Australian-led developments in electric motor energy efficiency testing

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Abstract

According to the International Energy Agency (IEA)[1], an average of 45 % of electricity used in major countries powers electric motor systems.

Australia has been regulating the minimum energy performance standards (MEPS) of electric motors since 2001 (MEPS1). The stringency of these levels was increased in 2006 (MEPS2). It is mandatory that, prior to their sale, all three phase cage rotor induction motors from 0.75 kW up to, but not including 185 kW must be registered and meet the MEPS2 requirements as specified in Australian/New Zealand Standard AS/NZS 1359.5:2004.

To ensure the effectiveness of this regulation, Australia has been focusing efforts on compliance testing, to inform standards development, and harmonisation at the domestic and international levels. In the last three years the Australian Equipment Energy Efficiency (E3) Program has tested more than 100 motors as part of its compliance activities.

Australia has also been leading a number of other initiatives at the international level. In particular, Australia has been acting as Task Leader of the International Energy Agency 4E EMSA 'Testing Centres' Task C, which began in 2009. Under this task, a Testing Centres network has been developed to raise the quality of testing of motors worldwide by developing networks between laboratories in different countries. The aim of this has been to facilitate discussion and sharing of experience with motor testing in laboratories around the World.

Further international benchmarking was done by a 'software round robin' to examine the impact of calculating efficiency values by different laboratory software packages/implementation using the same data and IEC testing procedure algorithms.

Another initiative that Australia has been managing is a project on 'Harmonisation of Test Methods' conducted under the Asia Pacific Partnership (APP) Building and Appliances Task Force (BATF). This involved a comparative analysis of results from the testing of 27 motors in China, to four different test methods, as described in the international test method standard: IEC 60034-2-1:2007.

Australia has also undertaken a project on measuring the efficiency of motors when driven by different VSDs.

Introduction

Australia has been regulating the minimum energy performance standards (MEPS) of three phase cage rotor induction motors since 2001 ('MEPS1'). The stringency of these levels was increased in 2006 ('MEPS2'). It is mandatory that, prior to their sale, all such electric motors with power output ratings from 0.75 kW up to but not including 185 kW must be registered and meet the MEPS2 requirements specified by the Australian/New Zealand Standard AS/NZS 1359.5:2004 (see www.energyrating.gov.au). Currently, in Australia and New Zealand there are over 3,700 electric motors registered as meeting the MEPS2 efficiency levels, which makes them available for legal sale.

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1. From IEA 2011 information paper "Walking the torque", by Falkner and Holt, available at: www.iea.org

ards development, and harmonisation at the domestic and international levels.

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Motor testing centres network developed under the IEA's 4E EMSA

Electric motor systems are responsible for 45 % of global electricity consumption. The technology, know-how and guiding principles for reducing this consumption by 20–30 % already exist, but are not yet widely applied. The 4E Electric Motor Systems Annex aims to raise awareness worldwide about the energy saving potential of motor systems, and to provide guidance to exploit these. EMSA provides a forum for a direct and in-depth exchange on experience with motor systems efficiency policy in different countries.

At present, seven national Governments are members of the Annex: Australia, Austria, Denmark, The Netherlands, South Africa, Switzerland, and the United States of America. EMSA's work focuses on the following areas:

- motor systems policy;
- testing centres;
- international standards;
- capacity building;
- bridge to SEAD[2].

Australia has taken the role of Task Leader for the International Energy Agency's 4E EMSA Task C called 'Testing Centres'. Under this task, a Testing Centres network has been developed to raise the quality of motor testing and measurements worldwide by developing networks between motor testing laboratories in different countries in order to facilitate the exchange of experiences and develop best practice.

This work began in 2009 with the first workshop held in Nantes in France alongside EEMODS. A total of three Testing Centres workshops have now been held: in Nantes in 2009; in Zurich 2010; and Alexandria in USA in 2011.

The workshops have all been judged successful, each with around 40 attendees from North America, Europe, and the Asia-Pacific region. There have been attendees from manufacturers, universities, and independent laboratories, as well as government representatives and other experts. Participants have been fully engaged and useful clarification and information sharing has taken place. In particular, the group has focussed on interpreting and clarifying the use of the IEC 60034-2-1 test method in a practical laboratory setting and with regulation in mind.

Ultimately these exchanges have led to the development of a guide to motor testing using IEC 60034-2-1. This guide has now been submitted as a contribution towards the revision of that standard.

The Testing Centres work is part of the International Energy Agency (IEA) 4E Electric Motor Systems Annex (EMSA). (www.motorsystems.org).

TESTING CENTRES NETWORK ACTIVITIES RELATED TO THE IEC TEST METHOD

There is a need to be able to measure motor efficiency accurately, so as to be able to monitor, control and regulate the efficiency of the motors that are sold. Induction motor test and measurements techniques were almost fully developed by the middle of the 20th century. However, we are still dealing with issues of conformity between test methods and test laboratories. IEC 34-2 was one of the original test method standards. There are, however, areas of contention, such as the way additional load losses are assigned as 0.5 % of input power, when, to be confident of the results, the actual additional load losses need to be determined from measurements in a manner similar to that which is described in the US-developed IEEE112 Method B. in which additional load losses are determined by smoothing the residual losses.

In 2007, the new edition IEC 60034-2-1 test method was published. It lists ten different test methods for induction motors and included two major additions:

- the determination of additional load losses using smoothing of residual losses; and
- the Eh-star method.

The Testing Centres Network identified and discussed the issues with this standard which needed clarification. These included:

- the order in which individual tests and measurements are carried out;
- a proposal to have software supplied with the new standard;
- removal of sealing elements;
- selection of measurement points;
- correction of iron losses for stator resistance voltage drop;
- measurement averaging times.

Based on the outcomes of the first two Testing Centres workshops, a guide for using IEC 60034-2-1 was developed and circulated to Testing Centres members in May 2011. As the IEC test method standard is updated and refined, there should eventually be no need for a guide for the future editions of IEC 60034-2-1. The IEC WG28, which is charged with reviewing this standard, at its last meeting (in Zurich), made good progress in generating a more uniform standard. It is expected that the revised edition of IEC 60034-2-1 will have a single preferred efficiency measurement method to be used for regulatory purposes, namely the method of summation of losses, with direct determination of stray load losses by smoothing of the residual losses.

SOFTWARE 'ROUND ROBIN'

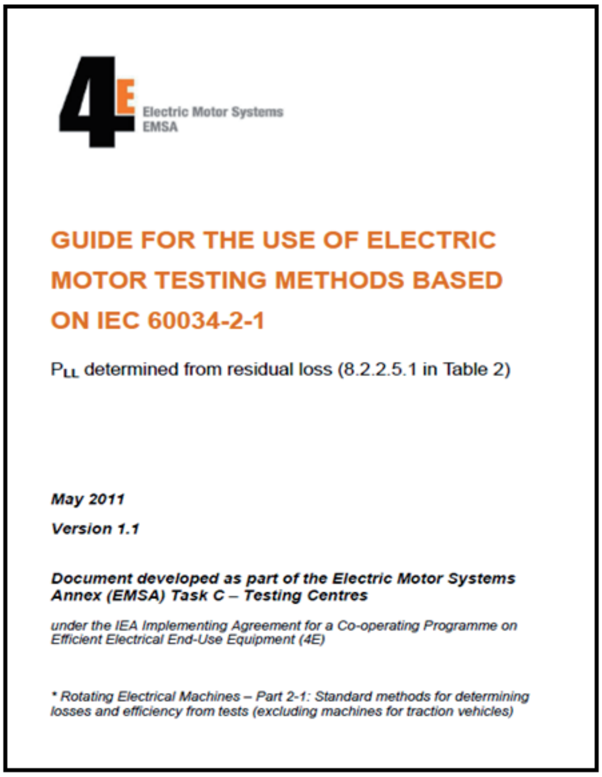
The Software Round Robin was to designed to simulate a round-robin motor efficiency measurement trial, but without exchanging an actual motor. Instead, ten participating laboratories were provided with test data obtained from an 11 kW,

2. Super-efficient Equipment and Appliance Deployment Initiative, see http://www.superefficient.org/

2 pole motor, and asked to calculate the motor's loss components, and its overall efficiency, according to the requirements set out in IEC 60034-2-1: 2007. This project simulated a round-robin in which the test object was invariant (ie, did not suffer from any variations due to ageing, maltreatment during transport etc) and in which the electrical, thermal and mechanical instrumentation was without error, exactly the same test method and technique was used, and under exactly the same laboratory power supply and ambient temperature conditions.

The results of the round robin were quite surprising, with variations of approximately ±0.2 percentage points in calculated efficiency values, providing an effective uncertainty in calculations alone which is unacceptable for international regulation of motor efficiency. Analysis of the results of the calculations from the participating laboratories provided information about the ways in which those organizations interpreted the standard, and highlighted some ambiguities in the standard's description of the calculation algorithm. It also indicated possible errors in the calculation software from each laboratory.

This was seen as a significant step in revising and rewriting the standard in order to achieve an increased level of confidence in motor efficiency measurements. Further details were presented at the EEMODS 2011 conference (Baghurst *et al* 2011).


4E Electric Motor Systems EMSA

GUIDE FOR THE USE OF ELECTRIC MOTOR TESTING METHODS BASED ON IEC 60034-2-1

P_{LL} determined from residual loss (8.2.2.5.1 in Table 2)

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under the IEA Implementing Agreement for a Co-operating Programme on Efficient Electrical End-Use Equipment (4E)

* Rotating Electrical Machines – Part 2-1: Standard methods for determining losses and efficiency from tests (excluding machines for traction vehicles)

Figure 1: Cover of EMSA guidance document for IEC test methods.

Results from an APP project on harmonisation of test methods

The Asia-Pacific Partnership on Clean Development and Climate (APP), which ended in April2011, brought together Australia, Canada, China, India, Japan, Republic of Korea and the United States to address the challenges of climate change, energy security, and air pollution in a way that encourages economic development and reduces poverty. The APP was made up of eight different Task Forces, including the Buildings and Appliances Task Force (BATF).

Under the BATF, a project on the 'Harmonisation of Test Methods' was undertaken by Australia. The aim was to help improve the harmonisation of test method standards in an effort to reduce the impact of this major barrier in developing successful standards for regulation and labelling programs.

As part of this project a unique set of electric motor test data was generated by testing 27 motors with three different power ratings: 0.75 kW, 11 kW, 55 kW. The motors were purchased

Figure 2: The third Testing Centres workshop in Alexandria, USA, on 12 September 2011.

in China and tested at the Shanghai Electrical Apparatus Research Institute (SEARI) to four test methods from the international test method standard, IEC 60034-2-1:2007. Three of these methods were (indirect) summation of losses methods: P_{LL} (stray load losses) determined from residual loss; P_{LL} from assigned value; and P_{LL} from an Eh-star test. Nine of the motors were also tested to the fourth method – the output:input method, which provides a direct measurement of efficiency.

A comparative analysis of the results from the four different test methods, shows the differences in the measured/estimated efficiency between the different methods, as well as the differences in the estimated losses for the three indirect methods for the 27 motors tested.

The general approach to examining the data was to:

- undertake a meta-accounting/gap analysis of tests undertaken and reported;
- examine and compare the efficiency load curves for each motor for each test, with a focus on the 75 % and 100 % loading of the motors;
- examine the impact on efficiency ranking when using different testing approaches;
- examine the variability of the main variables and, if possible, undertake a sensitivity analysis of the inputs to provide empirical confidence intervals of the output calculations; and
- include an engineering/physical explanation of observations where possible.

From the motors tested, and the analysis undertaken, the conclusions reached included the following:

1. There is no significant statistical difference between the efficiency values recorded by the four different methods (at both 75 % and 100 % loading). This does not mean that there is no underlying difference, rather that the sample size is probably insufficient to disprove this statistically. However, this is consistent with no systematic bias between the different testing methods.
2. For the statistical tests to show any significance the number of tests would need to be increased.
3. On the efficiency estimates (strict statistical assessment notwithstanding):
   a. the assigned loss method generally provides the lowest efficiency measure, which is expected due to the approach laid out in the IEC test standard;
   b. the direct torque (output:input) method appears to have a tendency to give a higher value of efficiency for smaller motors;
   c. there is a decrease in the variation of the measured/estimated efficiency with increasing size of motor;
   d. similarly, the least efficient motors show a greater variation in efficiency estimates.
4. For the three indirect test methods, the losses which were examined showed:
   a. the assigned method provided the largest stray losses, as expected, and it is this that explains the lowest efficiency estimates;
   b. for all the other losses measured there was no discernable difference between the measurements done under the four different methods (as would be expected since they are the same aspect being measured in the same way);
   c. the stator losses, as a proportion of all losses, increased with motor size.
5. Not all the measured data were reported, so it was not possible to undertake a detailed check of the algorithms or undertake a sensitivity analysis of the measured variables.
6. The ranking of the motors does not change if different testing methods are used to determine the ranking criteria. This was found for both the 75 % and 100 % motor efficiency values, both of which showed the same ranking.
7. The efficiency of all the motors varies at different values of output power, as expected, and to reach maximum efficiency around the 75 % loading level.

Based on the findings, a number of recommendations were made for any future detailed testing and research. In particular, it was recommended that:

- if the intention is to examine the test procedure, the tests should focus on multiple tests on the same motor, rather than run multiple tests on motors from the same production batch to remove one element of variation; and
- all data should be reported in such research projects to allow additional checks and research to be done.

More detailed analysis was presented at the EEMODS 2011 conference (Lane *et al* 2011).

Project on testing motors controlled by VSDs

Significant energy savings can potentially be made in global electricity use if the energy efficiency of motor systems is optimized. Energy savings may be made in circumstances where the same task may be performed in a longer time using a reduced process speed, under which conditions the process is rendered more energy efficient: a VSD allows the speed of the motor to be so varied – according to the system load – and hence offers energy savings.

This has led to more focus by industry and governments on the energy savings potential of using VSDs in variable load situations. Furthermore, a wide range of questions has recently been raised at various international fora about the use and testing of VSDs and motor combinations.This increased interest in the potential efficiency gains of using variable speed drives (VSDs) in motor systems has led to a greater need for comparative test data. Also, reflecting the increased interest in VSDs, an IEC draft standard, *IEC 60034-2-3: Specific test methods for determining losses and efficiency of converter-fed AC machines*, is currently being developed.

In 2011, a VSD testing project was carried out at CALTEST, a testing facility in South Australia, with the aim of investigating the impact of a number of variables on various VSD-motor combinations.

The pilot study was carried out on motors and VSD equipment with ratings of 1.1 kW and 11 kW; two rating levels which differ by an order of magnitude, and which could be accommodated by the loading and measurement equipment available.

In the first instance, four drives and four motors were obtained commercially as follows:

- two 1.1 kW VSD units (Brands A and C);
- two 11 kW VSD units (Brands A and C);
- two 1.1 kW 'standard' cage rotor motors each of a different make (Brand A and B);
- two 11 kW 'standard' cage rotor motor (Brand A and B as above).

The following tests and measurements were undertaken:

- standard MEPS tests on all four motors;
- measurements according to draft standard IEC 60034-2-3 on all motors in order both to test the draft standard, and to gain a knowledge of the differences in loss characteristics between the different manufacturers' products and between the different size motors from a given manufacturer;
- standby power measurements on the four VSD units;
- losses (associated with VSD and motor) and efficiency measurements on the following motor/VSD combinations:
  - manufacturer A's VSD supplying manufacturer A's standard motor;
  - manufacturer B's VSD supplying manufacturer B's standard motor;
  - manufacturer A's VSD supplying manufacturer B's standard motor;
  - manufacturer B's VSD supplying manufacturer A's standard motor.

TEST METHODS

The efficiency of a converter-fed motor alone may be determined by the 'summation of losses' method, in which a comparison of motors is made on the basis of no-load measurements undertaken with both a sinusoidal and a converter-derived supply. This method is described in IEC 60034-2-1, Clause 6.5.2 (IEC 2007). However, the testing in this case involves both the motor and the VSD (converter) and therefore this method is not applicable.

The testing equipment that is normally used for the measurement of cage-rotor induction motor efficiency was not suitable for this study because of the very wide range of drive speeds required. Measurements on VSD-fed motors require an order of magnitude greater speed range.

In February 2011, the Yokogawa Corporation in Japan released a new power analyser with facilities which were designed especially to evaluate the efficiency of systems such as VSD-fed induction machines. The WT1800 series power analyser has six power measurement modules together with facilities for accepting either analog or digital signals representing motor speed and torque. It has very high accuracy and wide bandwidth, and extensive internal computational capability, which allows efficiencies, as described above, to be directly calculated and displayed in real time. A sample of such an analyzer was made available for evaluation as part of this study. A new test set-up was built with this analyser measuring input electrical power, electrical power supplied by the VSD unit to the motor, and motor (mechanical) output power.

Operating points at which measurements were made were as follows:

- speeds: 100, 75, 50 and 25% of synchronous speed (based on 50 Hz);
- torque: 100, 75, 50 and 25% of rated torque at each of the above speeds;
- measurement of standby power were also made and recorded.

RESULTS

The testing resulted in the following responses to the questions posed:

1. *Are commercially available cage rotor induction motors suitable for VSD operation?* The motors used in this study were normal commercial induction motors, not specifically designed for VSD use. The efficiency results of the combination of such a motor and VSD is close to the requirements for MEPS, indicating that there is only a small efficiency penalty in using such a system.
2. *What is the magnitude and significance the standby power requirements of VSDs, and how do these losses vary with rating and between manufacturers?* Of the two sets of drives tested, the percentage loss on standby was higher for the 1.1 kW than the 11 kW drives but very similar between makers.
3. *How are the losses associated with VSD-supplied motors divided between the controller and the motor itself?* Efficiency of the VSD and the motor drops with decreasing load and speed. In all cases the VSD efficiency remained high and losses are smaller than the motor.
4. *How should the data acquired from the testing of VSD-supplied motors be presented?* While not shown in this paper, surface plotting appears to indicate differences between systems well.
5. *At what speed and load points should measurements be made*? A relatively smooth surface of efficiency vs speed and load using only the four points selected in this study was found. This implies that selection of points is non-critical.
6. *How important is it to 'match' the drive to the motor?* Testing combinations of VSD and motor indicate that the best efficiency, at least in the simple, non optimized case, may not be achieved by using the same manufacturer for both VSD and motor. Also, the combination of drive and motor by one manufacturer is not necessarily optimum in its "as received" or "out of the box" condition. Some combinations were found to be better than others. This has implica-

tions for operators seeking to replace a VSD or a motor in a project where a particular piece of hardware is no longer available. It may not be possible in the field to predict the overall VSD/motor efficiency. Some effort in fine-tuning the drive to the motor might be required but unless the user makes the measurements undertaken in this study, the necessity for such 'tuning' may not be apparent.

Conclusions

Australia is taking a strong leadership role in international efforts to harmonise testing methods for electric motors. The work is being driven by Australia's need for unambiguous, harmonised, domestic and international standards for testing and measurement methods for motors in order to support its own motor efficiency regulation program. This regulation, delivered under the 'E3' program, has been in place for over ten years.

This impetus has meant that Australia has been leading projects in relation to:

- an international testing centres network;
- comparisons of different test methods specified by IEC standards;
- development of test methods for VSD-driven motors.

For further information about motor efficiency regulation under the collaborative initiative called the Equipment Energy Efficiency Program (E3), which involves representatives drawn from all jurisdictions in Australia and New Zealand, please visit the Australian Government's Energy Rating website at www.energyrating.gov.au.

Glossary

APP	Asia-Pacific Partnership on Clean Development and Climate, see: http://www.asiapacificpartnership.org/
BATF	Buildings and Appliances Task Force, under the APP
DCCEE	The Department of Climate Change and Energy Efficiency, Australia
EEMODS	A series of internation conferences, Energy Efficiency in Motor Driven Systems, see http://www.eemods.org/
E3	The Equipment Energy Efficiency Program, which includes representatives drawn from all jurisdictions in Australia and New Zealand
EMSA	Electric Motor Systems Annex, under IEA-4E
IEA	International Energy Agency
IEA-4E	Co-operating Programme on Efficient Electrical End-Use Equipment, see http://www.iea-4e.org/
IEC	International Electrotechnical Commission, see http://www.iec.ch
IEEE	Institute of Electrical and Electronics Engineers, a professional body and technology advancment organisation, see http://www.ieee.org/
MEPS	Minimum Energy Performance Standards
VSD	Variable speed drive, used to control an electric motor

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