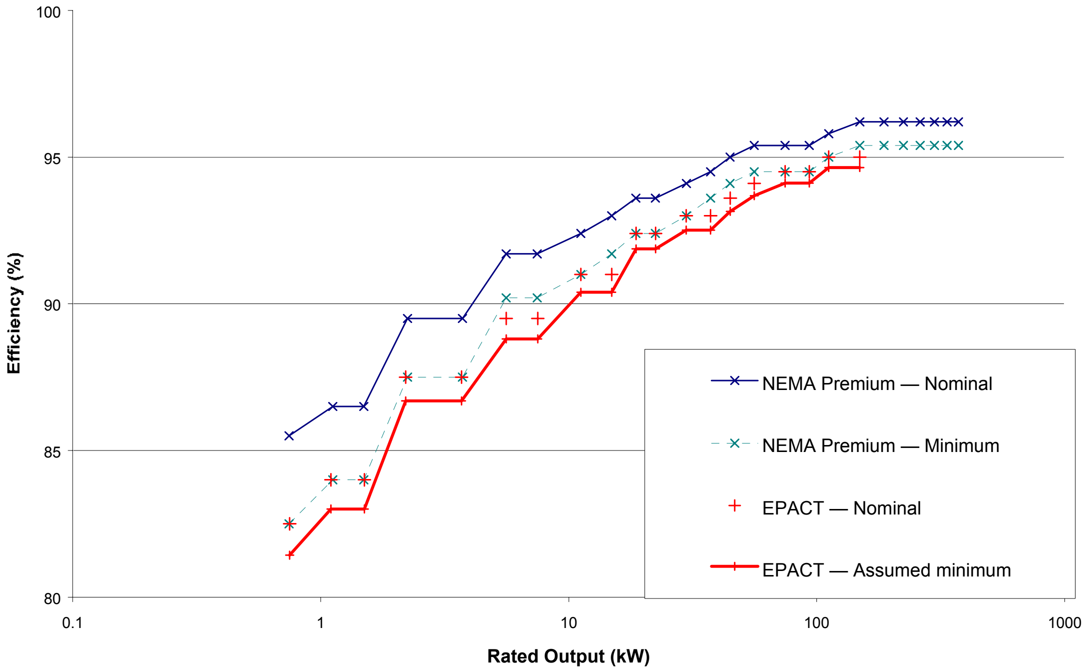
There is some deviation from this general rule as outputs get smaller. With the smaller outputs, stator copper losses represent a larger proportion of the total input. For a given output, a 50 Hz motor will be larger, and there will be extra losses due to the longer length of winding. Therefore one may expect to assign slightly more stringent efficiency requirements to 60 Hz motors of up to, say, 5.5 kW rated output.

With that proviso, when comparing motor efficiency requirements, there is no need to make adjustment for the electricity supply frequency.

2.3 Tolerances and uncertainties of measurement

One factor that contributes to the apparent difference between efficiencies of 50 Hz and 60 Hz motors is that the North American (or 60 Hz) levels are set as "average" values of efficiency, whereas the requirements in Australia and New Zealand (for 50 Hz motors) are minimum values (also described as a "drop dead tolerance"). Therefore, when comparing the two sets of requirements, an allowance must be made for manufacturing variation, and this makes the North American requirements less stringent than they appear to be a first glance. This system takes account of manufacturing tolerances and the natural variation that occurs between individual motors that are actually intended to be identical.

Figure 2: Difference between Minimum and Weighted Average Efficiencies



When the requirement is given as an absolute, or near absolute, minimum, virtually all motors are required to meet the efficiency specified, and the purchaser can be sure that the efficiency will be at least as good as that specified. Even so, when carrying out tests on samples to see whether or not they comply, the regulatory authority will generally make allowance for the uncertainties of measurement, a value that is normally specified in the relevant Standard.

Figure 2, which is based on North American requirements for 4-pole enclosed motors, gives an indication of the scale of this effect. In the comparisons in Section 5, it is the minimum values that are shown in the graphs.

3. Other considerations

3.1 Form of the performance test

The measurement of efficiency is generally a "type test". As such it is carried out on the first motor of a batch, and on a representative sample of motors from a production run. The tests are used to check that the motor as built conforms to its design, and also to check that the design calculations accurately predict motor performance generally. Thus the measurement of efficiency is not a special test, and the application of mandatory minimum efficiency requirements does not impose additional testing costs upon the manufacturer.

However, industry rumour suggested that some manufacturers may have been in the habit of quoting "enhanced" or "optimistic" efficiency values to customers. Therefore regulators, importers and purchasers may need to satisfy themselves that the efficiency figures they are quoted accurately reflect actual motor performance.

3.2 Test Laboratories

It may be expected that manufacturers have the proper facilities to carry out the measurement of motor efficiency. A possible exception is that some smaller manufacturers may not have a dynamometer suitable for measuring output that is accurate enough to enable accurate determination of stray losses.

In terms of acceptability of test results, much depends on what the authorities in an importing economy will accept. However, there is a growing trend towards mutual recognition agreements that make test results from accredited, independent test laboratories widely acceptable. However, this subject is outside the scope of this study.

3.3 Open and enclosed motors

Some economies differentiate between open motors and enclosed motors. In the case of open motors, cooling air is drawn from outside, passes through the motor and is expelled. With enclosed motors, the cooling air is blown over the outside of the motor (some larger motors may have a heat exchanger arrangement). Normally, one would expect open motors to be the more efficient, as only a single shaft-mounted fan is needed. With an enclosed motor, air needs to be circulated within the motor as well as having a fan to blow the air over the outside of the motor enclosure. In addition, the cooling path is not so effective, and one would expect the motor to run hotter. In practice, however, efficiencies assigned to open motors tend to be lower that for enclosed motors. As the majority of motors are of the enclosed type, it is likely that the requirements reflect the effort that has gone into the design rather than any physical law.

The comparisons in Section 5 are made on enclosed motors.

3.4 Shape of efficiency curves

It is interesting to note that some sets of efficiency requirements produce a smooth curve when plotted, while others appear almost disjointed. The latter curves are generally based on an analysis of what was available at the time the analysis was carried out, with one factor being the way that motors are designed with a restricted number of outer diameters so that increasing the output of a motor means either increasing only the length, or making the motor fatter but shorter.

4. Target efficiencies of various economies

4.1 Australia and New Zealand

4.1.1 Development

Investigations on a minimum energy performance standard (MEPS) for three-phase cage induction motors started in 1995 with a stakeholders' consultation meeting held in Sydney in March of that year. The concept received general support. Initially, it was thought that a level should be set such that the worst 20% of motors (by sales) would be excluded. However, an analysis of the market, plus consideration of natural improvement, led to a modified proposal that would exclude approximately 40% of motors on the market in 1995.

When the time came to write the detailed requirements, it was found that the "40% level" for 2-pole and 4-pole motors was approximately the same as the requirements for the European "eff 2" grade. For the sake of harmonisation and ease of compliance, it was decided to adopt the European "eff 2" grade as the MEPS level. Furthermore, the "eff 1" grade was adopted as a "High Efficiency" grade. One aim of having a specified "High Efficiency" grade was to prevent the existing anomaly of some suppliers having so-called "high efficiency" motors whose efficiency was actually lower than a rival supplier's standard motors. It was thought it would also provide a target for manufacturers to aspire to, as well as representing a possible future minimum standard.

The standard containing the minimum efficiency requirements, AS/NZS 1359.5:2000, has been made mandatory by regulations. The commencement date varied from October 2001 in some Australian states to 1 July 2002 in New Zealand.

4.1.2 Policy of meeting world's best practice

In Australia, the original policy for energy efficiency regulation was for measures to be on a "no-regrets" basis. In other words, the measures were expected to be economic in their own right, as well as showing significant energy savings. Zero value was given to greenhouse gas emissions avoided.

This policy has now been replaced in Australia by one of meeting world's best regulatory practice. Under this policy, Australia adopts the most stringent energy performance standard that is in place for a given product class, providing it meets the requirements for regulatory impact. The necessary notice period means that Australia lags the leading country by two to three years, but is generally at the forefront of followers.

An advantage of the policy of meeting world's best practice is that there is no debate over what the optimum stringency level is from an economic perspective; the results in such cases depend mainly on the analysis techniques used due to uncertainties within the data collected and the assumptions made. In effect, the policy gives greater weight to trade and availability aspects.

The situation in New Zealand is different, as that country has not adopted the policy of adopting world's best practice. There, a number of factors are taken into consideration, including the national and individual costs and benefits and the stance taken by trading partners. As New Zealand depends on international trade for most of its energy using products, stringency levels are usually selected to align with what is available. Nevertheless, it is possible to adopt a more stringent energy efficiency level than is in place elsewhere; it is not necessary to follow another country's lead.

The desire for trans-Tasman alignment or other factors may lead to Australia adopting world's best regulatory practice earlier than implied by the basic policy. However, in both Australia and New Zealand proposals for new or amended regulation are subject to the production of a satisfactory regulatory impact statement (RIS).

4.1.3 Target efficiencies

In Australia and New Zealand, minimum efficiency levels are prescribed by AS/NZS 1359.5. The minimum efficiency may be achieved at full load or at 75% load. The Australian / New Zealand Standard imposes a stricter definition of "minimum" than most other countries.

The standard defines a high efficiency class as well as the minimum efficiency that a motor must meet.

Separate sets of tables are given, and are used according to which test standard was used. Table 1 and Table 2 give the requirements.

Table 1: Australian and New Zealand Efficiency Classes (IEEE Test Method)

Rated output kW	MINIMUM EFFICIENCY TEST METHOD A %				MINIMUM 'HIGH' EFFICIENCY TEST METHOD A %			
	2 pole	4 pole	6 pole	8 pole	2 pole	4 pole	6 pole	8 pole
0.73	72.3	72.7	70.7	66.7	78.8	80.5	76.0	71.8
0.75	72.3	72.7	70.7	66.7	78.8	80.5	76.0	71.8
1.1	74.6	74.6	73.6	69.9	80.6	82.2	78.3	74.7
1.5	76.9	76.9	75.7	73.0	82.6	83.5	79.9	76.8
2.2	79.5	79.5	78.1	76.1	84.1	84.9	81.9	79.4
3	81.2	81.2	79.9	78.2	85.3	86.0	83.5	81.3
4	82.8	82.8	81.6	80.1	86.3	87.0	84.7	82.8
5.5	84.4	84.4	83.3	82.0	87.2	87.9	86.1	84.5
7.5	85.8	85.8	84.7	83.7	88.3	88.9	87.3	86.0
11	87.2	87.2	86.4	85.6	89.5	89.9	88.7	87.7
15	88.3	88.3	87.7	87.1	90.3	90.8	89.6	88.9
18.5	89.0	89.0	88.6	88.0	90.8	91.2	90.3	89.7
22	89.5	89.5	89.1	88.7	91.2	91.6	90.8	90.2
30	90.5	90.5	90.2	89.9	92.0	92.3	91.6	91.2
37	91.1	91.1	90.8	90.6	92.5	92.8	92.2	91.8
45	91.7	91.7	91.5	91.2	92.9	93.1	92.7	92.4
55	92.2	92.2	92.0	91.8	93.2	93.5	93.1	92.9
75	92.9	92.9	92.8	92.7	93.9	94.0	93.7	93.7
90	93.4	93.2	93.2	93.0	94.2	94.4	94.2	94.1
110	93.8	93.8	93.7	93.5	94.5	94.7	94.5	94.5
132	94.2	94.1	94.1	93.8	94.8	94.9	94.8	94.8
150	94.5	94.5	94.4	94.1	95.0	95.2	95.1	95.2
185	94.5	94.5	94.4	94.1	95.0	95.2	95.1	95.2

Table 2: Australian and New Zealand Efficiency Classes (IEC Test Method)

Rated output kW	MINIMUM EFFICIENCY TEST METHOD B %				MINIMUM 'HIGH' EFFICIENCY TEST METHOD B %			
	2 pole	4 pole	6 pole	8 pole	2 pole	4 pole	6 pole	8 pole
0.73	74.0	74.4	72.4	68.4	80.5	82.2	77.7	73.5
0.75	74.0	74.4	72.4	68.4	80.5	82.2	77.7	73.5
1.1	76.2	76.2	75.2	71.5	82.2	83.8	79.9	76.3
1.5	78.5	78.5	77.3	74.6	84.1	85.0	81.5	78.4
2.2	81.0	81.0	79.6	77.6	85.6	86.4	83.4	80.9
3	82.6	82.6	81.4	79.7	86.7	87.4	84.9	82.7
4	84.2	84.2	83.0	81.5	87.6	88.3	86.1	84.2
5.5	85.7	85.7	84.6	83.3	88.5	89.2	87.4	85.8
7.5	87.0	87.0	86.0	85.0	89.5	90.1	88.5	87.2
11	88.4	88.4	87.6	86.8	90.6	91.0	89.8	88.8
15	89.4	89.4	88.8	88.2	91.3	91.8	90.7	90.0
18.5	90.0	90.0	89.6	89.0	91.8	92.2	91.3	90.7
22	90.5	90.5	90.1	89.7	92.2	92.6	91.8	91.2
30	91.4	91.4	91.1	90.8	92.9	93.2	92.5	92.1
37	92.0	92.0	91.7	91.5	93.3	93.6	93.0	92.7
45	92.5	92.5	92.3	92.0	93.7	93.9	93.5	93.2
55	93.0	93.0	92.8	92.6	94.0	94.2	93.9	93.7
75	93.6	93.6	93.5	93.4	94.6	94.7	94.4	94.4
90	94.1	93.9	93.9	93.7	94.8	95.0	94.8	94.7
110	94.4	94.4	94.3	94.1	95.1	95.3	95.1	95.1
132	94.8	94.7	94.7	94.4	95.4	95.5	95.4	95.4
150	95.0	95.0	94.9	94.7	95.5	95.7	95.6	95.7
185	95.0	95.0	94.9	94.7	95.5	95.7	95.6	95.7

4.1.4 Scope

The Australian and New Zealand requirements apply to three-phase cage induction motors, both open and enclosed, and including motors intended for hazardous locations. They do not apply to submersible motors, those with a short-time rating, or to motors that are not separable from the driven equipment. Multi-speed motors (those with two or more discreet speeds) are also outside the scope of the Standard. There is provision for the regulatory authorities to grant exemptions.

4.1.5 Future requirements

Australia is considering making the current high efficiency levels a future mandatory minimum. A new high efficiency or premium range would be introduced. These motors would` probably have 15% lower losses than the new minimum efficiency motors.

4.2 Brazil

By decree of 11 December 2002, Brazil introduced requirements for "nominal minimum efficiency" for three-phase cage induction motors and for high efficiency. The test method is similar to IEEE 112. The values are shown in Table 3.

There is a number of exclusions. They include motors for hazardous areas, “variable speed” motors and motors with special windings.

Table 3: Brazil basic and high efficiency requirements

OUTPUT		BASIC				HIGH EFFICIENCY			
HP	kW	2p	4p	6p	8p	2p	4p	6p	8p
1	0.75	77.0	78.0	73.0	66.0	80.0	80.5	80.0	70.0
1.5	1.1	78.5	79.0	75.0	73.5	82.5	81.5	77.0	77.0
2	1.5	81.0	81.5	77.0	77.0	83.5	84.0	83.0	82.5
3	2.2	81.5	83.0	78.5	78.0	85.0	85.0	83.0	84.0
4	3	82.5	83.0	81.0	79.0	85.0	86.0	85.0	84.5
5	3.7	84.5	85.0	83.5	80.0	87.5	87.5	87.5	85.5
6	4.5	85.0	85.5	84.0	82.0	88.0	88.5	87.5	85.5
7.5	5.5	86.0	87.0	85.0	84.0	88.5	89.5	88.0	85.5
10	7.5	87.5	87.5	86.0	85.0	89.5	89.5	88.5	88.5
12.5	9.2	87.5	87.5	87.5	86.0	89.5	90.0	88.5	88.5
15	11	87.5	88.5	89.0	87.5	90.2	91.0	90.2	88.5
20	15	88.5	89.5	89.5	88.5	90.2	91.0	90.2	89.5
25	18.5	89.5	90.5	90.2	88.5	91.0	92.4	91.7	89.5
30	22	89.5	91.0	91.0	90.2	91.0	92.4	91.7	91.0
40	30	90.2	91.7	91.7	90.2	91.7	93.0	93.0	91.0
50	37	91.5	92.4	91.7	91.0	92.4	93.0	93.0	91.7
60	45	91.7	93.0	91.7	91.0	93.0	93.6	93.6	91.7
75	55	92.4	93.0	92.1	91.5	93.0	94.1	93.6	93.0
100	75	93.0	93.2	93.0	92.0	93.6	94.5	94.1	93.0
125	90	93.0	93.2	93.0	92.5	94.5	94.5	94.1	93.6
150	110	93.0	93.5	94.1	92.5	94.5	95.0	95.0	93.6
175	132	93.5	94.1	94.1		94.7	95.0	95.0	
200	150	94.1	94.5	94.1		95.0	95.0	95.0	
250	185	94.1	94.5			95.4	95.0		

4.3 Canada and the United States of America

4.3.1 Minimum levels

In North America, both Canada and the United States have minimum efficiency requirements for motors. In Canada, the efficiency levels were originally used to define where a subsidy for high efficiency motors would be paid. Once a high proportion of motors sold were claiming the subsidy, the subsidy was removed and the level became a mandatory minimum.

In the United States, mandatory efficiency levels are set under the Energy Policy Act (EPACT). They are the same as the Canadian levels, and are values for the weighted average of efficiencies.

Table 4: U.S. and Canada minimum efficiency standards

Output HP	Nominal Full-Load Efficiency					
	Closed Motors			Open Motors		
	2-pole	4-pole	6-pole	2-pole	4-pole	6-pole
1	75.5	82.5	80.0		82.5	80.0
1.5	82.5	84.0	85.5	82.5	84.0	84.0
2	84.0	84.0	86.5	84.0	84.0	85.5
3	85.5	87.5	87.5	84.0	86.5	86.5
5	87.5	87.5	87.5	86.5	87.5	87.5
7.5	88.5	89.5	89.5	87.5	88.5	88.5
10	89.5	89.5	89.5	89.5	89.5	90.2
15	90.2	91.0	90.2	89.5	91.0	90.2
20	90.2	91.0	90.2	90.2	91.0	91.0
25	91.0	92.4	91.7	91.0	91.7	91.7
30	91.0	92.4	91.7	91.0	92.4	92.4
40	91.7	93.0	93.0	91.7	93.0	93.0
50	92.4	93.0	93.0	92.4	93.0	93.0
60	93.0	93.6	93.6	93.0	93.6	93.6
75	93.0	94.1	93.6	93.0	94.1	93.6
100	93.6	94.5	94.1	93.0	94.1	94.1
125	94.5	94.5	94.1	93.6	94.5	94.1
150	94.5	95.0	95.0	93.6	95.0	94.5
200	95.0	95.0	95.0	94.5	95.0	94.5

Note that the United States still uses horsepower as the unit of motor output.

Premium efficiency

NEMA is introducing a "Premium" class, the requirements for which are shown in Table 5 (for enclosed motors) and

Table 6 (for open motors).

Table 5: NEMA Premium efficiencies for enclosed motors

Output HP	2 POLE		4 POLE		6 POLE	
	Nominal Efficiency	Minimum Efficiency	Nominal Efficiency	Minimum Efficiency	Nominal Efficiency	Minimum Efficiency
1	77.0	74.0	85.5	82.5	82.5	80.0
1.5	84.0	81.5	86.5	84.0	87.5	85.5
2	85.5	82.5	86.5	84.0	88.5	86.5
3	86.5	84.0	89.5	87.5	89.5	87.5
5	88.5	86.5	89.5	87.5	89.5	87.5
7.5	89.5	87.5	91.7	90.2	91.0	89.5
10	90.2	88.5	91.7	90.2	91.0	89.5
15	91.0	89.5	92.4	91.0	91.7	90.2
20	91.0	89.5	93.0	91.7	91.7	90.2
25	91.7	90.2	93.6	92.4	93.0	91.7
30	91.7	90.2	93.6	92.4	93.0	91.7
40	92.4	91.0	94.1	93.0	94.1	93.0
50	93.0	91.7	94.5	93.6	94.1	93.0
60	93.6	92.4	95.0	94.1	94.5	93.6
75	93.6	92.4	95.4	94.5	94.5	93.6

Output HP	2 POLE Nominal Efficiency	2 POLE Minimum Efficiency	4 POLE Nominal Efficiency	4 POLE Minimum Efficiency	6 POLE Nominal Efficiency	6 POLE Minimum Efficiency
100	94.1	93.0	95.4	94.5	95.0	94.1
125	95.0	94.1	95.4	94.5	95.0	94.1
150	95.0	94.1	95.8	95.0	95.8	95.0
200	95.4	94.5	96.2	95.4	95.8	95.0
250	95.8	95.0	96.2	95.4	95.8	95.0
300	95.8	95.0	96.2	95.4	95.8	95.0
350	95.8	95.0	96.2	95.4	95.8	95.0
400	95.8	95.0	96.2	95.4	95.8	95.0
450	95.8	95.0	96.2	95.4	95.8	95.0
500	95.8	95.0	96.2	95.4	95.8	95.0

Table 6: NEMA Premium efficiencies for open motors

Output HP	2 POLE Nominal Efficiency	2 POLE Minimum Efficiency	4 POLE Nominal Efficiency	4 POLE Minimum Efficiency	6 POLE Nominal Efficiency	6 POLE Minimum Efficiency
1	77.0	74.0	85.5	82.5	82.5	80.0
1.5	84.0	81.5	86.5	84.0	86.5	81.5
2	85.5	82.5	86.5	84.0	87.5	81.5
3	85.5	82.5	89.5	84.0	88.5	86.5
5	86.5	84.0	89.5	84.0	89.5	87.5
7.5	88.5	86.5	91.0	89.5	90.2	88.5
10	89.5	87.5	91.7	90.2	91.7	90.2
15	90.2	88.5	93.0	91.7	91.7	90.2
20	91.0	89.5	93.0	91.7	92.4	91.0
25	91.7	90.2	93.6	92.4	93.0	91.7
30	91.7	90.2	94.1	93.0	93.6	92.4
40	92.4	91.0	94.1	93.0	94.1	93.0
50	93.0	91.7	94.5	93.6	94.1	93.0
60	93.6	92.4	95.0	94.1	94.5	93.6
75	93.6	92.4	95.0	94.1	94.5	93.6
100	93.6	92.4	95.4	94.5	95.0	94.1
125	94.1	93.0	95.4	94.5	95.0	94.1
150	94.1	93.0	95.8	95.0	95.4	94.5
200	95.0	94.1	95.8	95.0	95.4	94.5
250	95.0	94.1	95.8	95.0	95.4	94.5
300	95.4	94.5	95.8	95.0	95.4	94.5
350	95.4	94.5	95.8	95.0	95.4	94.5
400	95.8	95.0	95.8	95.0	95.8	95.0
450	95.8	95.0	96.2	95.4	96.2	95.4
500	95.8	95.0	96.2	95.4	96.2	95.4

4.4 China

China has recently introduced mandatory minimum efficiencies and a voluntary high efficiency grade for induction motors. The requirements of the China Standard GB 18613-2002 are very similar to those of the Australia and New Zealand Standard (the main difference is that the minimum efficiency requirements for 6-pole motors are in places a little less stringent). The measurement method is similar to IEC 60034-2, that is equivalent to the Australian and New Zealand "Method B". An interesting feature is that GB 18613-2002 specifies limits for stray losses, with the limit ranging from 2.5% for the smallest motors to 1.3% for motors of 200kW and above.

China does not have any requirements for 8-pole motors.

Table 7: Minimum and High Efficiency Requirements for China

Rated output	Minimum Efficiency			High Efficiency		
kW	2 poles	4 poles	6 poles	2 poles	4 poles	6 poles
0.55		71.0	65.0		80.7	75.4
0.75	75.0	73.0	69.0	77.5	82.3	77.7
1.1	76.2	76.2	72.0	82.8	83.8	79.9
1.5	78.5	78.5	76.0	84.1	85.0	81.5
2.2	81.0	81.0	79.0	85.6	86.4	83.4
3	82.6	82.6	81.0	86.7	87.4	84.9
4	84.2	84.2	82.0	87.6	88.3	86.1
5.5	85.7	85.7	84.0	88.6	89.2	87.4
7.5	87.0	87.0	86.0	89.5	90.1	89.0
11	88.4	88.4	87.5	90.5	91.0	90.0
15	89.4	89.4	89.0	91.3	91.8	91.0
18.5	90.0	90.0	90.0	91.8	92.2	91.5
22	90.5	90.5	90.0	92.2	92.6	92.0
30	91.4	91.4	91.5	92.9	93.2	92.5
37	92.0	92.0	92.0	93.3	93.6	93.0
45	92.5	92.5	92.5	93.7	93.9	93.5
55	93.0	93.0	92.8	94.0	94.2	93.8
75	93.6	93.6	93.5	94.6	94.7	94.2
90	93.9	93.9	93.8	95.0	95.0	94.5
110	94.0	94.5	94.0	95.0	95.4	95.0
132	94.5	94.8	94.2	95.4	95.4	95.0
160	94.6	94.9	94.5	95.4	95.4	95.0
200	94.8	94.9	94.5	95.4	95.4	95.0
250	95.2	95.2	94.5	95.8	95.8	95.0
315	95.4	95.2		95.8	95.8	

4.5 European Union

For 2 and 4 pole motors, the EU has three classes of motor efficiency defined. These are nominated "eff 1", "eff 2" and "eff 3", with "eff 1" being the most efficient. These designations are currently used as labels; the designs are shown in Figure 3. However, analysis by de Almeida[1] has shown that in the case of Europe it would be economic to set a MEPS level at the "eff 1" level.

In the meantime, the classifications are used as the basis for voluntary agreements between the European Commission and industry, whereby a number of manufacturers have agreed that a majority of motors will meet "eff 2" by an agreed date. This target has been met, although there is some concern that the agreement does not apply to imported motors, nor even to all manufacturers within the European Union.

Figure 3: Labels for European efficiency classes

Table 8 lists the efficiency values that define these classes. These values are those obtained by testing to the existing IEC standard, i.e. "Method B" in AS/NZS 1359.5.

Table 8: European efficiency classes

Power	Min Class Eff 2 (%)		Min Class Eff 1 (%)	
kW	2 Pole	4 Pole	2 Pole	4 Pole
1.1	76.2	76.2	82.2	83.8
1.5	78.5	78.5	84.1	85.0
2.2	81.0	81.0	85.6	86.4
3.0	82.6	82.6	86.7	87.4
4.0	84.2	84.2	87.6	88.3
5.5	85.7	85.7	88.5	89.2
7.5	87.0	87.0	89.5	90.1
11.0	88.4	88.4	90.6	91.0
15.0	89.4	89.4	91.3	91.8
18.5	90.0	90.0	91.8	92.2
22.0	90.5	90.5	92.2	92.6
30.0	91.4	91.4	92.9	93.2
37.0	92.0	92.0	93.3	93.6
45.0	92.5	92.5	93.7	93.9
55.0	93.0	93.0	94.0	94.2
75.0	93.6	93.6	94.6	94.7

These classes are, over the range to which they apply, equivalent to the classes in Australia and New Zealand. The "eff 1" class is the Australian/New Zealand "high efficiency" class, and the "eff 2" class complies with the MEPS. The European "eff 3" class does not meet the Australian and New Zealand MEPS requirements.

4.6 India

India has adopted the European Union efficiency classes as a voluntary industry standard.

4.7 Malaysia

Malaysia is set to adopt the European level 2 as a MEPS in 2004, moving to level 1 in 2009. Details are not yet known.

4.8 Chinese Taipei

Chinese Taipei has had minimum motor efficiencies for several years, but they are not particularly stringent. The values, taken from Chinese National Standard CNS 2934, C4088 are given in Table 9.

A more recent standard, CNS 14400, C 4482 specifies higher values of motor efficiency. There are separate values for enclosed motors and for open ventilated, but the differences are minor. Table 10 lists the values. It is planned that this Standard will come into force in due course. The exact date is not yet finalised, but the most likely date is 1 July 2003.

Table 9: Chinese Taipei existing minimum efficiencies

Output kW	Efficiency 2 poles	4 poles	6 poles	8 poles
0.18	54.5	56.0	55.0	—
0.37	63.0	63.5	62.0	—
0.75	68.0	69.5	68.0	—
1.5	74.5	75.5	74.5	—
2.2	77.0	78.5	77.0	—
3.7	80.0	81.0	80.0	—
5.5	82.0	82.5	82.0	—
7.5	83.0	83.5	83.0	—
11	84.0	84.5	84.0	—
15	85.0	85.5	84.5	—
18.5	85.5	86.0	85.0	—
22	86.0	86.5	85.5	—
30	86.5	87.0	86.0	—
37	87.0	87.5	86.5	—
45	87.5	88.0	87.0	85.5
55	88.0	88.5	87.5	86.0
75	88.5	89.0	88.0	86.5
90	89.0	89.5	88.5	87.0
110	89.5	90.0	89.0	87.5
132	90.0	90.5	89.5	88.0
160	90.5	91.0	90.0	88.5
200	91.0	91.5	—	—

Table 10: Chinese Taipei new efficiency levels

Output	Efficiency							
	Enclosed				Open			
kW	2 poles	4 poles	6 poles	8 poles	2 poles	4 poles	6 poles	8 poles
0.37	66.0	68.0	66.0	66.0	66.0	68.0	66.0	66.0
0.55	68.0	70.0	68.0	68.0	68.0	70.0	68.0	68.0
0.75	72.0	80.0	77.0	70.0	72.0	80.0	77.0	70.0
1.5	81.5	81.5	84.0	80.0	81.5	81.5	82.5	82.5
2.2	82.5	85.5	85.5	81.5	81.5	84.0	84.0	84.0
3	82.5	85.5	85.5	81.5	81.5	84.0	84.0	84.0

Output	Efficiency							
	Enclosed				Open			
kW	2 poles	4 poles	6 poles	8 poles	2 poles	4 poles	6 poles	8 poles
3.7	85.5	85.5	85.5	82.5	82.5	85.5	85.5	85.5
4	85.5	85.5	85.5	82.5	82.5	85.5	85.5	85.5
5.5	86.5	87.5	87.5	82.5	85.5	86.5	86.5	86.5
7.5	87.5	87.5	87.5	86.5	86.5	87.5	88.5	87.5
11	88.5	89.5	88.5	86.5	87.5	89.5	88.5	87.5
15	88.5	89.5	88.5	87.5	88.5	89.5	89.5	88.5
18.5	89.5	91.0	90.2	87.5	89.5	90.2	90.2	88.5
22	89.5	91.0	90.2	89.5	89.5	91.0	91.0	89.5
30	90.2	91.7	91.7	89.5	90.2	91.7	91.7	89.5
37	91.0	91.7	91.7	90.2	91.0	91.7	91.7	90.2
45	91.7	92.4	92.4	90.2	91.7	92.4	92.4	91.0
55	91.7	93.0	92.4	91.7	91.7	93.0	92.4	92.4
75	92.4	93.6	93.0	91.7	91.7	93.0	93.0	92.4
90	93.6	93.6	93.0	92.4	92.4	93.6	93.0	92.4
110	93.6	94.1	94.1	92.4	92.4	94.1	93.6	92.4
132	94.1	94.1	94.1	—	93.6	94.1	93.6	—
160	94.1	94.1	94.1	—	93.6	94.1	93.6	—
200	94.5	94.5	—	—	94.1	94.5	—	—

4.9 Thailand

Thailand is in the process of introducing minimum efficiency requirements for 4-pole motors, this speed representing an estimated 80% of sales.[2]

The plan is for the efficiency requirements to be "ramped-up" over time, with the "standard efficiency" becoming mandatory in 2002, "medium efficiency" in 2005 and the "high efficiency" in 2008.

The values are given in Table 11, and are interesting in that although Thailand is a 50 Hz area, the "high efficiency" values are the same as the North American ones. The test method prescribed is also based on IEEE 112. The proposal was prepared by an American-based firm of consultants to the Thailand National Energy Policy Office, and there may have been insufficient distinction made between test method and target efficiency values.[3]

Another interesting aspect is that the range extends up to 373 kW (500 horsepower), well beyond the 200 HP (150 kW) of the North American requirements.

Table 11: Thailand efficiency classes (4-pole motors)

Output Rating kW	Standard Efficiency %	Medium Efficiency %	High Efficiency %
0.7	76.8	80.0	82.5
1.1	79.0	81.5	84.0
1.5	81.1	82.5	84.0
2.2	81.4	84.0	87.5
3.7	83.9	85.5	87.5

Output Rating kW	Standard Efficiency %	Medium Efficiency %	High Efficiency %
5.6	84.8	87.5	89.5
7.5	85.6	87.5	89.5
11.2	87.4	88.5	91.0
15	88.3	90.2	91.0
19	88.9	91.0	92.4
22	89.8	91.0	92.4
30	90.4	91.7	93.0
37	91.0	92.4	93.3
45	91.5	93.0	93.6
56	92.0	93.0	94.1
75	92.0	93.6	94.5
93	92.2	93.6	94.5
112	92.8	94.1	95.0
149	93.8	94.5	95.0
187	93.5	94.5	95.0
224	93.5	94.5	95.4
298	93.8	94.5	95.4
373	94.0	95.0	95.8

5. Comparison of requirements

5.1 Minimum efficiency requirements

Figure 4, Figure 5, Figure 6 and Figure 7 give comparisons of minimum efficiency requirements for 2-, 4-, 6- and 8-pole motors respectively.

Figure 4: Comparison of Minimum Efficiency Requirements for 2 pole Motors

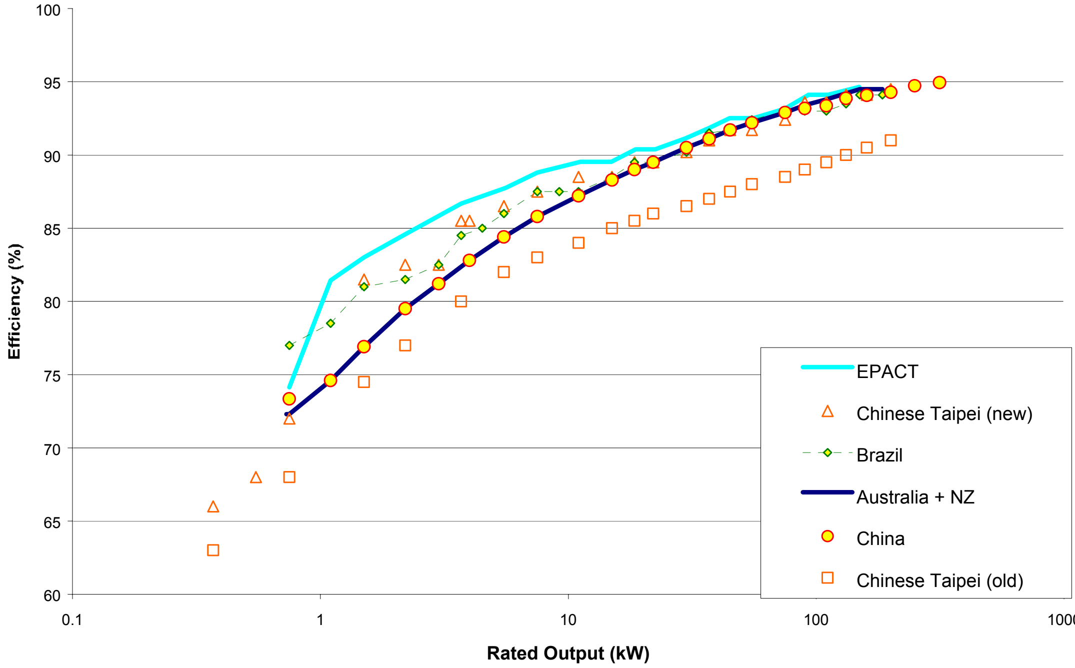


Figure 5: Comparison of Minimum Efficiency Requirements for 4 pole Motors

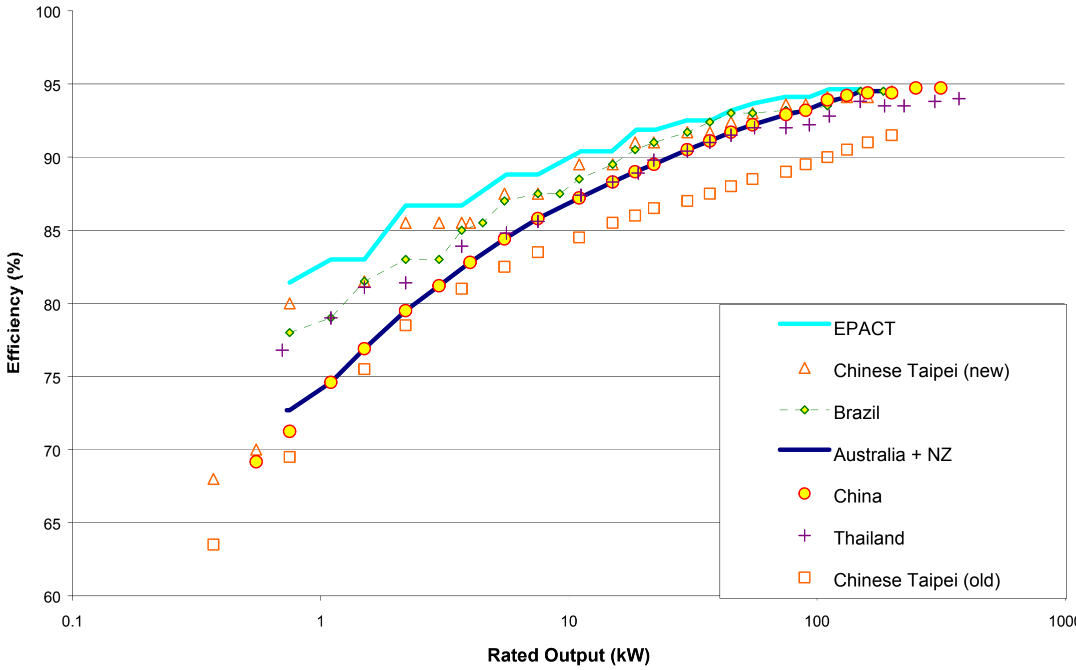


Figure 6: Comparison of Minimum Efficiency Requirements for 6 pole Motors

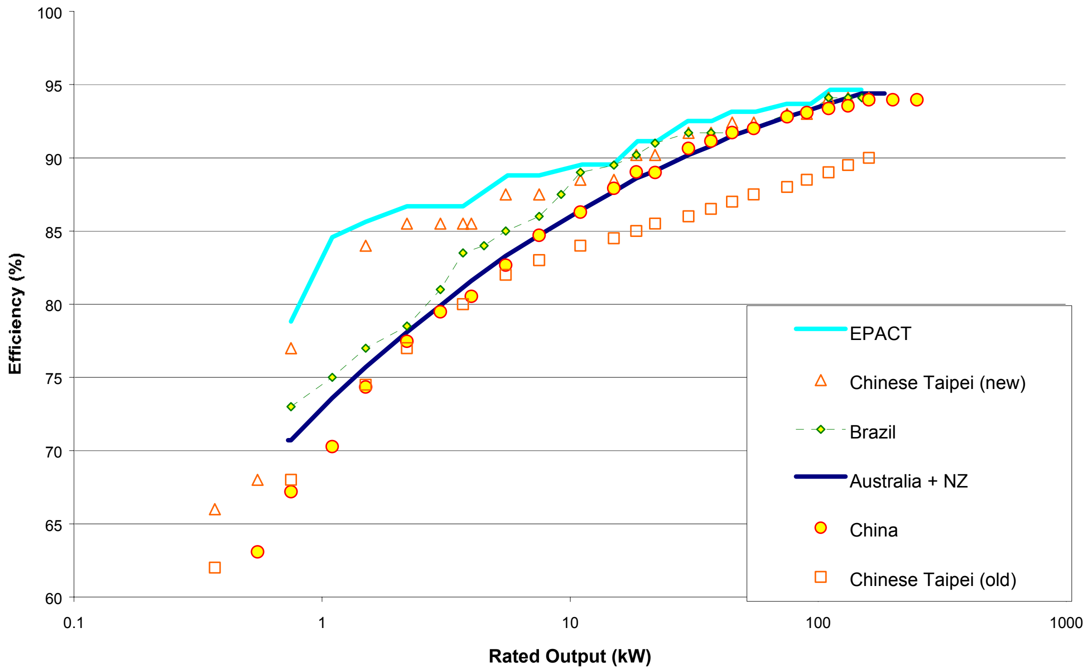
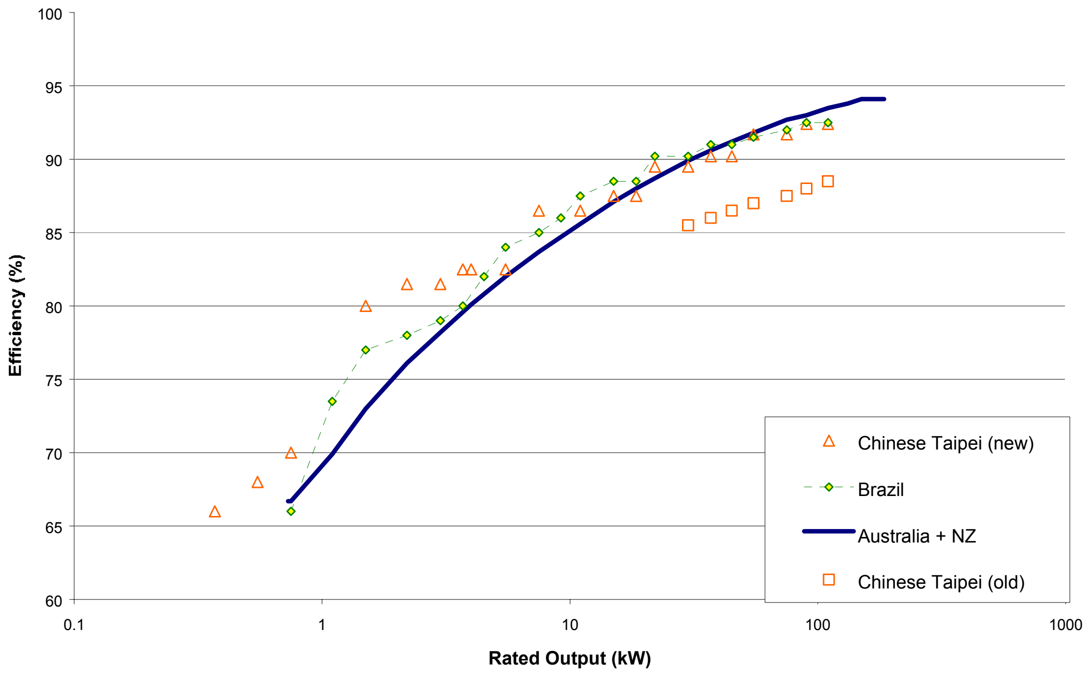


Figure 7: Comparison of Minimum Efficiency Requirements for 8 pole Motors



The trends that may be noticed are:

- Economies that have a 50 Hz supply tend to have similar requirements;
- Economies that have a 60 Hz supply tend to require higher efficiencies for small sizes of motor (see Section 2.2 above);
- Requirements for larger motors tend to be similar.

Note that the European levels are not specifically shown as over the range where they exist they coincide with the Australian and New Zealand values.

5.2 High efficiency requirements

Figure 8, Figure 9, Figure 10 and Figure 11 compare, for 2-, 4-, 6- and 8-pole motors respectively, the efficiencies that motors must achieve if they are to be designated as "high efficiency".

Figure 8: Comparison of High Efficiency Requirements for 2 pole Motors

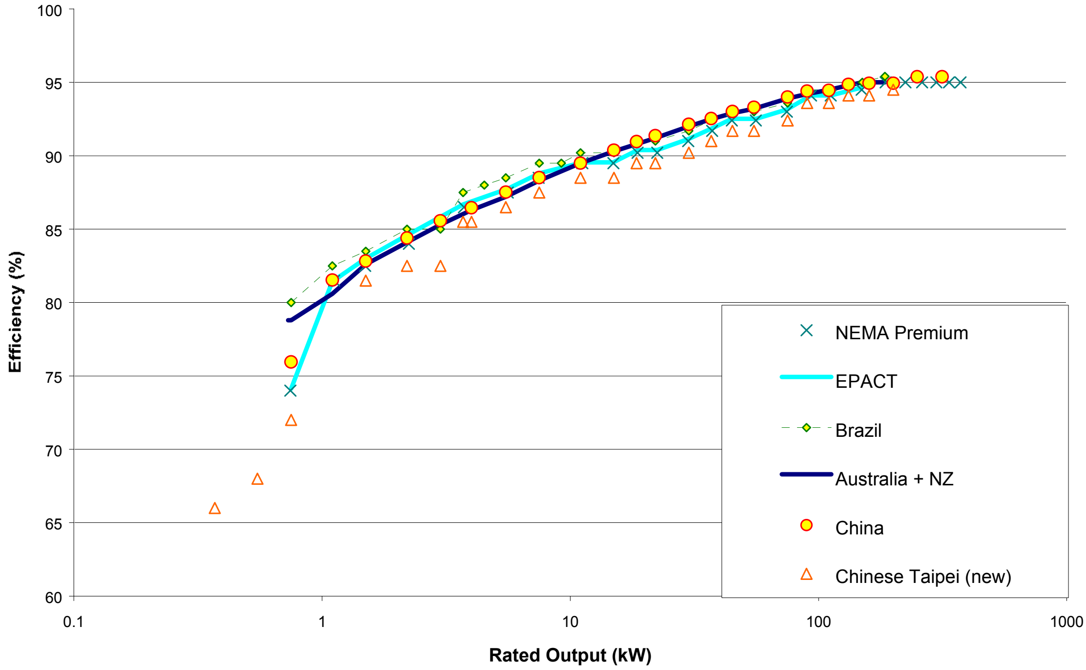


Figure 9: Comparison of High Efficiency Requirements for 4 pole Motors

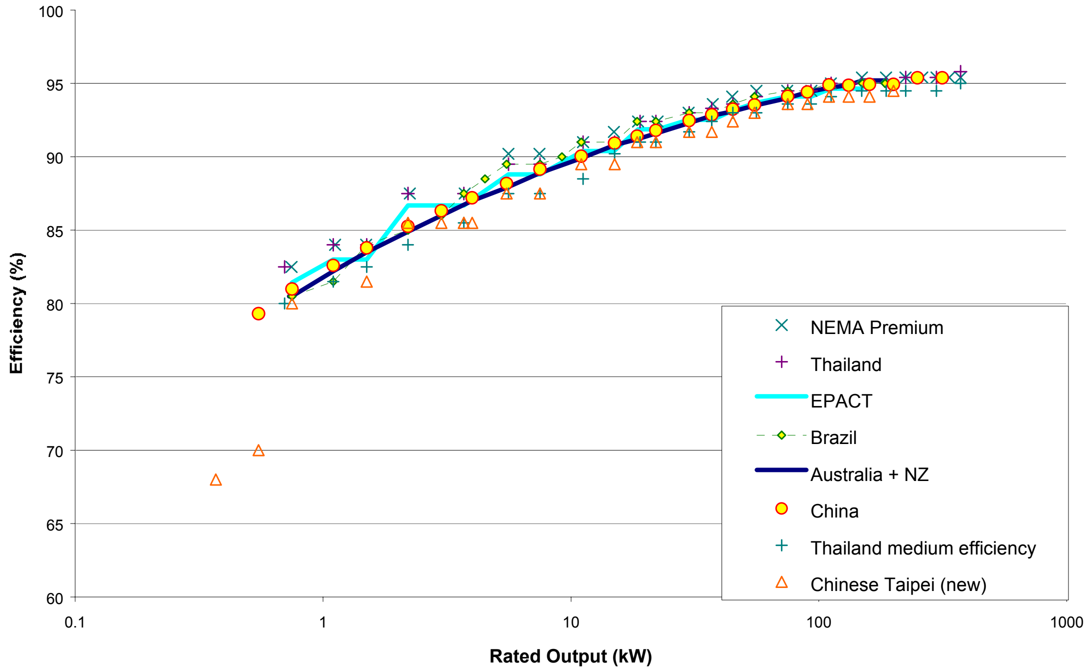


Figure 8 and Figure 9 show that for 2-pole and 4-pole motors requirements for high efficiency motors are all very similar. It is likely that these levels will become mandatory in some economies in a few years time. As well as North America, which already have these levels mandated, Thailand has set a date for mandating the higher level of efficiency, and Australia is actively considering doing so.

Figure 10: Comparison of High Efficiency Requirements for 6 pole Motors

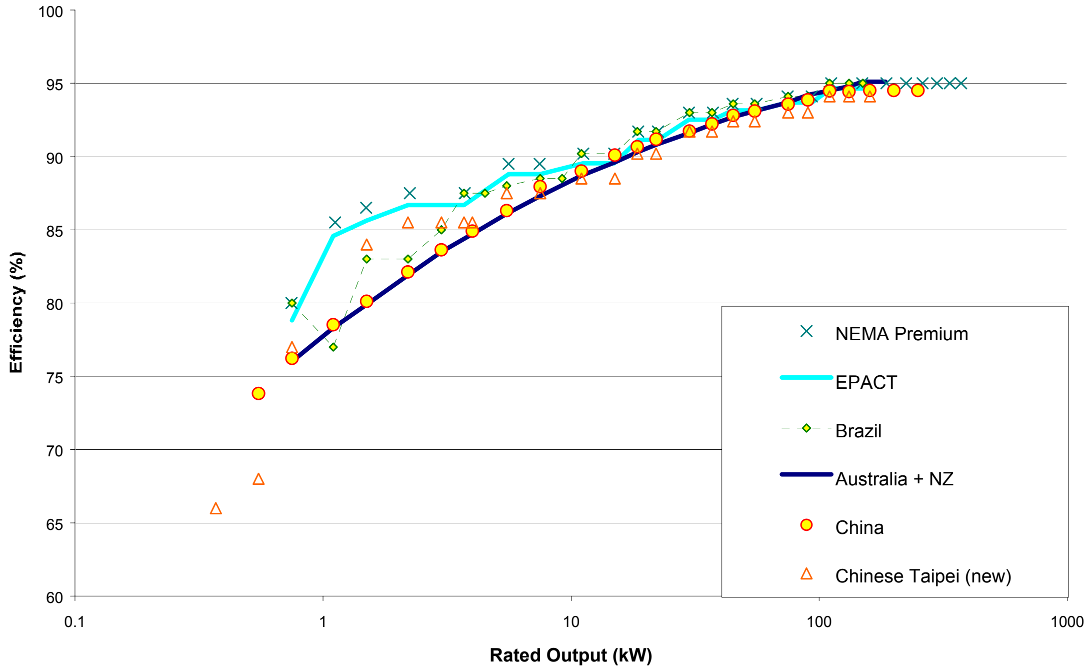
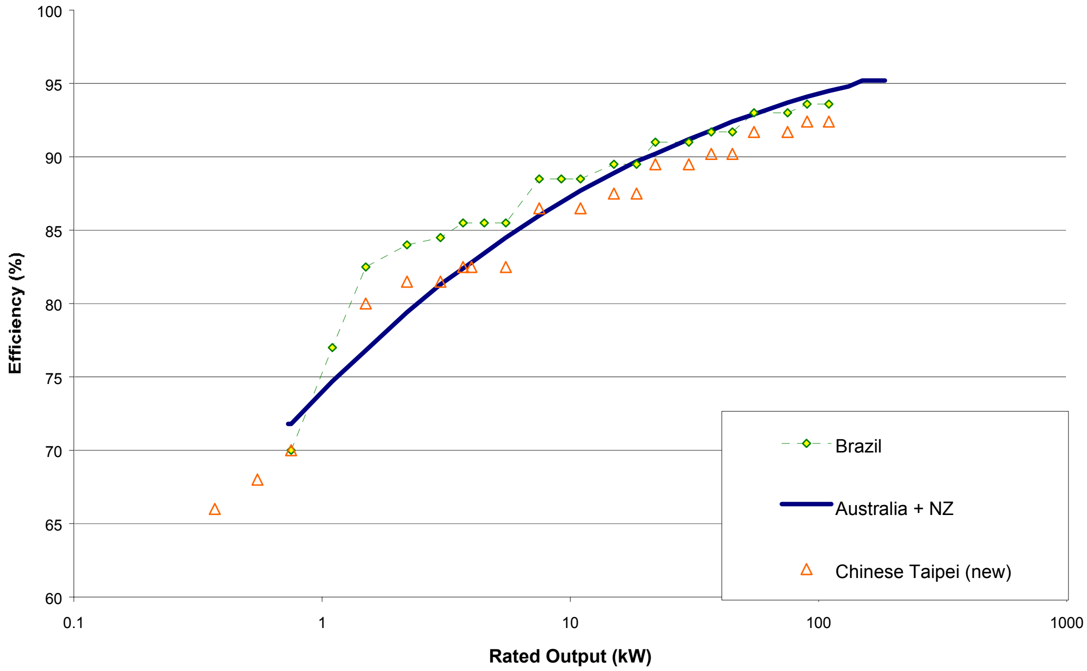
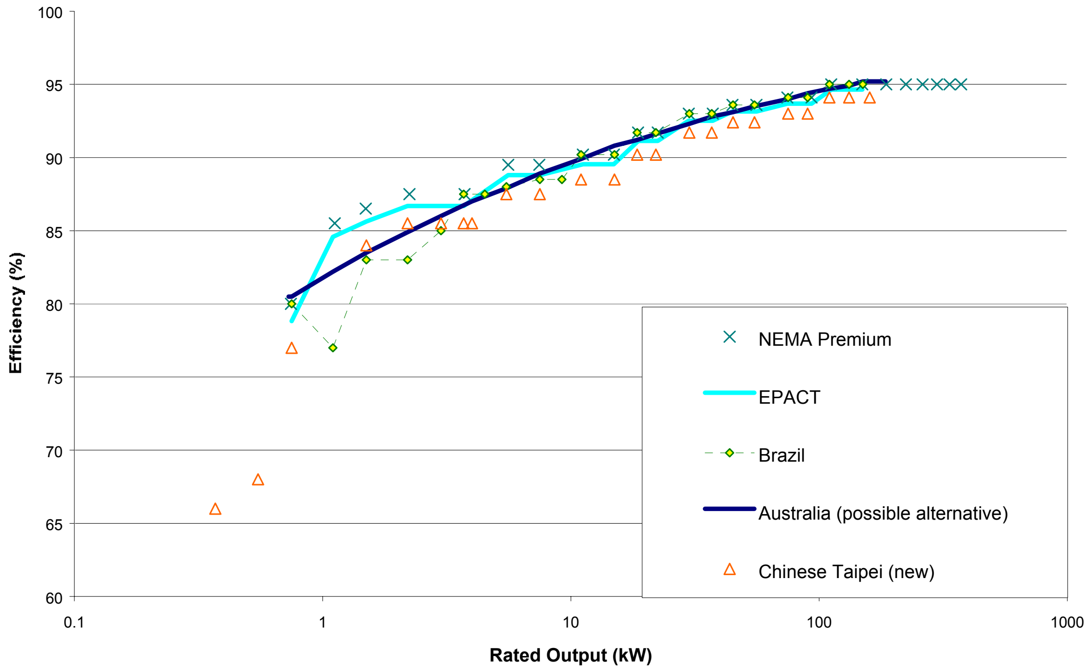


Figure 11: Comparison of High Efficiency Requirements for 8 pole Motors



The alignment in the case of 6-pole and 8-pole motors is not so tight. However, it is possible that more stringent levels may be justified for 50 Hz 6-pole motors. Australia is considering setting a future MEPS for 6-pole motors at a level higher than the current high efficiency level. In this case, the levels are likely to be similar to those shown by the modified curve in Figure 12.

Figure 12: 6-pole high efficiency with alternative Australian values



6. High output motors

6.1 High efficiency large motors

A criticism made by the steering group for the review of Australian mandatory efficiency requirements was that the existing standard does not allow large motors — those of 185 kW and above — to be called "high efficiency". To enable such marking on a voluntary basis, it would be possible to extend the range covered by the high efficiency tables to include motors up to 550 kW output.

6.2 Characteristics of large motors

Most installations generally change over from low voltage (such as 400 V) to a higher voltage for motors somewhere within the range of 185 kW to 550 kW. This is because as the motors become larger, low voltage motors have increasingly high currents. These tend to result in the supply cables being large, expensive and inefficient. The switchgear also becomes larger. For the motor designer there can be problems with finding a suitable winding configuration, and with avoiding losses due to circulating currents within the conductors. On the other hand, small high-voltage motors may have an undue amount of volume taken up by insulation, again resulting in higher copper losses in the stator.

Hence it may be inappropriate to impose mandatory efficiencies on motors in this output range.

6.3 Efficiency values

All speeds of motors of this output range tend to have similar efficiencies. Therefore the same values for their "high efficiency" and "premium efficiency" curves would be appropriate. Table 12 shows the values proposed for Australia. These were chosen to align with the values proposed for Thailand, apart from the high efficiency values for 185 kW motors, which are the values in the existing standard for motors up to 185 kW.

Table 12: Suggested high efficiency for higher outputs (all speeds)

Output	"High efficiency"			Thailand High Efficiency
	2-pole	4-pole	6-pole	
185 kW	95.0%	95.2%	95.1%	95.0%
220 kW	95.4%	95.4%	95.4%	95.4%
300 kW	95.4%	95.4%	95.4%	95.4%
375 kW	95.8%	95.8%	95.8%	95.8%
450 kW	95.8%	95.8%	95.8%	—
550 kW	95.8%	95.8%	95.8%	—

7. Conclusions

While there are a number of economies with different mandatory requirements for the efficiency of three-phase cage induction motors, there is a trend towards alignment. For motors for use on a 50 Hz mains supply, the efficiency levels specified by Australia, China, the European Union and New Zealand are the most common. For 60 Hz motors, values related to the Canadian and United States levels are more common.

Greater alignment is apparent in the case of high efficiency motors, with the exception of 6-pole motors where the values for 50 Hz motors are possibly not stringent enough.

Several economies are working towards mandating the current high efficiency values as future minimum values. Close alignment of mandatory requirements would be possible at that point.

The matter of measurement method is currently a complicating factor. However, in the longer term it is expected that the new IEC 61972 will replace IEC 34-2 and will be technically equivalent to IEEE 112 and other Standards that are similar. In the meantime, comparison of motors tested to the different test methods may be made by reference to the Standards AS/NZS 1359.5, which has separate tables for its requirements depending on the test method used.

Some adjustment of efficiency requirements should be made according to whether the efficiency values specified represent average efficiencies or absolute minima.

To encourage the production of larger motors with good efficiency, “high efficiency” values could be specified for motors with outputs up to 550 kW.

Appendix A Notes on Economic Analysis for Motor Mandatory Requirements

For any analysis, a number of assumptions need to be made. The prime assumptions made for a preliminary assessment of an Australian study increasing the stringency of motor efficiency requirements are stated here.

A.1 Prices and costs

The price of a motor is assumed to depend on its efficiency class, and is assumed to be a step function between classes. This is because a motor that does not quite meet the "high efficiency" criterion for its output is still competing against normal efficiency motors and would find it difficult to claim a premium for its better-but-not-quite-convincing efficiency.

Real costs are difficult to determine, but there is general acknowledgement that there is at least some correlation between efficiency and cost, even though that difference may be less than expected.[4]

On the other hand, manufacturers have to take into account, and recover, the costs of design, development and changing production processes for higher efficiency motors as well as the more direct material costs. Therefore, present price differentials may be used as being representative.

A.2 Lifetime

The lifetime of a motor is another variable factor. De Almeida and Fonseca[5] use, for the purpose of assessing savings, lifetimes of 12, 15 and 20 years for motors of up to 7.7 kW, from 7.5 to 75 kW, and over 75 kW respectively. However, a proportion of motors are rewound at least once in their lifetime, especially larger ones (the smallest size motors are often replaced rather than repaired). Therefore, for the purposes of the Australian study, a common lifetime of 10 years was used.

A.3 Running hours and load factor

Values for annual hours of use can be taken from a study carried out by Professor Walters[6] and that was in turn based on a study for the European Union (Reference 5). The values are shown in Table 13.

Table 13 Average annual hours use of motors

Output range	Assumed annual hours use
0.75 — 7.5 kW	1820
11 — 75 kW	2830
>75 kW	3080

In all cases, an average load factor of 75% was assumed.

A.4 Electricity tariff

The selection of the tariff to be applied affects the results of analysis. There is little consensus of what is an appropriate value. Much depends on the tariff structure, and the proportion of the whole that is represented by a demand charge. Future electricity prices may be particularly uncertain. For this study, an arbitrary unit cost was chosen, with a sensitivity analysis carried out so that the effect of using a different value could be assessed.

A.5 Efficiency measurement method

It is suggested that motor efficiency (and, more relevant, motor losses) are based on measurements made in accordance with IEEE 112 or a technically equivalent Standard. This is considered a better representation of energy use in service, and hence more realistic for analysis, than the IEC 34-2 method of test.

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