International Standards for Electric Motors
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1 Introduction

The number of international standards and revisions in IEC relevant to electric motor efficiency is developing at a fast pace. In order to appreciate the work done and under way this overview has been compiled. It will be updated regularly.

Sources are:
IEC WG 12 responsible for IEC 60034-1 Rating and Performance, tolerances (published April 2004, under review starting in 2007)

IEC WG 28 responsible for IEC 60034-2-1 Testing Standards (approved 20 July 2007, final edited published on 10 September 2007),

IEC WG 31 responsible for ICE 60034-30 Energy Efficiency Classes (draft CDV, 31 August 2007, comments and vote until 1 February 2008),

Members from the SEEEM Community of Practice in IEC groups (WG 28, WG 31, TC2):

- Conrad U. Brunner (Switzerland)
- Brian Fletcher (MTP, UK)
- Szymon Liszka (FEWE, Poland)
- Kei Konishi (JEMA, Japan)
- Brenton Watkins (AGO, Australia)
- Qin He and Chen Weihua (SEARI, China)

Members of SEEEM TAG

- Anibal de Almeida (UoC, EuP)
- Austin Bonnett (Emerson 2006/07)

Personal communications:

- Martin Doppelbauer (Chair IEC WG 31, SEW-Eurodrive, 2006/07)
- M'hammed Aoulkadi (University of Darmstadt, 2006/07)
- James Raba (US DOE, May 2007)
- Rob Boteler (NEMA/Emerson 2006/07)
- Neil Elliott (ACEEE (2007)

2 Testing Standards

IEC 60034-2-1 (Edition 1)

Standard methods for determining losses and efficiency from test

Final draft published on 18 May 2007. The FDIS was voted favorably (results published 27 July 2007): 23 countries in favor, 5 abstentions, and no disapproval. Published on 10 September 2007.

All methods presented include stray load losses. The method of IEEE 112B is also included. The older 0.5% method of IEC 60034-2 (ed. 2) - still widely used in Europe, Japan, India, Australia, China, etc. - is no longer available. Final revision includes chapter 5.3 "Preferred methods" and tables 1 to 3 of different testing methods. Table 2 for AC induction machines below:

– 18 – 60034-2-1 © IEC:2007

Table 2 – Induction machines

Method	Clause	Preferred method	Required facilities	Uncertainty
Direct				
Torque measurement	8.1.1	All single phase and polyphase ≤ 1 kW	Torquemeter/dynamometer for full-load	Low
Calibrated machine test	Annex D		Calibrated machine	See Note 4
Dual-supply, back-to-back test	8.1.2		Machine set for full-load Two identical units	Low
Total losses				
Calorimetric method	Annex D		Special thermal enclosure	See Note 4
Single supply back-to-back test	8.2.1		Two identical units (wound rotor)	Low
Summation of losses, with and without load test				
P_{LL} determined from residual loss	8.2.2.5.1	Three phase > 1 kW up to 150 kW	Torquemeter/dynamometer for ≥ 1,25 × full-load	Low
P_{LL} from assigned value	8.2.2.5.3			Medium to high
P_{LL} from removed rotor and reverse rotation test	8.2.2.5.2		Auxiliary motor with rated power ≤ 5 × total losses P_T	High
P_{LL} from Eh-star test	8.2.2.5.4	(see Note 3)	Resistor for 150 % rated phase current	Medium
Summation of losses, without load test				
Currents, powers and slip from the equivalent circuit method P_{LL} from assigned value	8.2.2.4.3		If test equipment for other tests is not available (no possibility of applying rated load, no duplicate machine)	Medium/high

NOTE 1 Due to measurement inaccuracies, the determination of P_{LL} from residual losses is limited to correlation coefficients (see 8.2.2.5.1.2) greater than 0,95 and may have uncertainties of the determined efficiency exceeding ±0,5 %.

NOTE 2 In the "Uncertainty" column, "Low" indicates a procedure determining all loss-components from tests; "Medium" indicates a procedure which is based on a simplified physical model of the machine; "High" indicates a procedure that does not determine all loss-components by tests.

NOTE 3 The method for P_{LL} from Eh-star test is suitable for motors between 1 kW and 150 kW; larger ratings are under consideration. The method requires that the winding can be connected in star.

NOTE 4 Uncertainty to be determined.

Table 1 IEC 60034-2-1, chapter 5.3, table 2: Induction machines

The "Calibrated machine test" and the "Calorimetric method" are reviewed in Annex D, under "Other test methods" that are considered applicable mainly for large machines where the facility cost for other methods is not considered economical. They will be treated later in a separate document IEC 60034-2-2 which is not yet published (and then deleted from IEC 60023-2-1).

The concept of "Uncertainty" is explained in Note 2:

- Low a procedure determining all loss-components from tests;
- Medium a procedure which is based on a simplified physical model of the machine;
- High a procedure that does not determine all loss-components by tests.

The table recommends as "low uncertainty" the following methods:

1. Direct methods:
    a. Torque measurement for motors ≤ 1 kW (single and polyphase)
    b. Dual-supply, back-to-back test
2. Total losses

a. Single supply back-to-back test
3. Summation of losses:
   a. P_{LL} determined from residual loss, >1 kW and < 150 kW (three phase)

Relative importance of the five different kind of motor losses depending on motor size:

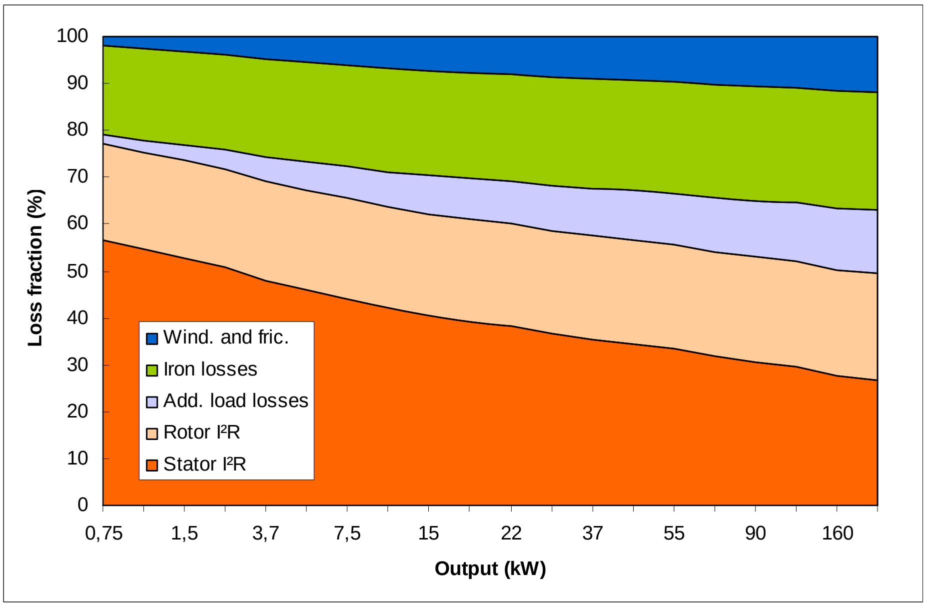

Figure 1 Fraction of losses (example 4-pole, Martin Doppelbauer 2006)

Available motor efficiency test results as of today:
1. University of Darmstadt Germany
2. University of Nottingham UK
3. Siemens Germany
4. SEARI Shanghai China
5. Natural Resources Canada

See below in detail:

1) **University of Darmstadt** (Andreas Binder, M'hammed Aoulkadi): published at EEMODS'05 and updated at EEMODS'07. 14 motors tested, results in Figures 2 to 4 below:

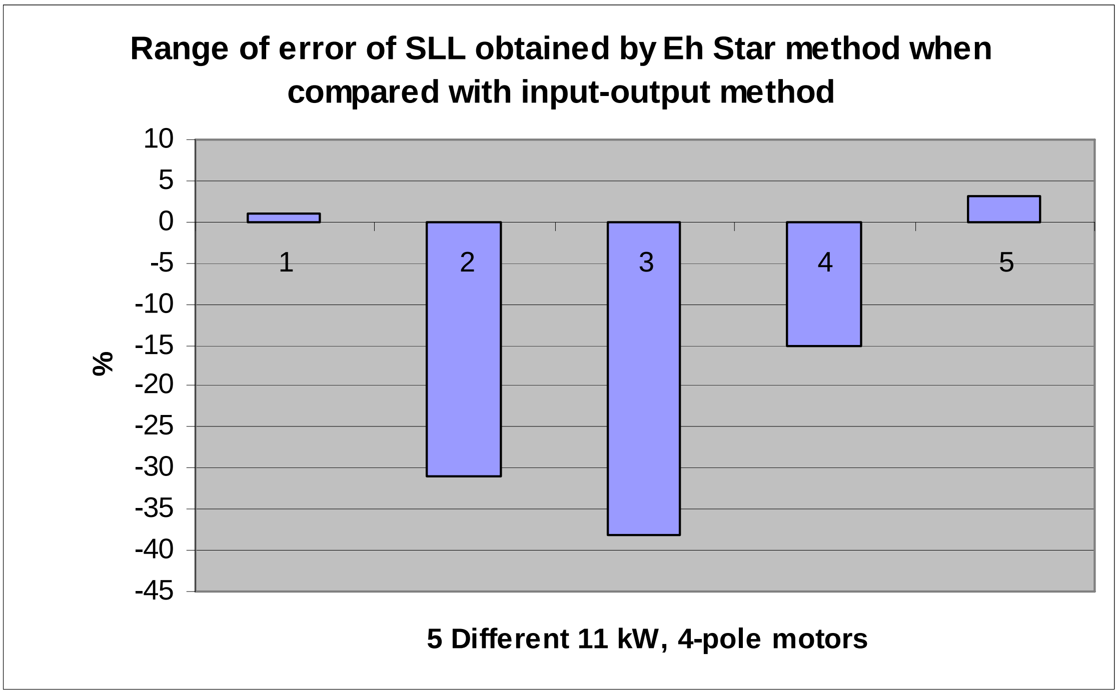

Figure 2 Results Darmstadt: 5 motors with 11 kW (compiled by Anibal de Almeida)

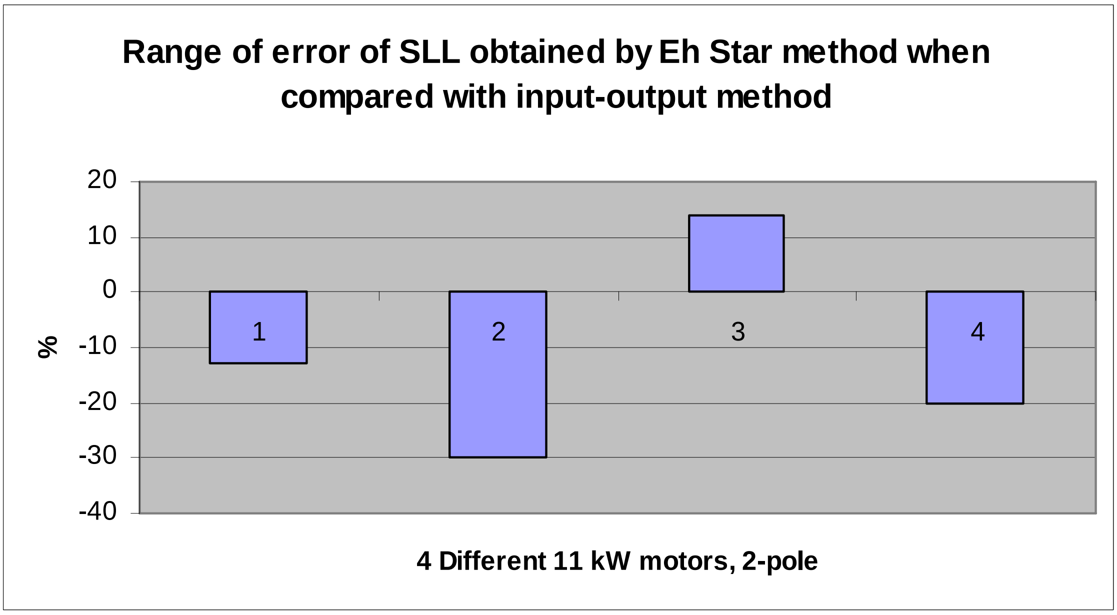

Figure 3 Results Darmstadt: 4 motors 11 kW (compiled by Anibal de Almeida)

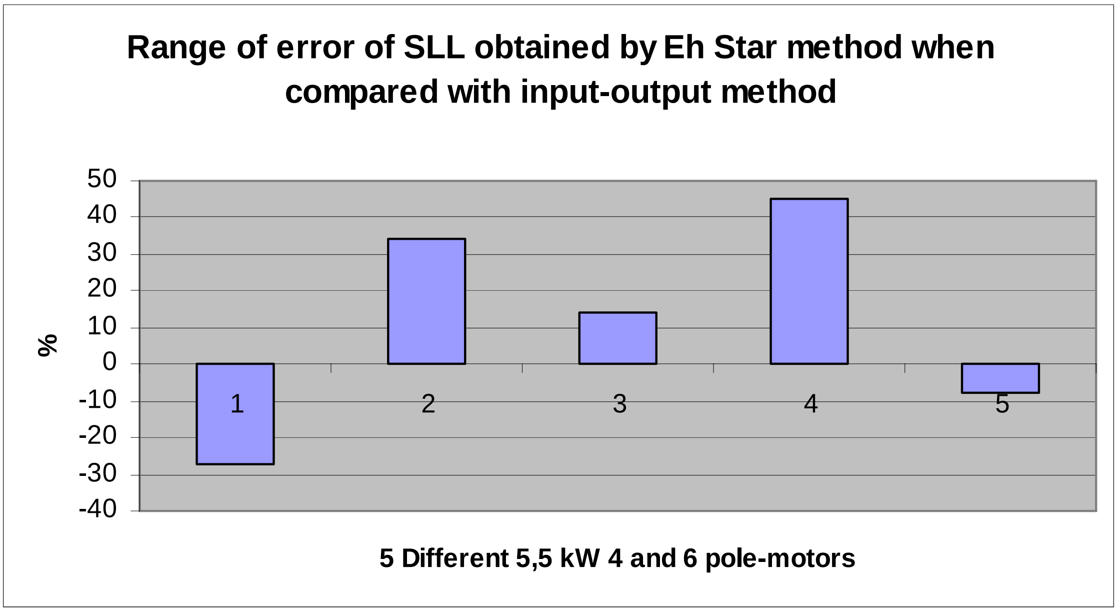

Figure 4 Results Darmstadt: 5 motors 5,5 kW (compiled by Anibal de Almeida)

2) **University of Nottingham** (K. J. Bradley) published by CEMEP 2005. 7 motors tested, results see graphs below:

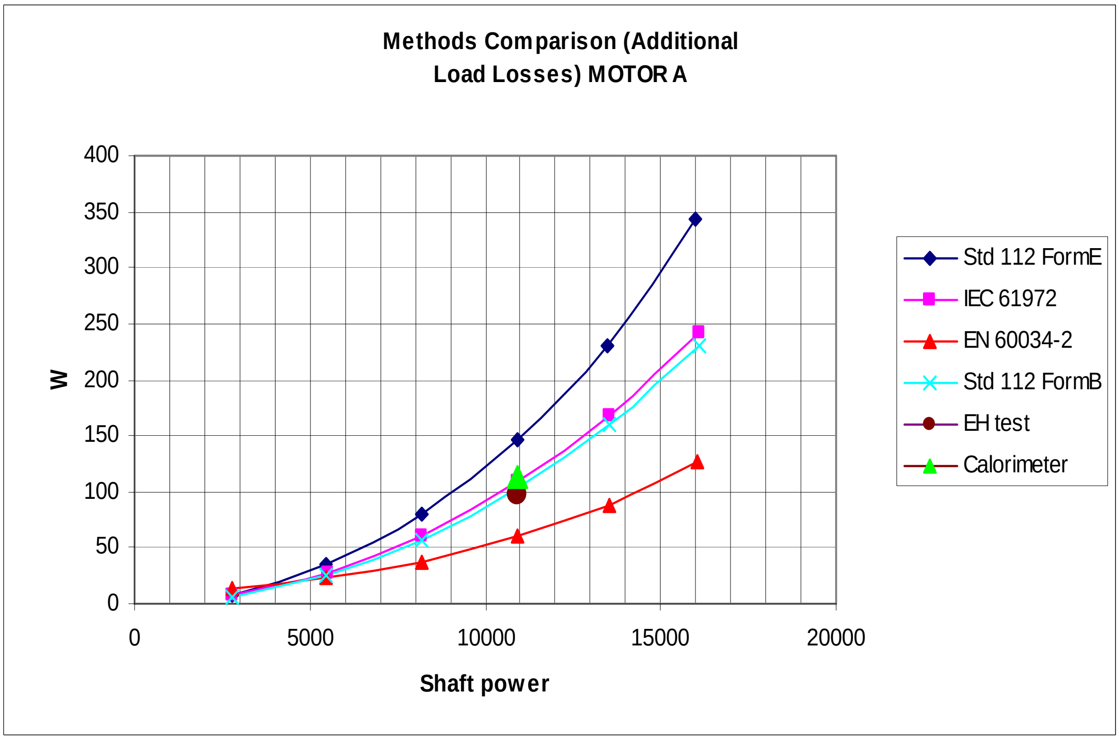

Figure 5 University of Nottingham: Result of 1 of 5 motors of 11 kW

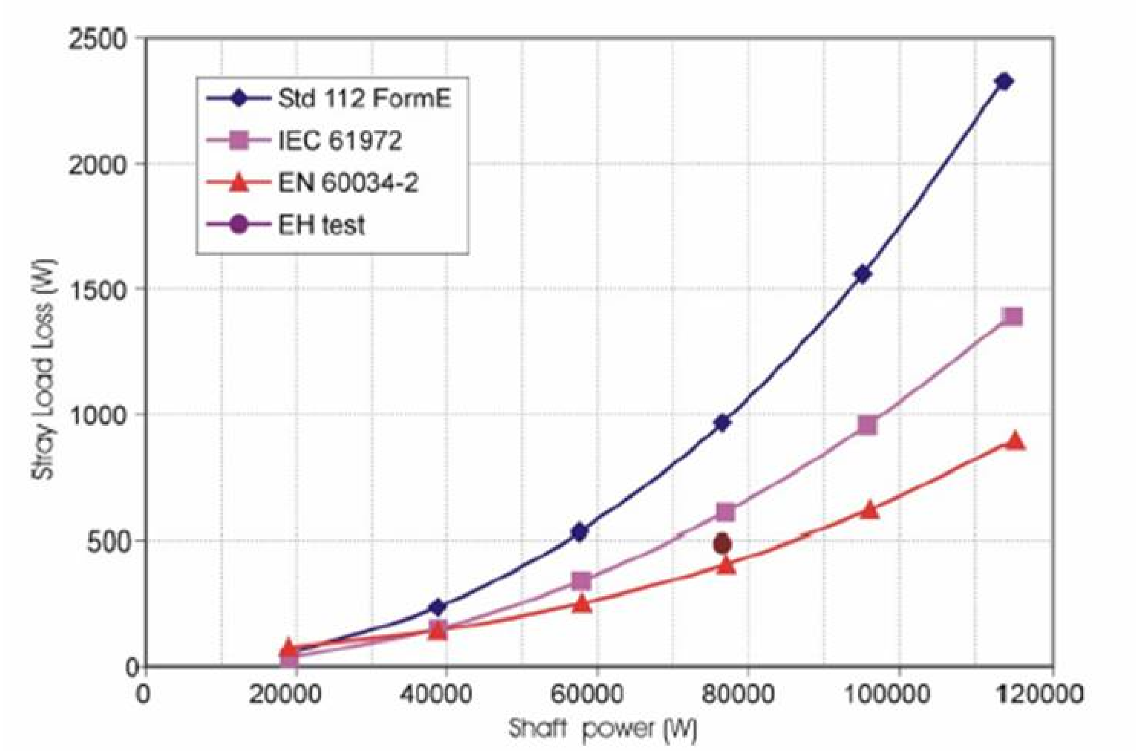

Figure 6 University of Nottingham: Result of 1 motor of 75 kW

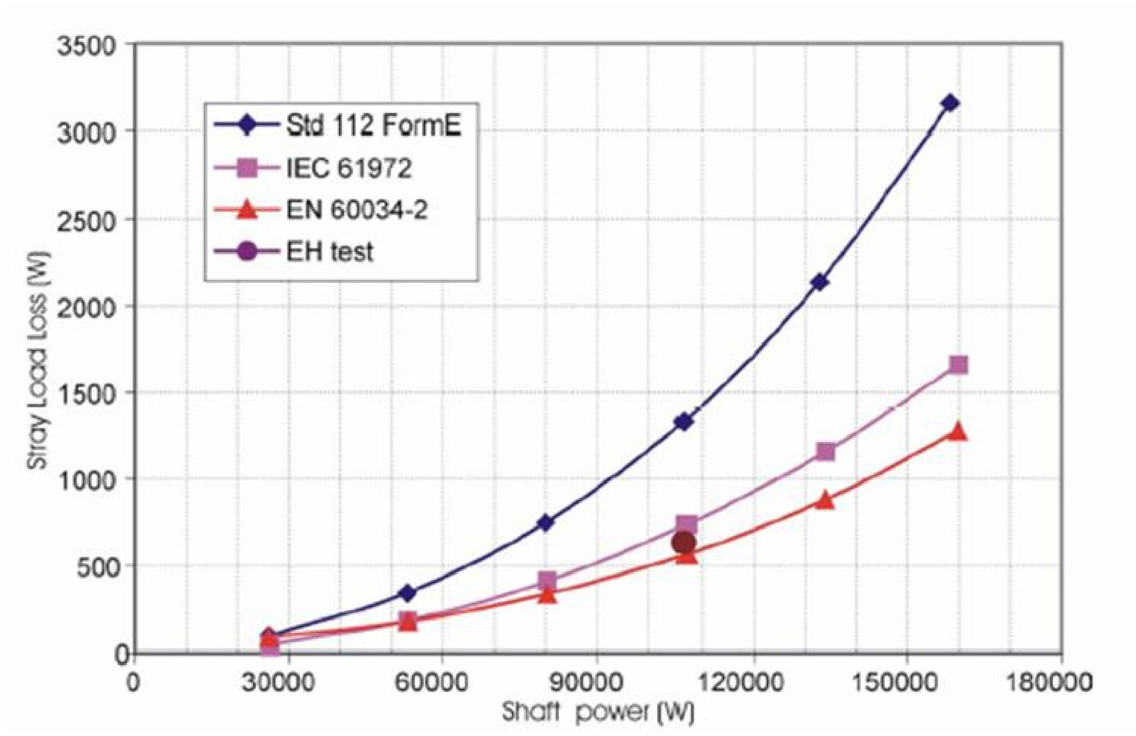

Figure 7 University of Nottingham: Result of 1 motor of 110 kW

3) **Siemens**: Result 1 motor of 315 kW (reported by Anibal de Almeida, EuP 2007)

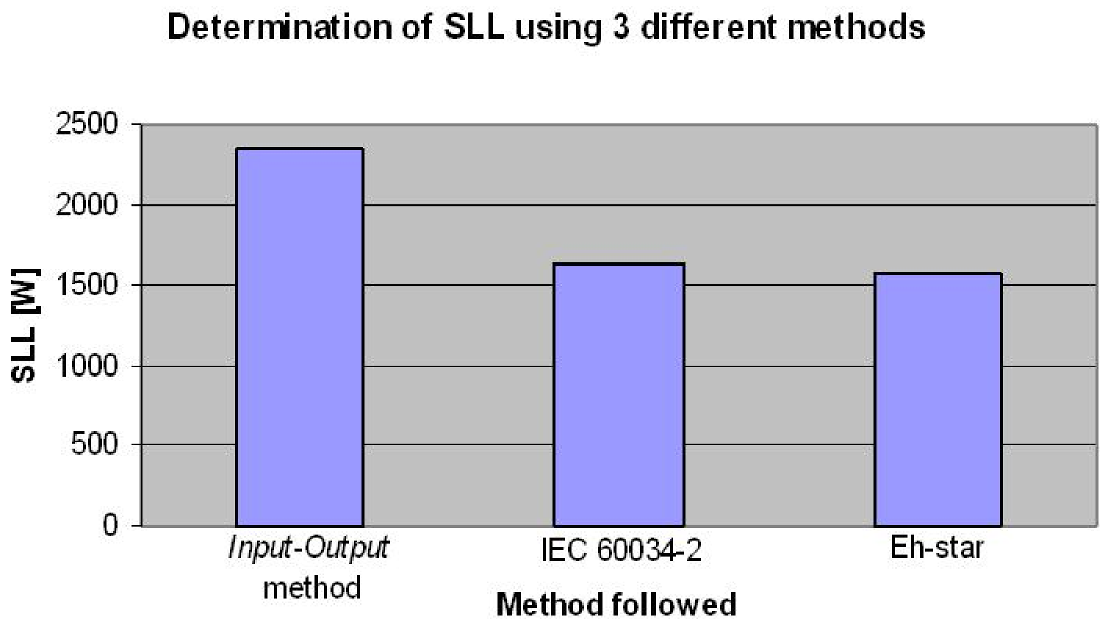

Figure 8 Siemens: Results 1 motor of 315 kW

4) **Natural Resources Canada** (Hydro Quebec/Manitoba Hydro, Dale Friesen and Pierre Angers), published at the Motors Summit 2007 in April 2007 in Zurich (www.seeem.org/news), 13 motors tested, see table with results below:

Size	Efficiency with indirect method	Efficiency with Eh-star method	Difference in percentage points
(hp)	(%)	(%)	(p.p.)
2	84.7%	85.1%	0.42%
5	88.7%	88.7%	0.00%
5	86.7%	86.5%	-0.21%
10	89.7%	89.6%	-0.04%
10	91.0%	91.1%	0.09%
20	93.2%	93.4%	0.17%
50	92.8%	93.1%	0.28%
55 kW	92.5%	93.1%	0.54%
75	93.0%	93.2%	0.16%
90 kW	93.7%	94.4%	0.71%
125	94.8%	95.1%	0.29%
150	95.9%	96.3%	0.34%
200	95.9%	95.9%	0.03%

Table 2 Dale Friesen/Pierre Angers: Results of 13 tests (presented at MS’07 in Zurich)

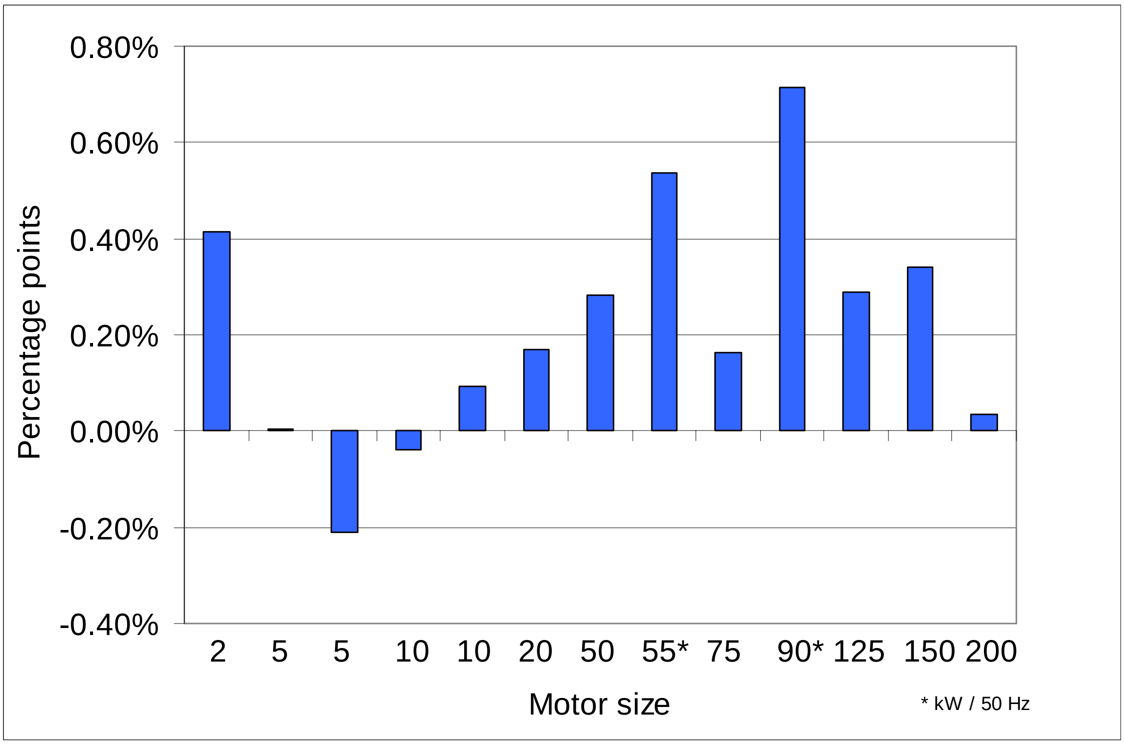

Figure 9 Dale Friesen/Pierre Angers: Results of 13 tests (presented at MS'07 in Zurich)

5) **Shanghai Electrical Apparatus Research Institute SEARI**, Chen Weihua, Li Xi Ying, Shanghai China: Test results presented at SEEEM side event 14 June 2007 in Beijing. 7 motors tested, see table with results below:

Type	UTP145T-4B2.0HP(#185)		UTP145T-4B 2.0HP(#179)			GX200L-4		GX132S2-2		Y112M-4		Y112M-4		Y100L1-4	
	112B	eh-star	112B		eh-star	112B	eh-star	112B	eh-star	RRT	eh-star	RRT	eh-star	112B	eh-star
	50Hz	50Hz	60Hz	50Hz	50Hz	50Hz	50Hz	50Hz	50Hz	50Hz	50Hz	50Hz	50Hz	50Hz	50Hz
P_N (kW)			1, 5			30		7, 5		4		4		2, 2	
P			4			4		2		4		4		4	
U_N(V)	380	380	460	380	380	380	380	380		380		380		380	
I_N(A)	3, 45	3, 45	6, 9	3, 45	3, 45	56, 9	56, 9	14, 5		8, 8		8, 8		5	
nN (r/min)	1410		1725	1410	1410	1475	1475	2915		1440		1440		1430	
Pin(W)	1809	1805, 3	1794, 9	1836	1836, 2	32313	32443	8395	8374, 8	4799	4791, 7	4803	4796, 6	2855	2854
pf（%）	82, 2		77, 1	82, 5		88, 4		90		79, 5		79, 58		80, 8	
$s_{(\%)}$	5, 74		4, 34	6, 71		1, 53		2, 82		3, 87		3, 80		6, 68	
I_0 (A)	1, 726		1, 797	1, 763		18, 09		4, 432		5, 378		5, 332			
θ (K)	62, 3		74, 1	75		64, 1		55		79		75, 9			
P_{cu1}(W)	122, 9		96, 6	129, 8		765, 7		297, 6		345, 4		345, 3		309, 4	
P_{cu2}(W)	93, 5		70, 1	110, 4		474, 3		222, 7		165		161, 7		161, 5	
$P_{fe(W)}$	57, 7		79	61, 7		579, 4		192, 2		191, 45		199, 61		126, 5	
P_{fw}(W)	22, 3		22, 8	17, 2		268, 9		49, 3		50, 73		57, 53		30, 8	
$P_{s(W)}$	21, 5	17, 9	33, 4	25, 2	25, 4	224, 2	354, 5	133, 2	113	46, 27	38, 9	38, 41	32, 0	27, 3	26, 3
η (%)-TEST	82, 4	82, 6	83, 2	81, 2	81, 2	92, 8	92, 5	89, 3	89, 55	83, 35	83, 48	83, 28	83, 39	77	77, 1
η (%)-Standard	82, 5 EPACT			82, 5 EPACT		93, 2 EFF1		89, 5 EFF1		84, 2 EFF2		84, 2 EFF2			

Table 3 SEARI Shanghai: Results from 7 tests (presented by Chen Weihua at EEMODS'07 side event)

Summary:

The results of 5 tests with total 42 (14+7+1+13+7) motors between 1.5 kW and 315 kW are available. The results show:

- All methods (also IEEE 112B) have considerable inaccuracies.
- The results of the additional stray load losses in different testing methods can vary up to +/- 50%.

- The average error between IEEE 112B and eh Star of the total losses (i.e. the efficiencies) is less than 0.3% (in the Friesen/Angers paper 9 out of 13, in the SEARI sample 7/7).
- The max error between IEEE 112B and eh Star is 0.7% of efficiency (these numbers have to be reviewed).
- The stray load losses are therefore relatively well represented by IEC 60034-2-1.

The conclusion Anibal de Almeida presented at the SEEEM side event on 14 June 2007:

- Eh-Star is an inexpensive method with fairly good accuracy where stray load losses are calculated mathematically.
- Comparison between a limited set of comparative tests using input-output methods and the Eh-Star method show a fair to good matching of the test results.
- Additional tests may be used to confirm the repeatability and accuracy of test results

The possible conclusion for SEEEM:

1. The new IEC 60034-2-1 draft is acceptable and should not be stalled.
2. Regulators can always stipulate a precise method or a required level of uncertainty ("low").
3. The ongoing campaign for an IEC Round Robin test should be used to refine testing methods, qualify testing laboratories and to reduce necessary tolerances.

3 Tolerances

Tolerances come from motor production (precision, material quality, quality control) and from testing accuracy (details of standards understood by the testing person and in the testing procedure applied, instrumentation quality and environmental data precision). IEC 60034-1 defines tolerances as maximum -15% of losses for motors up to 150 kW and max -10% above.

The discussion has started in IEC WG 28 to evaluate the tolerances (i.e. the necessary instrumentation, the required environmental conditions temperature, time, etc.) in order to make the tolerances smaller, i.e. the accuracy and repeatability larger.

The necessary definition of nominal efficiency (statistical average of a sample, in the US 5 equal motors) that is the base for setting MEPS versus the rated efficiency of one single motor, that can have a tolerance not larger than the standard prescribes.

The problems of regulators that have to certify (ex ante) and spot check (ex post) imported and domestically produced motors and motors in packaged systems has to be defined separately.

IEC has decided in June 2007 to start the revision of IEC 60034-1. The results of the new Round-Robin test can be then incorporated.

4 Energy Efficiency Classes

Document IEC 60034-30 (Edition 1)
Efficiency classes of single-speed three-phase cage induction motors (IE code)
Second draft document prepared by WG31, published as draft CDV (Committee Draft for Voting) 31 August 2007, comments and votes expected until 1 February 2008.

The classification is for 0.75 kW to 370 kW AC induction motors up to 1000 V with 2-, 4- and 6 poles in 50 Hz and 60 Hz line frequency and able to run continuously (S1). Classes IE1 to IE3 are normative, a new even higher class IE4 is informative. Testing is generally based on IEC 60034-2-1 (including additional stray load losses, method with low level of uncertainty).

Efficiency Levels	Efficiency Classes	Testing Standard	Performance Standard
	IEC 60034-30	IEC 60034-2-1	Mandatory
	Global 2008	incl. stray load losses 2008	Policy goal
Super Premium efficiency	IE4		
Premium efficiency	IE3		USA 2011
High efficiency	IE2		USA
			Canada
			Mexico
			Australia
			New Zealand
			Korea 2008
			Brazil 2009
			China 2011
			Europe 2011?
Standard	IE1		China
			Brazil
			Costa Rica
			Israel
			Taiwan
			India

Table 4 Efficiency classes and MEPS (A+B International) in 2008

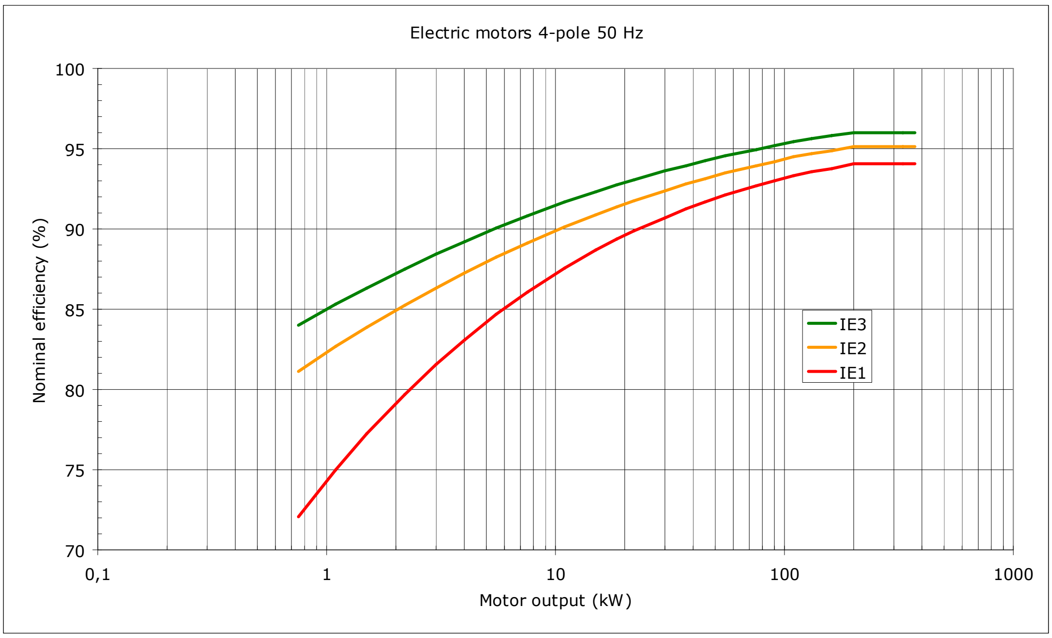

Figure 10 IEC 60034-30, draft CDV August 2007

5 New projects

IEC has approved two new proposals in its IEC TC2 meeting in 2 June 2007 in Milan Italy:

- **IEC "Guide for the selection and application of energy efficient motors including variable speed applications"**,
  A New Work Item Proposal 2/1477/RVN has been prepared by IEC WG 31 and has been approved 16 November 2007 (www.seeem.org/news). It will relate to existing document NEMA MG 10-2001 "Energy Management Guide for Selection and Use of Fixed Frequency Medium AC Squirrel-cage Polyphase Induction Motors". WG 31 has been charged to develop the guide. Contact the chairman directly: martin.doppelbauer@sew-eurodrive.de.

- **IEC "Round-Robin test for induction motors"**
  WG 28 has published on 26 October 2007 the 2/1475/INF document informing of 16 test laboratories from BR, CZ, DE, JP, PL and US participating in the round-robin. The project manager is Robert Bartheld (rbartheld@aol.com). See www.seeem.org for details.
  The goal is to compare IEC 61972 (equivalent to IEEE 122B) and new IEC 60034-2-1 (especially the eh Star method). The aim of the round-robin is:
  • to collect further experience with the test methods,
  • to obtain sets of test data allowing to assess measurement deviations between laboratories,
  • to eventually improve and optimize test procedures standardized in IEC 60034-2-1,
  • to provide a basis for reviewing the tolerance limits in IEC 60034-1

6 Testing facilities

Given the fact that MEPS for motors have to be followed up by independent and qualified testing laboratories, there will be a considerable shortage of testing capacity. Although most of the motor manufacturers have their internal testing laboratory but many of those have never qualified by any system of certification or accreditation.

The best known international accreditation system to secure the US IEEE 112 B (1996) and the Canadian CSA C390 (1998) testing is run by the US national Voluntary Laboratory Accreditation Program NVLAP by the US National Institute of Standards and Technology NIST (www.nist.gov) in the US Department of Commerce. There is documentation like the following:

- Caroll S. Brickenkamp, Lawrence I. Knab: Efficiency of Electric Motors, February 2007

- NIST Handbook 150-10 Checklist: Efficiency of Electric Motors, 4 May 2007 (http://ts.nist.gov/Standards/214.cfm)

- Directory of accredited laboratories: Efficiency of Electric Motors, 9 May 2007 (http://ts.nist.gov/Standards/scopes/eemot.htm), total number 13:
  - USA 5 (AR, NC, OH, TX, WI)
  - Canada 1
  - China 2
  - Japan 1
  - Malaysia 1
  - Mexico 1
  - Taiwan 2

- K.L. Stricklett, M. Vangel: NIST Technical Note 1432: Test procedures for Electric Motors under CFR Part 431, NIST June 2000

From latest China surveys (ICA, Victor Zhou at EEMODS'07) we know that China has some 2000 motor manufacturers, 300 of them large ones that make 90% of the volume. China has a motor production of some 5.66 million (according to Zhao Yuejin, CNIS 2006) pieces per year in 2006. This indicates that only two internationally accredited testing laboratories are not enough.

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