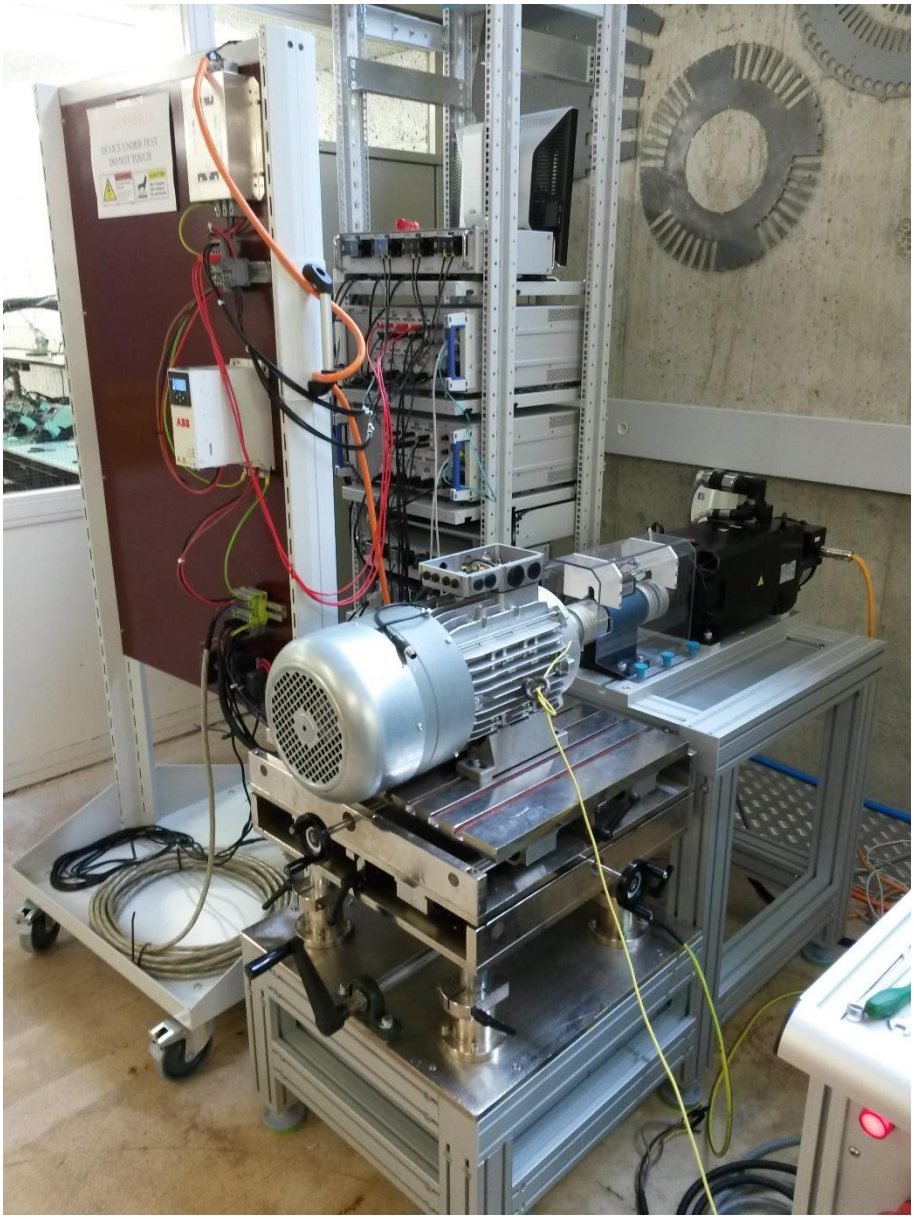
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Department of the Environment,
Transport, Energy and Communication DETEC

Swiss Federal Office of Energy SFOE
Energy Research

Final report 8 April 2019

Concept and Verification of Round Robin Test Program for Converters (RR'C)



BFH, Bild © Topmotors 2018

Date: 8 April 2019

Place: Bern

Publisher:
Swiss Federal Office of Energy SFOE
Research Programme Electricity Technologies
CH-3003 Bern
www.bfe.admin.ch
energieforschung@bfe.admin.ch

Co-financed by:
The following countries provide co-funding (cash and in kind) to the IEA 4E Electric Motor Systems Annex: Australia, Austria, Denmark, Netherlands, USA.

Agent:
Impact Energy Inc.
Gessnerallee 38a
CH 8001 Zurich
www.impact-energy.ch

Author:
Conrad U. Brunner, Impact Energy Inc., cub@impact-energy.ch
Rita Werle, Impact Energy Inc., rita.werle@impact-energy.ch

SFOE head of domain: Dr Michael Moser, Michael.moser@bfe.admin.ch
SFOE programme manager: Roland Brüniger, roland.brueniger@brueniger.swiss
SFOE contract number: SI/501665-01

Summary

The goal of the International Energy Agency's Technology Collaboration Programme Energy Efficient End-Use Equipment Electric Motor Systems Annex (IEA 4E EMSA) is to help the participating countries (Australia, Austria, Denmark, Netherlands, Switzerland and USA) design and implement successful policies for the market transformation of efficient electric motor systems mostly used in industry. EMSA builds an information platform for policy and technical exchange and is actively involved in the international standardization process.

Within EMSA, a collaboration program with IEC SC 22G WG 18 for the global Round Robin Program for Converter Losses (RR'C) was launched after the publication of the IEC 61800-9-2 in March 2017 [1]. The standard includes a calculation program and touches only briefly a physical testing program. Based on the calculation program reference losses have been defined and IE efficiency classes set for converters.

The goal of RR'C is to inform the revision of IEC 61800-9-2. RR'C aims to establish a practical and accurate testing method for converter losses between 0.12 kW and 1000 kW that return repeatable results while used in different laboratories. It will form the basis to establish a testing method and the statistical base for an informed decision on setting reference losses and defining IE classes for converters in IEC 61800-9-2, edition 2.

In the first phase of the RR'C a Uniform Testing Protocol (UTP) was defined and a first batch of 9 small converters were tested accordingly. Four international independent research laboratories in Switzerland, Australia, Denmark and USA contributed to this effort. A total of 58 tests with 9 converters from 4 different manufacturers were made. 24 different motors between 0.75 and 11 kW were used. The tests were run at 50 Hz and 60 Hz. By the end of February 2019, the report of the results of the first phase has been presented. Its findings have been transmitted to IEC SC 22G WG 18 and discussed at the WG 18 meeting on 19 February 2019 in Melbourne Australia. Subsequently, from March 2019 until October 2021 the second phase of RR'C will be operated. Here some 60 products between 0.12 kW and 1000 kW will be tested with 7 or more laboratories participating.

Zusammenfassung

Das Ziel des Technology Collaboration Programme Energy Efficient End-Use Equipment Electric Motor Systems Annex (IEA 4E EMSA) der Internationalen Energieagentur ist es, die teilnehmenden Länder (Australien, Österreich, Dänemark, Niederlande, Schweiz und USA) bei der Entwicklung und Umsetzung erfolgreicher Strategien für die Markttransformation von effizienten Elektromotorsystemen zu unterstützen, die hauptsächlich in der Industrie eingesetzt werden. EMSA bildet eine Informationsplattform für den politischen und technischen Austausch und ist aktiv am internationalen Normungsprozess beteiligt.

Innerhalb von EMSA wurde nach der Veröffentlichung der IEC 61800-9-2 im März 2017[1] ein Kooperationsprogramm mit der IEC SC 22G WG 18 für das globale Round Robin Program for Converter Losses (RR'C) gestartet. Die Norm beinhaltet ein Berechnungsprogramm und berührt nur kurz ein physikalisches Prüfprogramm. Basierend auf dem Berechnungsprogramm wurden Referenzverluste definiert und IE-Effizienzklassen für Umrichter festgelegt.

Das Ziel von RR'C ist es, Grundlagen für die Revision der IEC 61800-9-2 zu liefern. RR'C zielt darauf ab, eine praktische und genaue Testmethode für Umrichterverluste zwischen 0,12 kW und 1000 kW zu etablieren, die wiederholbare Ergebnisse liefert, wenn sie in verschiedenen Labors eingesetzt wer-

den. Sie bildet die Grundlage für die Festlegung einer Prüfmethode und die statistische Grundlage für eine fundierte Entscheidung über die Festlegung von Referenzverlusten und die Definition von IE-Klassen für Umrichter in IEC 61800-9-2, Ausgabe 2.

In der ersten Phase des RR'C wurde ein Uniform Testing Protocol (UTP) definiert und eine erste Charge von 9 kleinen Umrichtern entsprechend getestet. Vier internationale, unabhängige Forschungslabors in der Schweiz, Australien, Dänemark und den USA trugen dazu bei. Insgesamt wurden 58 Tests mit 9 Umrichtern von 4 verschiedenen Herstellern durchgeführt. Es wurden 24 verschiedene Motoren zwischen 0,75 und 11 kW eingesetzt. Die Tests wurden mit 50 Hz und 60 Hz durchgeführt. Bis Ende Februar 2019 wurde der Bericht der ersten Phasen vorgelegt. Die Ergebnisse wurden an die IEC SC 22 G WG 18 übermittelt und auf der WG18-Sitzung am 19. Februar 2019 in Melbourne Australien diskutiert. Anschliessend wird von März 2019 bis Oktober 2021 die zweite Phase von RR'C betrieben. Hier werden rund 60 Produkte zwischen 0,12 kW und 1000 kW getestet, an denen 7 oder mehr Labors teilnehmen.

Résumé

L'objectif du Programme de collaboration technologique de l'Agence internationale de l'énergie (AIE 4E EMSA) est d'aider les pays participants (Australie, Autriche, Danemark, Pays-Bas, Suisse et États-Unis) à concevoir et à mettre en œuvre des politiques efficaces pour la transformation du marché des systèmes de moteurs électriques efficaces utilisés principalement dans l'industrie. L'EMSA construit une plateforme d'information pour échange politique et technique et participe activement au processus international de normalisation.

Au sein de l'EMSA, un programme de collaboration avec la CEI SC 22G WG 18 pour le Round Robin Program for Converter Losses (RR'C) mondial a été lancé après la publication de la CEI 61800-9-2 en mars 2017 [1]. La norme comprend un programme de calcul et ne touche que brièvement un programme d'essais physiques. Sur la base du programme de calcul, les pertes de référence et des classes de rendement ont été définies pour les convertisseurs.

L'objectif du RR'C est d'éclairer la révision de la CEI 61800-9-2. RR'C vise à établir une méthode d'essai pratique et précise pour les pertes de convertisseurs entre 0,12 kW et 1000 kW qui donnent des résultats répétables lorsqu'ils sont utilisés dans différents laboratoires. Il servira de base à l'établissement d'une méthode d'essai et de la base statistique d'une décision éclairée sur l'établissement des pertes de référence et la définition des classes pour les convertisseurs dans la CEI 61800-9-2, édition 2.

Dans la première phase du RR'C, un protocole d'essai uniforme (PTU) a été défini et un premier lot de 9 petits convertisseurs a été testé en conséquence. Quatre laboratoires de recherche internationaux indépendants, en Suisse, en Australie, au Danemark et aux Etats-Unis, ont contribué à cet effort. Au total, 58 essais ont été réalisés avec 9 convertisseurs de 4 fabricants différents. 24 moteurs différents entre 0,75 et 11 kW ont été utilisés. Les essais ont été effectués à 50 Hz et 60 Hz. Fin février 2019, le rapport de la première phase a été présenté. Les conclusions ont été transmises au SC 22G WG 18 de la CEI et discutées lors de la réunion du WG 18 le 19 février 2019 à Melbourne, Australie. Par la suite, de mars 2019 à octobre 2021, la deuxième phase du RR'C sera effectuée. Une soixantaine de produits entre 0,12 kW et 1000 kW seront testés avec la participation de 7 laboratoires ou plus.

Contents

List of abbreviations

4E	Energy Efficient End-use Equipment
ACEE	Advisory Committee for Energy Efficiency in IEC
CES	Comité Électrotechnique Suisse
EEMODS	International conference on Energy Efficiency in Motor Driven Systems
EMSA	Electric Motor Systems Annex in 4E
ExCo	Executive Committee in 4E
IEA	International Energy Agency
IEC	International Electrotechnical Commission
ISO	International Organization for Standardization
MEPS	Minimal Energy Performance Standard
RR'C	Round Robin program for testing of converter losses
SFOE	Swiss Federal Office of Energy
SRF	Standard Reporting Format
UTP	Uniform Testing Protocol
TC	Technical Committee in IEC and ISO
TCP	Technical Cooperation Programme in IEA
VFD	Variable Frequency Drive
WG	Working Group in IEC and ISO

1. Introduction

International standards for electric motors and some additional components (Variable Frequency Drives (VFD), pumps, fans, compressors, etc.) serve as a prerequisite for setting national Minimum Energy Performance Standards (MEPS). MEPS can save an important part of electric energy by prohibiting the sale of inefficient products.

Switzerland is charged within the Electric Motor Systems Annex (EMSA) of the IEA Technology Collaboration Programme 4E to lead the Task "International Standards". Switzerland coordinates the work of EMSA members in IEC and ISO.

Within the Task International Standards, a program "Round Robin tests for converter losses" was launched in February 2018, in order to verify the testing method in IEC 61800-9-2, edition 1, for converter losses, and to inform the revision of this standard.

This report summarizes the completed tasks and achieved results for the period between 1 February 2018 and 28 February 2019 under the program RR'C. The report on the Task "International Standards" is given in a separate document.

2. Goal

The goal of RR'C is to establish a practical and accurate testing method for converter losses between 0.12 kW and 1000 kW that return repeatable results while used in different laboratories. It will form the basis to establish in phase 1 a testing method and in phase 2 the statistical base for setting reference losses and to define IE classes in IEC 61800-9-2, edition 2.

3. Work undertaken and findings obtained

3.1 The project organization: the RR'C leading team

- Project manager (PM):
  Sandie B. Nielsen/DK (Task Force leader), Andrea Vezzini/CH (deputy Task Force leader)
- Advisory group (technical support for the PM):
  Andrew Baghurst/CalTest, AU; Pierre Angers/Hydro Quebec, CA; Emmanuel Agamloh/Advanced Energy, USA; Kurt Stockman/University of Gent, BE; Chai Qing/China National Center for Quality Supervision and Test of Electrical Control and Distribution Equipment/Tianjin CN
- Steering committee (strategic support and financial resources):
  Conrad U. Brunner/CH (4E EMSA) (for phase 1 only), Maarten van Werkhoven/NL (4E EMSA), Roland Brüniger/Swiss government CH, Representative from Danish government DK
- Industry contact group:
  ABB (Freddy Gyllensten, Sweden), Danfoss (Norbert Hanigovszki, DK), Fuji Electric (Ikuya Sato, Japan), SEW Eurodrive (Tim Schumann, US); Siemens (Bill Finley, USA)

3.2 Timeline

The RR'C project is divided into two phases:
Phase 1: 1 November 2017 - 28 February 2019 (pilot testing phase, secure testing method)
Phase 2: 1 March 2019 - 31 October 2021(full testing phase, secure reference losses and efficiency classes)

3.3 The involved testing laboratories in phase 1

- Australia: CalTest, Port Elliot SA 5212,
- Denmark: Danish Technological Institute (DTI), 2630 Taastrup,
- Switzerland: Bern University of Applied Sciences (BFH), 2501 Biel,
- USA: Advanced Energy, Raleigh NC 27606.

3.4 The Uniform testing protocol

Andrew Baghurst, Sandie B. Nielsen, Andrea Vezzini, Edition 4, 1 October 2018
Table of contents:

The UTP will be upgraded for phase 2, based on the experiences and results of phase 1.

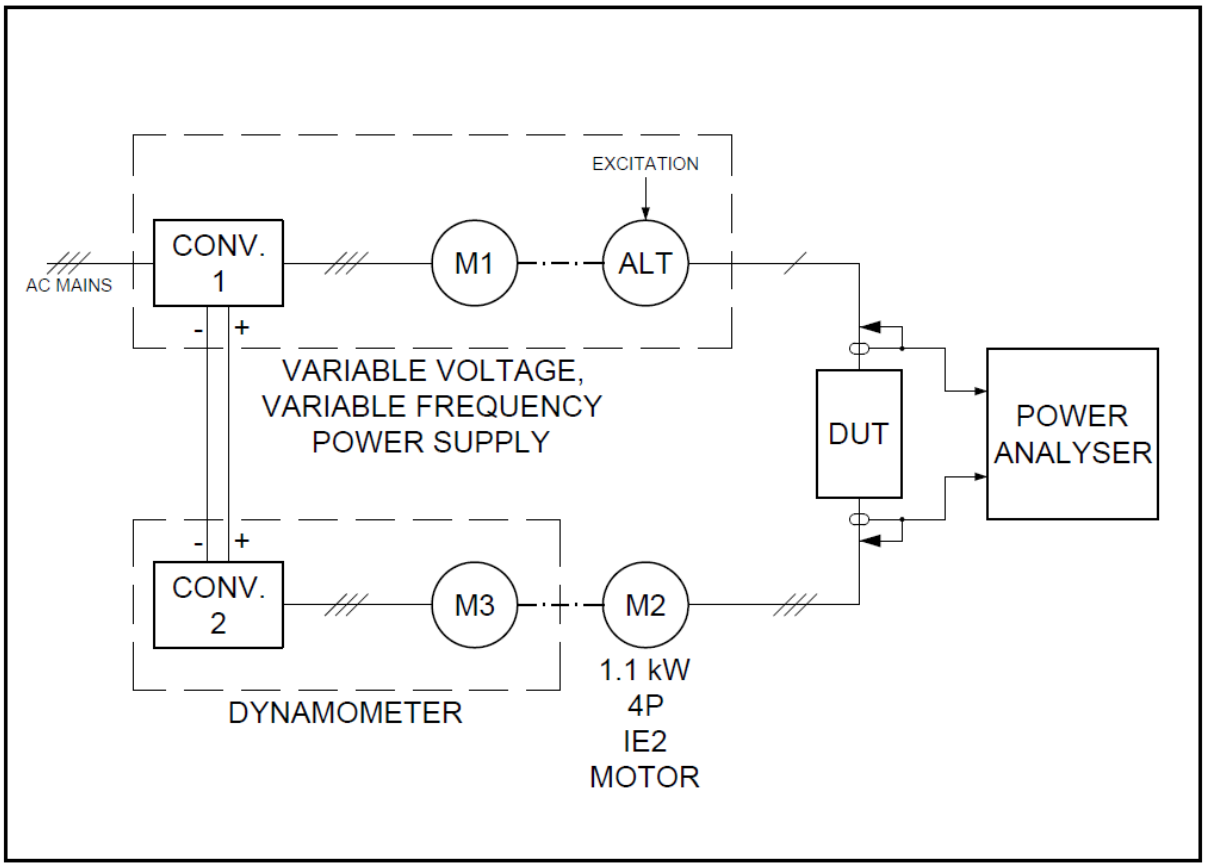


Figure 1 ***A possible test and measurement set-up, the loading motor shown here (M2) is for a converter (device under test 'DUT') rated at 1.1 kW (Source: UTP) [4]***

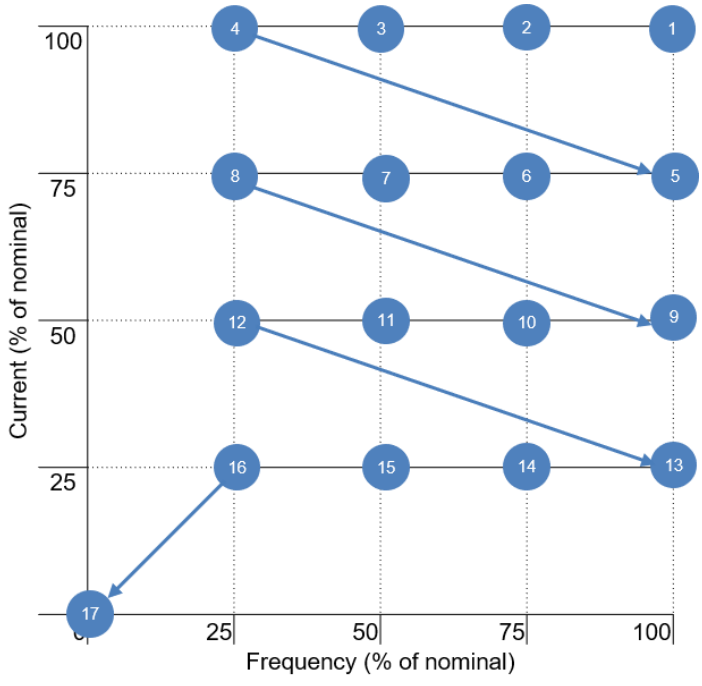
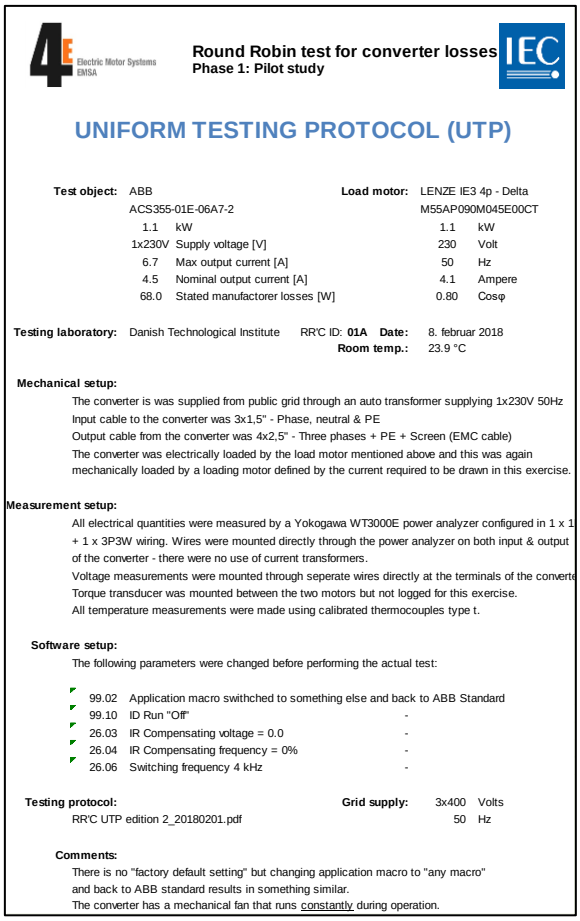


Figure 2 **17 operating points of the converter tests according to the UTP in phase 1**

3.5 The standard reporting format



Round Robin test for converter losses
Phase 1: Pilot study

UNIFORM TESTING PROTOCOL (UTP)

Test object: ABB
ACS355-01E-06A7-2
1.1 kW
1x230V Supply voltage [V]
6.7 Max output current [A]
4.5 Nominal output current [A]
68.0 Stated manufactorer losses [W]

Load motor: LENZE IE3 4p - Delta
M55AP090M045E00CT
1.1 kW
230 Volt
50 Hz
4.1 Ampere
0.80 Cosφ

Testing laboratory: Danish Technological Institute RR'C ID: **01A** **Date:** 8. februar 2018
Room temp.: 23.9 °C

Mechanical setup:
The converter is was supplied from public grid through an auto transformer supplying 1x230V 50Hz
Input cable to the converter was 3x1,5" - Phase, neutral & PE
Output cable from the converter was 4x2,5" - Three phases + PE + Screen (EMC cable)
The converter was electrically loaded by the load motor mentioned above and this was again mechanically loaded by a loading motor defined by the current required to be drawn in this exercise.

Measurement setup:
All electrical quantities were measured by a Yokogawa WT3000E power analyzer configured in 1 x 1 + 1 x 3P3W wiring. Wires were mounted directly through the power analyzer on both input & output of the converter - there were no use of current transformers.
Voltage measurements were mounted through seperate wires directly at the terminals of the converte
Torque transducer was mounted between the two motors but not logged for this exercise.
All temperature measurements were made using calibrated thermocouples type t.

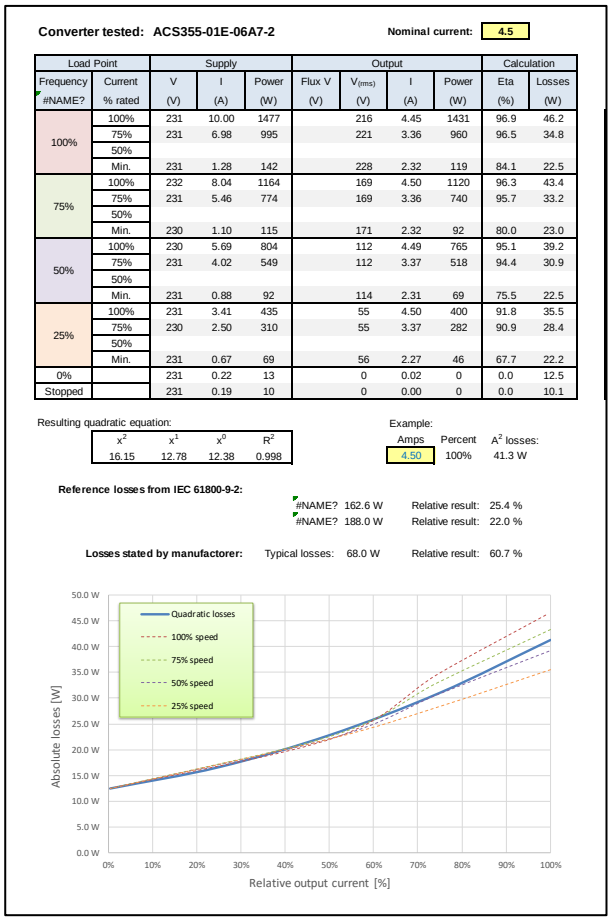
Software setup:
The following parameters were changed before performing the actual test:

99.02	Application macro swithched to something else and back to ABB Standard	
99.10	ID Run "Off"	-
26.03	IR Compensating voltage = 0.0	-
26.04	IR Compensating frequency = 0%	-
26.06	Switching frequency 4 kHz	-

Testing protocol: RR'C UTP edition 2_20180201.pdf
Grid supply: 3x400 Volts, 50 Hz

Comments:
There is no "factory default setting" but changing application macro to "any macro" and back to ABB standard results in something similar.
The converter has a mechanical fan that runs constantly during operation.

Information page



Converter tested: ACS355-01E-06A7-2 **Nominal current:** 4.5

Load Point		Supply			Output				Calculation	
Frequency	Current	V	I	Power	Flux V	$V_{(rms)}$	I	Power	Eta	Losses
#NAME?	% rated	(V)	(A)	(W)	(V)	(V)	(A)	(W)	(%)	(W)
100%	100%	231	10.00	1477		216	4.45	1431	96.9	46.2
	75%	231	6.98	995		221	3.36	960	96.5	34.8
	50%									
	Min.	231	1.28	142		228	2.32	119	84.1	22.5
75%	100%	232	8.04	1164		169	4.50	1120	96.3	43.4
	75%	231	5.46	774		169	3.36	740	95.7	33.2
	50%									
	Min.	230	1.10	115		171	2.32	92	80.0	23.0
50%	100%	230	5.69	804		112	4.49	765	95.1	39.2
	75%	231	4.02	549		112	3.37	518	94.4	30.9
	50%									
	Min.	231	0.88	92		114	2.31	69	75.5	22.5
25%	100%	231	3.41	435		55	4.50	400	91.8	35.5
	75%	230	2.50	310		55	3.37	282	90.9	28.4
	50%									
	Min.	231	0.67	69		56	2.27	46	67.7	22.2
0%		231	0.22	13		0	0.02	0	0.0	12.5
Stopped		231	0.19	10		0	0.00	0	0.0	10.1

Resulting quadratic equation:

x^2	x^1	x^0	R^2
16.15	12.78	12.38	0.998

Example:

Amps	Percent	A^2 losses:
4.50	100%	41.3 W

Reference losses from IEC 61800-9-2:
#NAME? 162.6 W Relative result: 25.4 %
#NAME? 188.0 W Relative result: 22.0 %

Losses stated by manufactorer: Typical losses: 68.0 W Relative result: 60.7 %

Result page

Figure 3 Standard Reporting Format (Source SRF) [5]

3.6 The tests

At the end of phase 1, as of the end of February 2019, the four laboratories tested 9 converters between 0.75 kW and 11 kW with 24 different motors in 58 individual tests. The motors were IE1, IE2 or IE3 with 2- or 4-poles, operated on 50 Hz or 60 Hz.

Owner	Brand	Size [kW]	RR'C No.	CalTest	DTI	BFH	AE
Australia	ABB	1.1	01A	X	X	X	X
	ABB	11.0	01B	X			
Denmark	Schneider	2.2	02A		X	X	X
	Parker	0.75	02B		X	X	X
Switzerland	Lenze	5.5	03A	X		X	X
	ABB	5.5	03B	X		X	X
	ABB	2.2	03C			X	
USA	Schneider	2.2	04A	X	X		X
	Schneider	3.0	04B	X	X		X

Table 1 Products tested (Source: RR'C report phase 1) [2]

3.7 The results

The test results, presented at the WG 18 meeting on 19 February 2019 in Melbourne, Australia, show a small band of deviation, both in absolute terms (W) and in relative terms (standard deviation). It also confirms that the 9 converters have with 19 % to 25 % much lower losses than the reference values in IEC 61800-9-2 (edition 1) of IE1.

Brand	Size [kW]	RR'C No.	Supp.	UTP rated Current [A]	Loss [W]	Span [W]	Max [W]	Min [W]	Std. dev. [W]	% of mean
Parker	0,75	02B	1 ph	3,40	30,3	± 0,5	30,9	29,9	0,3	1,08%
ABB	1,10	01A	1 ph	4,50	41,6	± 0,8	42,4	40,8	0,5	1,23%
Schneider	2,20	04A	3 ph	4,60	52,4	± 3,2	55,6	49,2	1,9	3,56%
Schneider	2,20	02A	3 ph	4,75	57,4	± 1,6	58,9	55,6	1,2	2,04%
ABB	2,20	03C	3 ph	4,90	63,1	± 1,3	64,0	61,4	1,2	1,84%
Schneider	3,00	04B	3 ph	8,65	58,1	± 0,8	59,1	57,5	0,6	0,97%
Lenze	5,50	03A	3 ph	12,00	124,3	± 0,7	125,0	123,7	0,5	0,39%
ABB	5,50	03B	3 ph	12,00	126,2	± 6,3	130,8	118,3	4,3	3,39%
ABB	11,00	01B	3 ph	21,40	220,9	± 1,0	221,9	219,9	0,9	0,39%

Table 2 Preliminary results of products tested (Source: RR'C report phase 1) [2]

Brand	Size [kW]	RR'C No.	Supp.	UTP rated Current [A]	Loss [W]	Supp. U [V]	Supp. I [A]	UTP calc. Apparent power [kVA]	IEC calc. Apparent power [kVA]	IEC 61800-9-2, ed.1 Calc. ref. [W]	Relation
Parker	0,75	02B	1 ph	3,40	30,3	230	4,00	1,354	1,593	163	0,19
ABB	1,1	01A	1 ph	4,50	41,6	230	6,70	1,793	2,669	188	0,22
Schneider	2,2	04A	3 ph	4,60	52,4	460	5,10	3,665	4,063	299	0,18
Schneider	2,2	02A	3 ph	4,75	57,4	400	5,80	3,291	4,018	237	0,24
ABB	2,2	03C	3 ph	4,90	63,1	400	5,30	3,395	3,672	299	0,21
Schneider	3,0	04B	3 ph	8,65	58,1	208	13,70	3,116	4,936	237	0,25
Lenze	5,5	03A	3 ph	12,00	124,3	400	13,00	8,314	9,007	581	0,21
ABB	5,5	03B	3 ph	12,00	126,2	400	12,00	8,314	8,314	581	0,22
ABB	11,0	01B	3 ph	21,40	220,9	400	23,10	14,826	16,004	1.010	0,22

Table 3 Comparing measured losses to reference in Watt vs. Watt (Source: RR'C report phase 1) [2]

4. National cooperation

The introduction of the Bern University of Applied Sciences BFH testing laboratory in Biel of Andrea Vezzini made a big difference from the earlier testing activities where only a link to EPF-L with Ronald Wetter had been established on motor testing. Now, with the fully equipped BFH laboratory, tests on converters and motors up to 45 kW can be made.

The 4E EMSA project is closely linked to the Swiss Topmotors program (www.topmotors.ch) and the Motor Summit (www.motorsummit.ch). The Motor Summit International was held in Zurich on 14 - 15 November 2018. As a side event, the task force for the Round Robin for Converter program (RR'C) losses staged a workshop on 13 November 2018.

5. International cooperation

The international cooperation includes the collaboration with IEC SC 22G WG18 that was agreed at the meeting on 26 - 28 February 2018 in Tampa FL, USA.

Presentations of the RR'C intermediary report were made at the 4E EMSA meeting on 12 November 2018 and at the RR'C workshop in Zurich on 13 November 2018 [3].

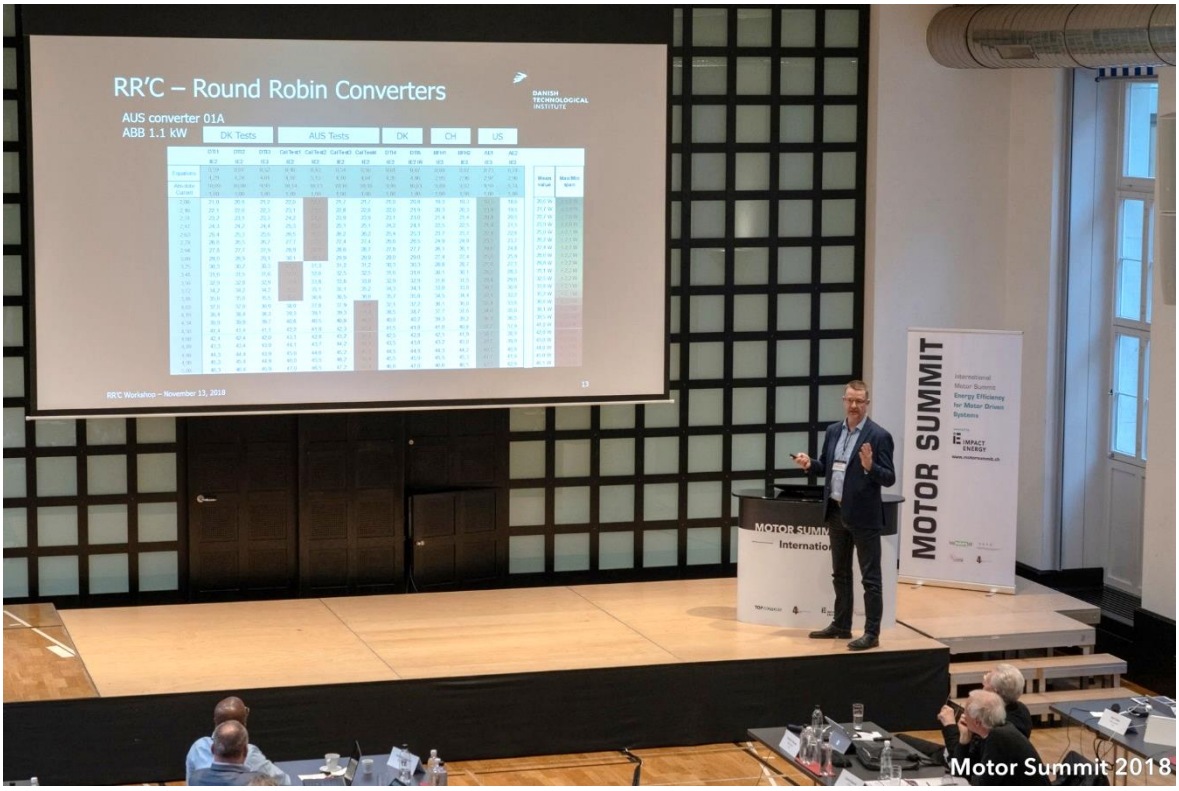


Figure 4 ***Members of the RR'C team presenting at the workshop on 13 November 2018 in Zurich: Conrad U. Brunner, Andrea Vezzini, Andrew Baghurst, Emmanuel Agamloh, Sandie B. Nielsen.***

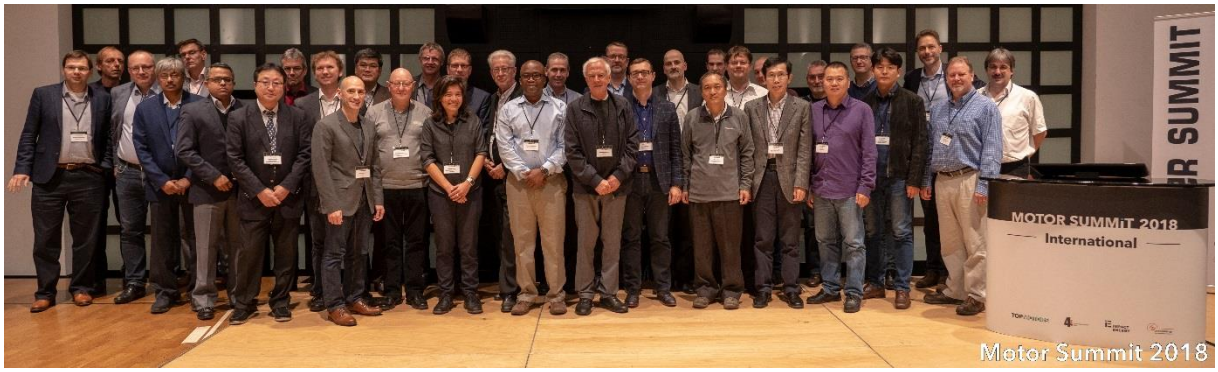


Figure 5 ***Group picture at the end of the RR'C Workshop on 13 November 2018 at the Motor Summit 2018 International in Zurich***

Tuesday 13 November 2018		
Time	**Topic**	**Speaker**
13:30	Welcome and introduction to the Round Robin for Converter Losses (RR'C)	Conrad U. Brunner, Impact Energy (Switzerland)
13:45	Introduction to Uniform Testing Protocol for the RR'C	Andrew Baghurst, CalTest (Australia)
	Report of test results Australia/CalTest	
14:15	Report of test results USA/AE	Emmanuel Agamloh, Advanced Energy (USA)
14:30	Report of test results Switzerland/BFH	Andrea Vezzini, Bern University of Applied Sciences (Switzerland)
14:45	Coffee break	
15:00	Report of test results Denmark/DTI	Sandie B. Nielsen, Danish Technological Institute (Denmark)
	Results RR'C phase 1	
15:30	Discussion of test results, Uniform Testing Protocol	Martin Doppelbauer, Karlsruhe Institute of Technology (Germany), chairman IEC TC 2
15:45	Open discussion	all
16:15	Way forward: necessary changes in IEC 61800-9-2	Tim Schumann, SEW-Eurodrive (USA), convenor SC 22G, WG 18
16:30	Plan for RR'C phase 2	Andrea Vezzini, Bern University of Applied Sciences (Switzerland)
16:45	Conclusions	Conrad U. Brunner, Impact Energy (Switzerland)
17:00	End of the RR'C Workshop	

Table 4 RR'C Workshop program on 13 November 2018 in Zurich

Since the start of the RR'C, EMSA members Andrew Baghurst (2010), Sandie B. Nielsen (2015) and Andrea Vezzini (2017) have been doing relevant work for the RR'C. They also contribute to the transfer of the RR'C testing results into the IEC 61800-9-2 (edition 2). The WG18 meeting in February 2019 was the moment to deliver the results of RR'C phase 1, the transfer of these results into IEC 61800-9-2, edition 2 as well as the start for RR'C phase 2. The results of phase 1 were presented at the WG18 meeting in Melbourne by Conrad U. Brunner, Andrew Baghurst, Sandie B. Nielsen and Andrea Vezzini. The new UTP testing method was discussed. The necessary adjustments for phase 2 which includes also more complex converters were confirmed.

6. Conclusions and Outlook 2019

In the framework of the EMSA program period, called Mini-Extension (November 2017 until February 2019), one key element is the testing program "Round Robin for Converters" which EMSA leads in collaboration with IEC SC 22G/WG18. The first phase to solidify the "Uniform Testing Protocol" was running until the end of February 2019, the full testing phase2 will then start in March 2019 and run presumably until October 2021. The findings will inform the revision of IEC 61800-9-2 for its planned second edition.

7. Publications

- Conrad U. Brunner: IEC standards for motor driven units, in: Motor Summit 2018, conference proceedings, 2018, Zurich, Switzerland

- Maarten van Werkhoven: International collaboration for efficient motor systems: Global Outlook and 4E EMSA, in: Motor Summit 2018, conference proceedings, 2018, Zurich, Switzerland
- Rita Werle: Motor systems today and tomorrow, in: Motor Summit 2018, conference proceedings, 2018, Zurich, Switzerland
- Sandie B. Nielsen: Global Round-Robin on Frequency Converters, in: Motor Summit 2018, conference proceedings, 2018, Zurich, Switzerland
- Andrew Baghurst: International converter efficiency measurements round-robin/feasibility study, in: Workshop Round Robin, Motor Summit 2018, Zurich, Switzerland
- Andrea Vezzini, Round Robin pilot study, in: Workshop Round Robin, Motor Summit 2018, Zurich, Switzerland
- Round Robin for Converter Losses, Report of Results of Phase 1, Zurich, March 2019

References

[1] IEC 61800-9-2:2017: Adjustable speed electrical power drive systems - Part 9-2: Ecodesign for power drive systems, motor starters, power electronics and their driven applications - Energy efficiency indicators for power drive systems and motor starters, Geneva, 3 March 2018

[2] Round Robin for Converter Losses, Report of Results from Phase 1, Zurich, March 2019

[3] Round Robin for Converter Losses, workshop at the Motor Summit 2018, presentations in proceedings: Motor Summit 2018, www.motorsummit.ch/2018

[4] Uniform Testing Protocol, edition 4, 2018

[5] Standard Reporting Format, V3, 2018

Appendix

Separately:

Round Robin for Converter Losses, Report of Results from Phase 1, Zurich, March 2019