4E Electric Motor Systems
EMSA

IEC

ROUND ROBIN OF CONVERTER LOSSES

# Report of Results of Phase 1

final1d 20190322

Photo: BFH ............................ Contact: Impact Energy, Gessnerallee 38a, CH 8001 Zurich Switzerland

**Authors:**

- Emmanuel Agamloh, Advanced Energy, USA
- Andrew Baghurst, CalTest, Australia
- Conrad U. Brunner, Impact Energy, Switzerland *
- Sandie B. Nielsen, DTI, Denmark *
- Andrea Vezzini, BFH, Switzerland *

All authors are members of IEC SC 22G WG18.

*) indicates members of the EMSA Task Force International Standards

**Testing period:**

15 December 2017 to 30 October 2018

The RR'C team would like to thank the sponsors of this work, namely the governments of Australia, Austria, Switzerland and USA. Also, we would like to thank the four participating laboratories for providing their facilities and skilled engineers as well as to the manufacturers who helped to acquire the converters and the motors for the test. We also thank the EMSA operating team for providing the operational base to manage the RR'C project. And we appreciate the support of IEC SC 22G and WG18 and its officers to improve the scientific basis for IEC 61800-9-2 and its second edition.

Zurich, 22 March 2019

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## Glossary and abbreviations

| | |
|---|---|
| 4E | IEA Technical Cooperation Programme: Energy Efficient End-use Equipment |
| BFH | Berner Fachhochschule (Bern University of Applied Sciences) |
| CDM | Complete drive module (defined in IEC 61800-9-2) (here used as synonym for VFD) |
| DTI | Danish Technological Institute |
| EEMODS | International Conference on Energy Efficiency in Motor Driven Systems |
| EMSA | Electric Motor Systems Annex of 4E, www.motorsystems.org |
| IEA | International Energy Agency, Paris, France, www.iea.org |
| IEC | International electrotechnical commission, Geneva, Switzerland, www.iec.ch |
| MEPS | Minimum Energy Performance Standard |
| PDS | Power drive system (defined in IEC 61800-9-2) |
| PLC | Programmable logic controller |
| PWM | Pulse width modulation |
| rms | root mean square |
| RR'C | Round Robin program for converter losses |
| SC 22G | IEC Subcommittee 22 G responsible for "Adjustable speed electric drive systems incorporating semiconductor power converters" |
| VFD | Variable frequency drive |
| VSD | Variable speed drive (here used as synonym for VFD) |
| WG18 | Working Group 18 of SC 22G, responsible for "Energy efficiency of adjustable speed electric power drive systems" |

## List of Figures

# 1. Executive summary

Advanced electric motor driven systems for pumps, fans, compressors, etc. often use today variable frequency converters to adjust the electric power demand to the required torque and speed of the application. The converter use can lead to large energy savings because the necessary electric power and the duration of its use can be reduced. On the other hand, frequency converters are costly electronic devices that need to be well designed, carefully chosen to the required task and well programmed during the operation of the motor system. Also, converters as power supplies have an intrinsic electric loss in standby and in operation, plus they also cause further losses in the driven electric motor due to the non-sinusoidal voltage and current delivered from its pulse width modulation.

The electric losses and efficiency of converters for motor driven systems have not yet, in a publicly available independent study, been systematically determined, analyzed and different products compared. A well-defined, internationally accepted and used measuring method for converter losses that delivers accurate and repeatable results, has not existed so far.

The Round Robin program for Converter Losses (RR'C) was initiated at the end of 2017 as a joint project between 4E EMSA[1] and IEC SC 22G WG18[2]. After the publication of the first standard for converter losses in IEC 61800-9-2, edition 1, on 3 March 2017 [1], the necessity arose to clarify the testing program for converter losses and to verify the so far not tested reference losses in order to set the future IE-classes for edition 2.

The RR'C program is divided in two phases:

- **Phase 1**
  From November 2017 to the end of February 2019
  phase 1 serves as a pilot phase of the RR'C with a small number of laboratories and converters to elaborate a testing method.
- **Phase 2**
  From beginning of March 2019 to the end of 2020
  phase 2 tries to provide sufficient evidence of a larger number of converters to serve as a basis to define reference losses and efficiency classes.

The current report covers the results, the key findings of the tests in phase 1 between December 2017 and October 2018 and the first set of recommendations for amending IEC 61800-9-2, edition 1.

The first goal of RR'C was to define a robust and practical testing method with the newly defined Uniform Testing Protocol (UTP) that will return highly repeatable results. The focus was therefore to compare results of multiple tests of the same converter and check the repeatability (and not the individual product performance[3]). The second goal was to provide sufficient statistical evidence of tested regular converters in the full scope of the converter market between 0.12 kW and 1000 kW to reappraise the reference losses in IEC 61800-9-2, edition 1 and thus be able to secure the definition of the IE classes. The entire Round Robin was to be guided by a transparent and scientific approach.

With the project management from EMSA, the co-financing from the four EMSA members Australia (AU), Denmark (DK), Switzerland (CH) and USA, the following four independent testing laboratories have been involved in the definition of the UTP and the converter testing of phase 1:

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[1] IEA 4E Electric Motor Systems Annex, www.motorsystems.org

[2] International Electrotechnical Commission (IEC), Technical Committee TC22, Subcommittee (SC) 22 G, Working Group (WG) 18

[3] This was the reason in phase 1 to publish the details of products and manufacturers. In phase 2, the comparison of product performance is in focus. Then, the manufacturers will be treated anonymously.

- Advanced Energy, USA: Emmanuel Agamloh,
- CalTest, AU: Andrew Baghurst,
- DTI, DK: Sandie B. Nielsen (RR'C Task Force Leader),
- BFH, CH: Andrea Vezzini/CH (RR'C Task Force Co-Leader).

The converters were mostly provided by the manufacturers for free or with a discount. The load motors were taken from laboratory's stock. In phase 1 only standard diode type converters were tested.

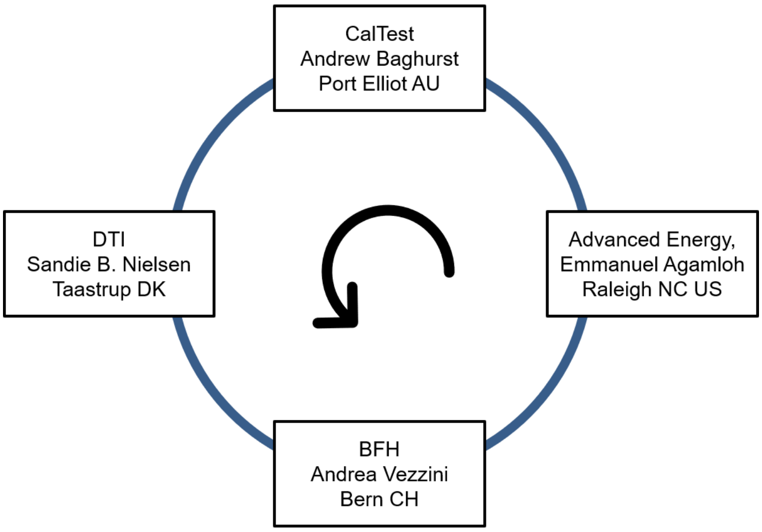
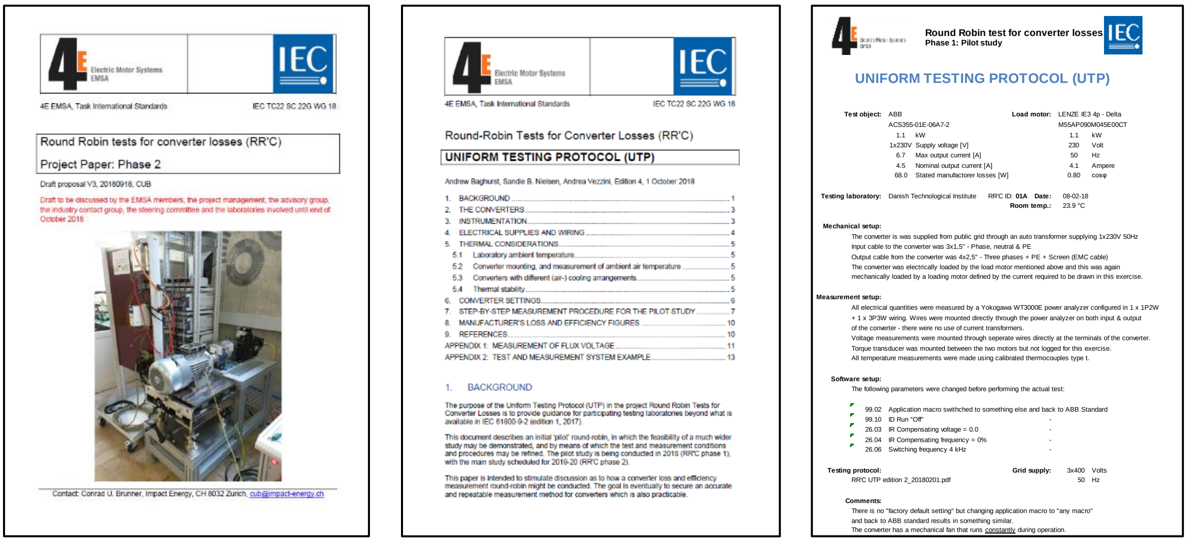


**Figure 1** **The Round Robin circle with the four testing laboratories**

Three major documents were prepared during phase 1, see **Fehler! Verweisquelle konnte nicht gefunden werden.** The revised UTP and the current Standard Reporting Format (SRF) are presented in documents attached to this report.



4E EMSA, Task International Standards IEC TC22 SC 22G WG 18

Round Robin tests for converter losses (RR'C)

Project Paper: Phase 2

Draft proposal V3, 20180918, CUB

Draft to be discussed by the EMSA members, the project management, the advisory group, the industry contact group, the steering committee and the laboratories involved until end of October 2018

Contact: Conrad U. Brunner, Impact Energy, CH 8032 Zurich, cub@impact-energy.ch

Project Paper phase 2
(V3, 20180918)

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4E EMSA, Task International Standards IEC TC22 SC 22G WG 18

Round-Robin Tests for Converter Losses (RR'C)

UNIFORM TESTING PROTOCOL (UTP)

Andrew Baghurst, Sandie B. Nielsen, Andrea Vezzini, Edition 4, 1 October 2018

1. BACKGROUND

The purpose of the Uniform Testing Protocol (UTP) in the project Round Robin Tests for Converter Losses is to provide guidance for participating testing laboratories beyond what is available in IEC 61800-9-2 (edition 1, 2017).

This document describes an initial 'pilot' round-robin, in which the feasibility of a much wider study may be demonstrated, and by means of which the test and measurement conditions and procedures may be refined. The pilot study is being conducted in 2018 (RR'C phase 1), with the main study scheduled for 2019-20 (RR'C phase 2).

This paper is intended to stimulate discussion as to how a converter loss and efficiency measurement round-robin might be conducted. The goal is eventually to secure an accurate and repeatable measurement method for converters which is also practicable.

Uniform Testing Protocol
(UTP, edition 4, 20181001)

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**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:** 08-02-18
**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 1P2W + 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 converter.
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.

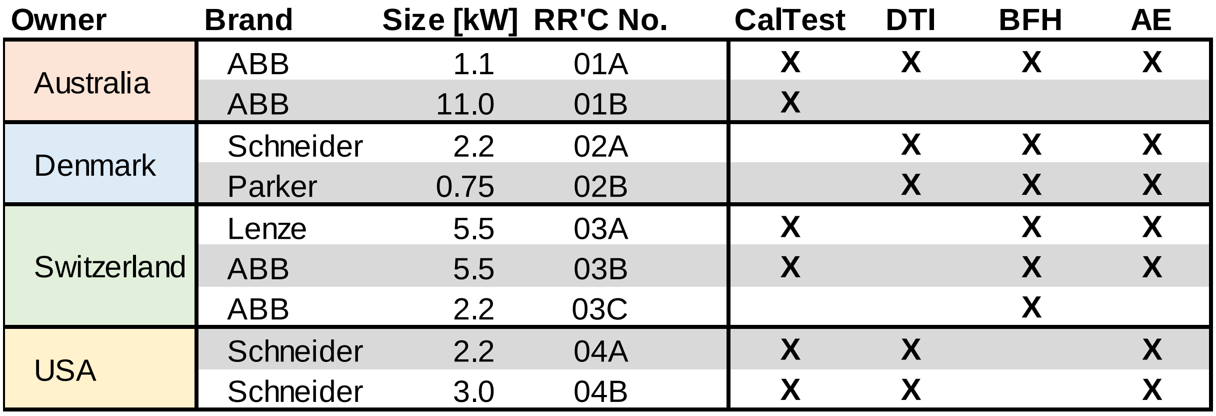
Standard Reporting Format
(SRF 20180927)

**Figure 2** **Overview three working papers**

**The testing program** in phase 1 included 9 converters from 0.75 kW to 11 kW from four different manufacturers (see Figure 3). A total of 58 tests were made by four independent laboratories, using

24 different load motors in efficiency classes of IE1, IE2 and IE3 from 12 different manufacturers. Tests were run at 50 Hz and 60 Hz.

To further the knowledge on converter losses, a number of tests were also run to find out about the feasibility of the selected load motor by type, size, poles, efficiency class, etc. Some of these results (2-pole, larger size motors, etc.) showed higher deviations and some of these results were not included in the final compilation and discussion of repeatability of the results.



| 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 |

**Figure 3** **List of tested products and the testing laboratories**

The tests, according to the UTP, were run in a scientific manner with 17 operating points covering the entire operating field of a converter/motor. If possible, these points should be measured in the following sequence in four different frequencies between 100 %, 75 %, 50 % and 25 % plus 0 %, see Figure 4.

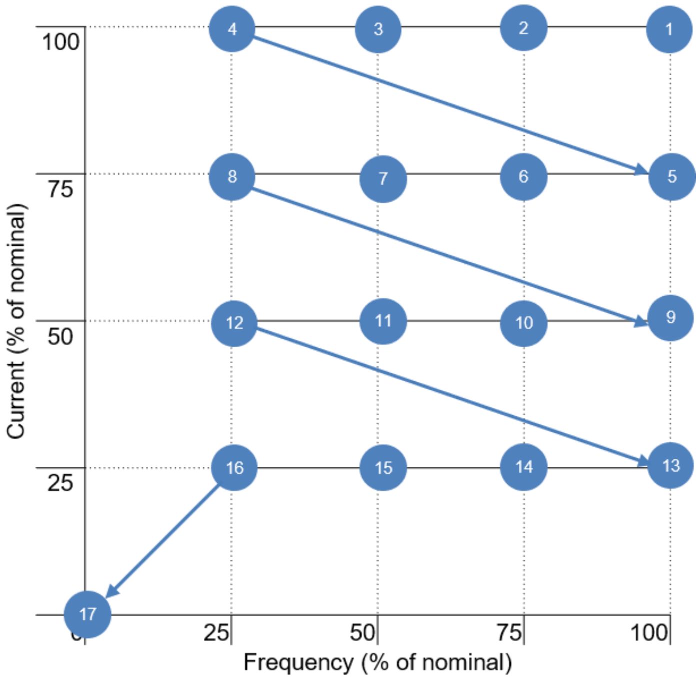


**Figure 4** **17 operating points of the converter tests according to the UTP in phase 1**

*Note to the issue of selecting operating points:*

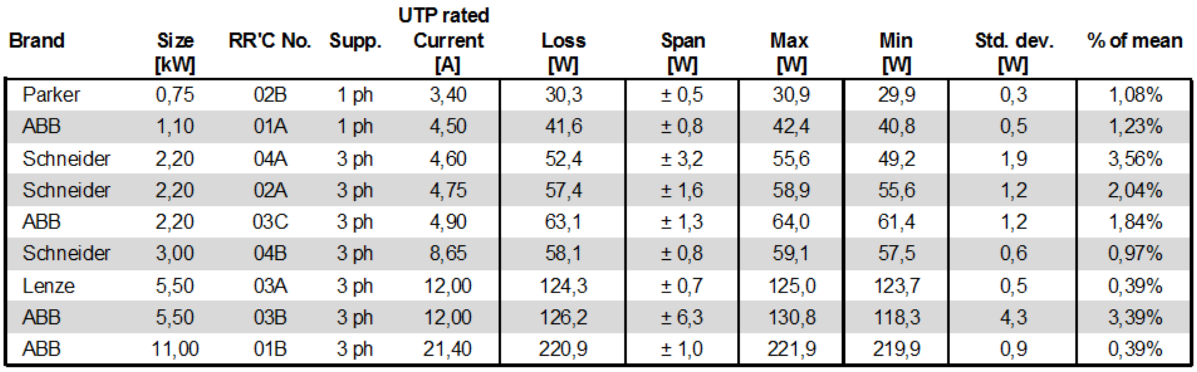
*Two critical comments on the test method and its operating points defined in IEC 61800-9-2, edition 1:*

- *the first thing you would want to know from a converter is how the motor would operate, and how much the total system losses are, at its nameplate rated speed, and not at 90% of that value. In IEC 61800-9-2, edition 1, only 90% of speed is tested because of the general concern with 'overmodulation'. Still, this has no consequence to the end user, who wants to know what happens at 100% of base speed.*
- *Second, the 'operating points' at stand-still (0% of rated speed) for a range of currents are not useful. The converter almost certainly will not be able to supply those currents, and if it were so to do, the motor, deprived of any forced cooling means, would surely burn out in a relatively short time.*

*In any case, our thesis has been that the converter should, for this purpose, be set to produce a constant V/f ratio, in which case, at zero (fundamental) frequency output, the voltage is zero, and motor current likewise. This is, after all, the point at which the 'standby power' for the converter is measured, constituting the 'C' value in the quadratic relationship upon which this exercise has been based.*

*The choice of the number and place of operating points for practical applications which will eventually be included in the IEC 61800-9-2, edition 2, will be discussed later.*

The test results of all the tests on the 9 converters are shown in see Figure 5.



| 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% |

**Figure 5 List of aggregated results of all tests**

The results of the measured absolute losses of each converter in all the tested operating points can also be presented in a standardized reporting format, defined as the SRF, as a second-degree polynomial equation with a coefficient of determination $R^2$ near 100%, see Figure 6 and the equation therein.

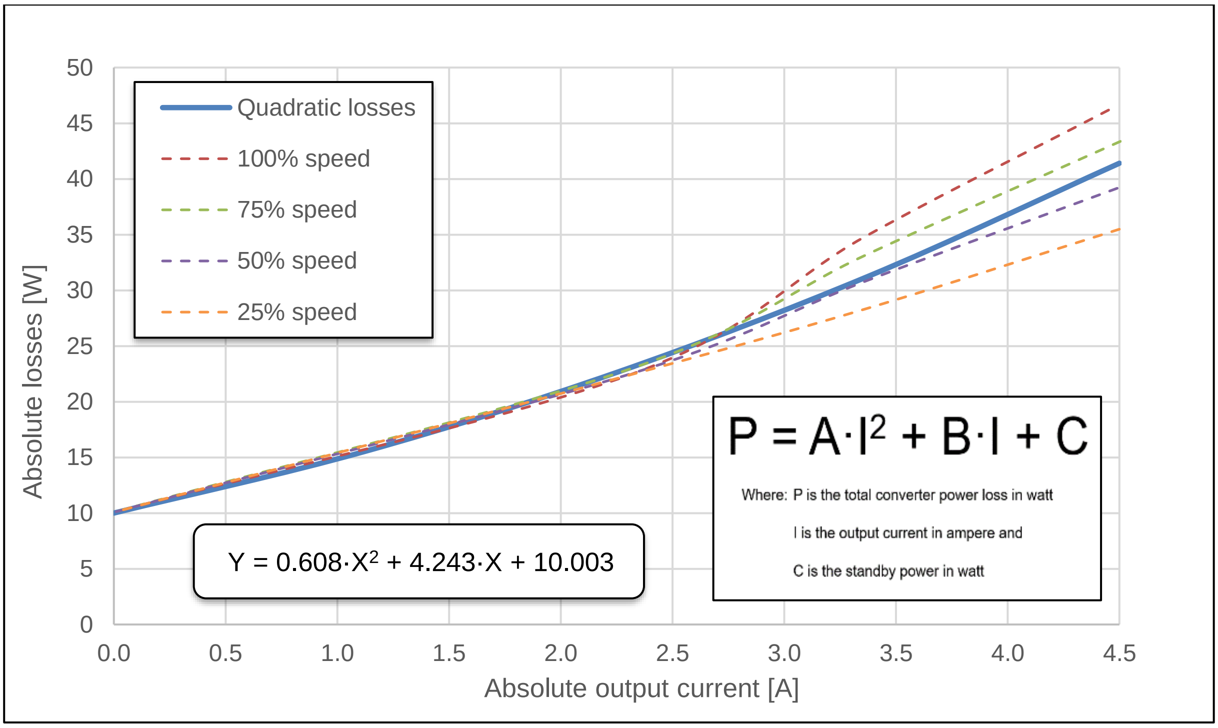


Figure 6 Graphic result with second-degree polynomial equation

**The key results** of the tests show:

- The UTP is a valuable instrument to return highly repeatable results from tests in different laboratories.
- It was shown that selection of the motor for load have a certain sensitivity to size and number of poles whereas manufacturer and efficiency class are less important. In conclusion load motors must be (kW) sized to the converter in question and fulfill energy class IE2 or IE3. All load motors must be 4-pole asynchronous motors.
- The tests can be equally made at 50 Hz and 60 Hz fundamental frequency.
- High precision measuring instruments from at least two different manufacturers have been used without any influence on the results.
- In the tested group of 9 converters from 0.75 kW to 11 kW the maximum span between minimum and maximum loss at full load was between 0.5 W and 6.3 W. The relative span was between 0.39 % and 3.56 %. The standard deviation was between 0.3 W and 1.9 W.
- The measured converter losses were all less than one third of the reference losses of IE1 in IEC 61800-9-2, edition 1.

**The recommendations** for the advancement of the converter testing method include the following topics:

- The nominal and rated output current in ampere of any converter must be clearly defined.
  - A solution has been introduced in section 3.4.1 A reference output current table of this report
- The converters can be tested with any asynchronous motor to return reasonable results. But it is recommended to use IE2 or IE3 and only 4-pole motors of the same nominal rating as the converter to keep repeatability of the test results high.
- The no load/off point must be precisely defined to return repeatable results. Auxiliaries like fans, etc. can distort the measuring results.

- So far, the 17 operating points have been chosen because of the scientific necessity to have the measurements covering the entire operating field. The necessary operating points for the tests will be reappraised for practical reasons to be required in IEC 61800-9-2, edition 2. In phase 2, only 13 operating points will be used.
- For phase 2 of the UTP study it is recommended to include converters with all typical accessories, filters, 4Q etc. to evaluate the influence of these factors to the losses. Matrix converters shall also be included.
- The comparison of losses and performance in basic drive modules and in complete drive modules (including auxiliaries) shall be distinguished clearly in phase 2.

# 2. Background, goal

## 2.1 Initiative

On Wednesday 6 September 2017, in Rome Italy, just before EEMODS'17 was starting, a group of 8 members of IEC SC 22G WG 18 met with three representatives from EMSA with the idea to improve the testing method of converters described in IEC 61800-9-2, edition 1. A cooperation between EMSA and WG18 was arranged with a two-phase approach with four independent labs to take the lead. The first draft of a Uniform Testing Protocol was mandated to Andrew Baghurst within a short period of time to be used in all the laboratories for the subsequent tests. The funding for phase 1 was to be arranged with the Swiss, Danish, Australian and US government agencies already involved as members of EMSA. The four testing labs for phase 1 and the RR'C leadership were decided like this:

| | |
|---|---|
| • Advanced Energy, USA: | Emmanuel Agamloh, |
| • CalTest, AU: | Andrew Baghurst, |
| • DTI, DK: | Sandie B. Nielsen (RR'C Task Force Leader), |
| • BFH, CH: | Andrea Vezzini/CH (RR'C Task Force Co-Leader). |

## 2.2 Timeline

The timing with two phases was set like this:

- Phase 1
  from November 2017 to the end of February 2019
  as a pilot phase with a small number of laboratories and converters, to clarify the testing method with a Uniform Testing Protocol (UTP).
- Phase 2
  from the beginning of March 2019 to end of 2020
  to provide sufficient evidence of tested converters between 0.12 kW and 1000 kW to reappraise the reference losses and to secure the choice of the IE classes.

The timeline was coordinated with the tentative schedule for the revision of IEC 61800-9-2, edition 2 with a first CD to be published in summer of 2019.

A first orientation of the RR'C program, the first version of the UTP and the results of the first 26 tests was held at the IEC WG18 meeting on 26 February 2018 in Tampa Florida USA.

A public workshop was held on 13 November 2018 at the Motor Summit 2018 in Zurich Switzerland.

This report as the result of RR'C phase 1 with 58 tests, will be presented and discussed at the IEC SC 22G WG 18 meeting in Melbourne Australia on 19 - 20 February 2019. WG 18 will then decide what to include in the revised IEC 61800-9-2, edition 2.

## 2.3 Motives for the RR'C

In the last decade, the development of methods for motor efficiency testing and motor efficiency classification the test methods for motor efficiencies were clarified by international Round Robin testing programs. Their results were discussed and published in the motor community. This work preceded the initial setting of efficiency classes in 2008 (IEC 60034-30, edition 1, 2008). In the following years, the test methods were again improved (IEC 60034-2-1, edition 2, 2014) and the classification updated with the technical development (IEC 60034-30-1, edition 1, 2014). Subsequent Round Robin programs verified the repeatability of the currently used preferred method [2].

The test and calculation method for converter losses and the efficiency classification have been set (IEC 61800-9-2, edition 1, 2017) without preceding systematical tests in independent laboratories with the results publicly available. The testing method in IEC 61800-9-2, edition 1 has been considered not precise enough to return repeatable results. Also, the calculation method given in IEC 61800-9-2 has been criticized for not being readily and generally applicable by any manufacturer because no verified calculation program was available from IEC. Also, the necessary inputs in any similar calculation program require a considerable effort in default values and component tests.

In the current situation of national Minimum Energy Performance Standards (MEPS) being set, the methods for check testing have not been well enough defined for independent laboratories to verify the results.

### 2.4 Goals

The first goal of RR'C was to define a robust and practical testing method with a newly defined Uniform Testing Protocol (UTP) that will return highly repeatable results.

The second goal of the RR'C was to provide sufficient statistical evidence of tested regular converters in the market between 0.12 kW and 1000 kW to reappraise the reference losses in IEC 61800-9-2, edition 1 and thus be able to secure the definition of the IE classes.

The entire Round Robin was to be guided by a transparent and scientific approach.

### 2.5 RR'C organization

The RR'C Task Force and its leadership from 4E EMSA, WG18 and industry has been selected and mandated.

- **Project manager** (PM):
  Sandie B. Nielsen/DK (Task Force leader), Andrea Vezzini/CH (Co-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, Bjarke Hansen/Danish government DK
- **Industry contact group**:
  It was considered necessary to hold close contact with representatives of major industries that manufacture converters. The following group was invited as 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).

### 2.5 Plan of RR'C phase 2 (see chapter 5)

During 2018, the plan of the RR'C phase 2 was developed. Currently, 7 labs will participate in the tests of small and medium size converters, 2 or 3 industry laboratories will participate in stationary tests of larger converters between 200 and 1000 kW according to the UTP. Three of the current laboratories will continue and four new laboratories Canada, China, Germany and Japan) will expand the group of testing laboratories.

It is planned to tests some 60 converters between 0.12 kW and 1000 kW and accept different types of diode and matrix converters.

The definitive program for phase 2 will be decided at the SC22 G WG 18 meeting on 19 - 21 February 2019 in Melbourne, Australia.

# 3. Compiled results and findings

## 3.1 Phase 1 tests performed

The tests performed in phase 1 of the RR’C was distributed around the world between 4 independent laboratories.

| | |
|---|---|
| USA | Advanced Energy, Raleigh NC |
| Denmark | Danish Technological Institute, Aarhus |
| Switzerland | Bern University of Applied Sciences, Biel |
| Australia | CalTest, Port Elliot, SA |

The converters and load motors used for phase 1 was in most cases already “in-stock” at the labs, and the rest were purchased for the purpose.

For reasons of simplicity / recognizability the following chapter refers to the size of converters as the kW size of the motor intended for the specific converter respectively. Especially for the smaller converters the nominal output current is relatively high compared to the kW motor size nominal current.

One part of phase 1 of the project was to show whether this relatively lower absolute value of the nominal current of the motors was enough to show the efficiency of the converters involved.

The complete testing program in phase 1 included 9 converters ranging in nominal output power from 0.75 kW to 11 kW from four different manufacturers (see Figure 7).

A total of 58 tests were made, using 24 different motors in efficiency classes of IE1, IE2 and IE3 from 13 different manufacturers.

Tests were performed at both 50 & 60 Hz input and output frequencies with corresponding voltage levels and combinations hereof.

| 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 |

**Figure 7 Phase 1 converters overview**

For some of the converters the tests included both 50 Hz and 60 Hz load to establish independency on the output circuits.

Furthermore, it should be noted, that some of the motors used served as load for multiple setups. One example of this was the Busck motor at the DTI lab. This is constructed in such a way that it can be used as both a 50 Hz load (2.2 kW – 4.91 A) and a 60 Hz load (2.53 kW – 4.91 A):

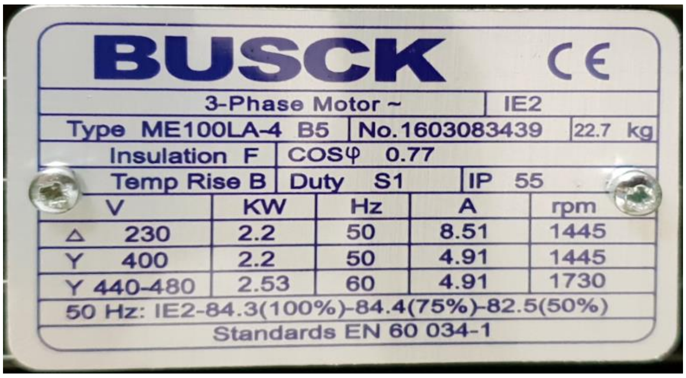


**Figure 8** Busck 4-pole motor from DTI, 2.2 kW 50 Hz, 2.53 kW, 60 Hz

When elaborating the 58 tests performed (see Figure 9), the distribution of the energy classes of the motors used show a limited number of IE1 motors (14%), about one third was IE2 motors (33%) and more than half of the motors used was IE3 (53%).

This is likely a good representation of the motor market for conventional converters in the year 2018.

| | | | | CalTest | | | DTI | | | BFH | | | AE | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Owner** | **Brand** | **Size [kW]** | **RR'C No.** | **IE1** | **IE2** | **IE3** | **IE1** | **IE2** | **IE3** | **IE1** | **IE2** | **IE3** | **IE1** | **IE2** | **IE3** |
| Australia | ABB | 1.1 | 01A | | **4** | | | **4** | **1** | | | **2** | | | **2** |
| | ABB | 11.0 | 01B | | **4** | | | | | | | | | | |
| Denmark | Schneider | 2.2 | 02A | | | | **1** | **1** | **2** | | | **2** | | | **2** |
| | Parker | 0.75 | 02B | | | | | **1** | **1** | | | **2** | **1** | | |
| Switzerland | Lenze | 5.5 | 03A | | **1** | | | | | **1** | | **1** | | | **2** |
| | ABB | 5.5 | 03B | **1** | | | | | | **1** | | **1** | | | **2** |
| | ABB | 2.2 | 03C | | | | | | | | | **3** | | | |
| USA | Schneider | 2.2 | 04A | | **1** | | **2** | **2** | | | | | | | **4** |
| | Schneider | 3.0 | 04B | | **1** | | **1** | | | | | | | | **4** |

| **IE1** | **IE2** | **IE3** |
|---|---|---|
| 8 | 19 | 31 |
| 14% | 33% | 53% |

**Total no. of tests:** **58**

**Figure 9** Phase 1 converters elaborating motors used

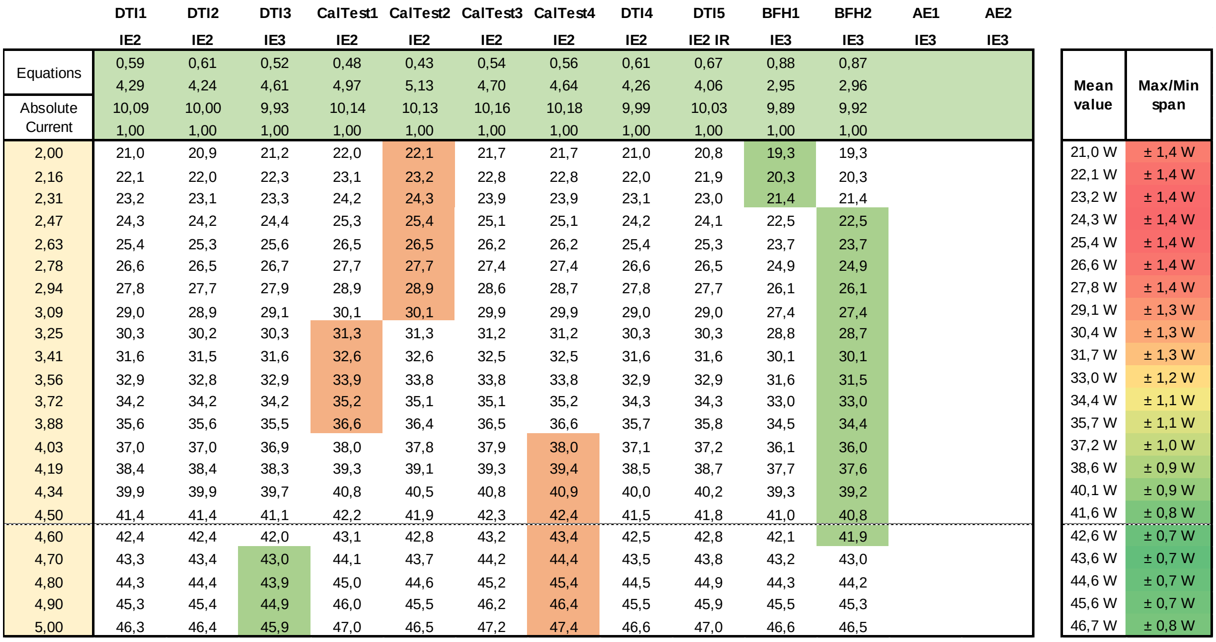
## 3.2 Results of each converter

The detailed description of the tested nine converters follows in chapter 6.2.

### 3.2.1 Converter No. 01A: ABB 1.1 kW, nominal output 6.7 Amps – 1 phase supply

Below, in Figure 10, are the collected results of the tests performed by four labs on the ABB 1.1 kW converter No. 01A.

The measurements from Advanced Energy have been removed, as the load motor used here was a 2.2 kW machine resulting in deviations beyond acceptable values.



|  | DTI1 | DTI2 | DTI3 | CalTest1 | CalTest2 | CalTest3 | CalTest4 | DTI4 | DTI5 | BFH1 | BFH2 | AE1 | AE2 | Mean value | Max/Min span |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  | IE2 | IE2 | IE3 | IE2 | IE2 | IE2 | IE2 | IE2 | IE2 IR | IE3 | IE3 | IE3 | IE3 |  |  |
| Equations | 0,59 | 0,61 | 0,52 | 0,48 | 0,43 | 0,54 | 0,56 | 0,61 | 0,67 | 0,88 | 0,87 |  |  |  |  |
|  | 4,29 | 4,24 | 4,61 | 4,97 | 5,13 | 4,70 | 4,64 | 4,26 | 4,06 | 2,95 | 2,96 |  |  |  |  |
| Absolute Current | 10,09 | 10,00 | 9,93 | 10,14 | 10,13 | 10,16 | 10,18 | 9,99 | 10,03 | 9,89 | 9,92 |  |  |  |  |
|  | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 |  |  |  |  |
| 2,00 | 21,0 | 20,9 | 21,2 | 22,0 | 22,1 | 21,7 | 21,7 | 21,0 | 20,8 | 19,3 | 19,3 |  |  | 21,0 W | ± 1,4 W |
| 2,16 | 22,1 | 22,0 | 22,3 | 23,1 | 23,2 | 22,8 | 22,8 | 22,0 | 21,9 | 20,3 | 20,3 |  |  | 22,1 W | ± 1,4 W |
| 2,31 | 23,2 | 23,1 | 23,3 | 24,2 | 24,3 | 23,9 | 23,9 | 23,1 | 23,0 | 21,4 | 21,4 |  |  | 23,2 W | ± 1,4 W |
| 2,47 | 24,3 | 24,2 | 24,4 | 25,3 | 25,4 | 25,1 | 25,1 | 24,2 | 24,1 | 22,5 | 22,5 |  |  | 24,3 W | ± 1,4 W |
| 2,63 | 25,4 | 25,3 | 25,6 | 26,5 | 26,5 | 26,2 | 26,2 | 25,4 | 25,3 | 23,7 | 23,7 |  |  | 25,4 W | ± 1,4 W |
| 2,78 | 26,6 | 26,5 | 26,7 | 27,7 | 27,7 | 27,4 | 27,4 | 26,6 | 26,5 | 24,9 | 24,9 |  |  | 26,6 W | ± 1,4 W |
| 2,94 | 27,8 | 27,7 | 27,9 | 28,9 | 28,9 | 28,6 | 28,7 | 27,8 | 27,7 | 26,1 | 26,1 |  |  | 27,8 W | ± 1,4 W |
| 3,09 | 29,0 | 28,9 | 29,1 | 30,1 | 30,1 | 29,9 | 29,9 | 29,0 | 29,0 | 27,4 | 27,4 |  |  | 29,1 W | ± 1,3 W |
| 3,25 | 30,3 | 30,2 | 30,3 | 31,3 | 31,3 | 31,2 | 31,2 | 30,3 | 30,3 | 28,8 | 28,7 |  |  | 30,4 W | ± 1,3 W |
| 3,41 | 31,6 | 31,5 | 31,6 | 32,6 | 32,6 | 32,5 | 32,5 | 31,6 | 31,6 | 30,1 | 30,1 |  |  | 31,7 W | ± 1,3 W |
| 3,56 | 32,9 | 32,8 | 32,9 | 33,9 | 33,8 | 33,8 | 33,8 | 32,9 | 32,9 | 31,6 | 31,5 |  |  | 33,0 W | ± 1,2 W |
| 3,72 | 34,2 | 34,2 | 34,2 | 35,2 | 35,1 | 35,1 | 35,2 | 34,3 | 34,3 | 33,0 | 33,0 |  |  | 34,4 W | ± 1,1 W |
| 3,88 | 35,6 | 35,6 | 35,5 | 36,6 | 36,4 | 36,5 | 36,6 | 35,7 | 35,8 | 34,5 | 34,4 |  |  | 35,7 W | ± 1,1 W |
| 4,03 | 37,0 | 37,0 | 36,9 | 38,0 | 37,8 | 37,9 | 38,0 | 37,1 | 37,2 | 36,1 | 36,0 |  |  | 37,2 W | ± 1,0 W |
| 4,19 | 38,4 | 38,4 | 38,3 | 39,3 | 39,1 | 39,3 | 39,4 | 38,5 | 38,7 | 37,7 | 37,6 |  |  | 38,6 W | ± 0,9 W |
| 4,34 | 39,9 | 39,9 | 39,7 | 40,8 | 40,5 | 40,8 | 40,9 | 40,0 | 40,2 | 39,3 | 39,2 |  |  | 40,1 W | ± 0,9 W |
| 4,50 | 41,4 | 41,4 | 41,1 | 42,2 | 41,9 | 42,3 | 42,4 | 41,5 | 41,8 | 41,0 | 40,8 |  |  | 41,6 W | ± 0,8 W |
| 4,60 | 42,4 | 42,4 | 42,0 | 43,1 | 42,8 | 43,2 | 43,4 | 42,5 | 42,8 | 42,1 | 41,9 |  |  | 42,6 W | ± 0,7 W |
| 4,70 | 43,3 | 43,4 | 43,0 | 44,1 | 43,7 | 44,2 | 44,4 | 43,5 | 43,8 | 43,2 | 43,0 |  |  | 43,6 W | ± 0,7 W |
| 4,80 | 44,3 | 44,4 | 43,9 | 45,0 | 44,6 | 45,2 | 45,4 | 44,5 | 44,9 | 44,3 | 44,2 |  |  | 44,6 W | ± 0,7 W |
| 4,90 | 45,3 | 45,4 | 44,9 | 46,0 | 45,5 | 46,2 | 46,4 | 45,5 | 45,9 | 45,5 | 45,3 |  |  | 45,6 W | ± 0,7 W |
| 5,00 | 46,3 | 46,4 | 45,9 | 47,0 | 46,5 | 47,2 | 47,4 | 46,6 | 47,0 | 46,6 | 46,5 |  |  | 46,7 W | ± 0,8 W |

**Figure 10** **Collected results of converter No. 01A – ABB 1.1 kW**

The losses at 4.5 A, the defined "nominal" output current corresponding to a standard 1.1 kW 4-pole motor, shows very good agreement.

The statistics at this load point are as follows:

Mean value: **41.6** W with a standard deviation of **0.51** W

The averaged efficiency of the converter at this operating point was measured to **96.8%.**

For reference it should be noted that the testing standard for converters IEC 61800-9-2, edition 1 have a suggested reference IE1 loss for a 1.71 kVA unit (1.1 kW informative) of 163 W.

This would lead to a relative value of 41.6/163 ≈ 0.26.

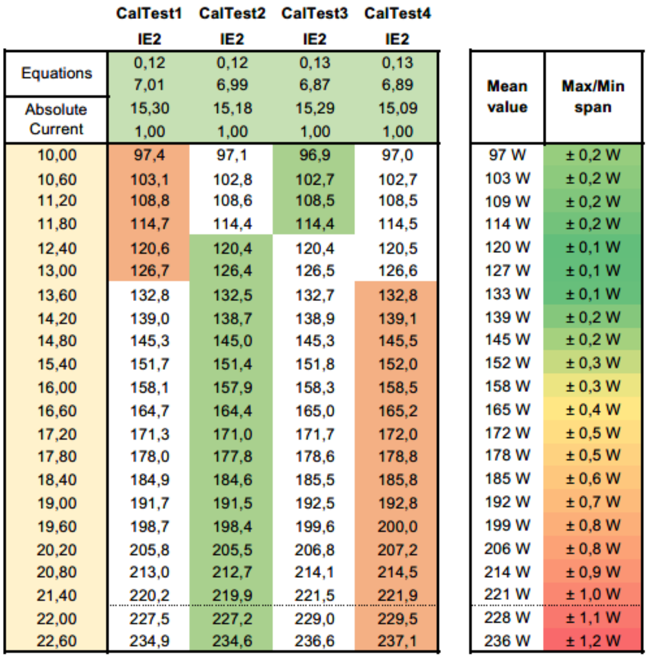
In the specific case with this converter, the reference becomes higher.
The calculated rated apparent power of this converter is: $S_R = \sqrt{3} \cdot U_R \cdot I_R = 1.73 \cdot 230 \cdot 4.5 = 1.793$ kVA.

The reference losses would then amount to 188 W corresponding to a relative value of 0.22.

### 3.2.2 Converter No. 01B: ABB 11 kW, nominal output 23.1 Amps – 3 phase supply

Below, in Figure 11, are the collected results of the tests performed on the ABB 11 kW converter No. 01B.

This converter was only measured by one of the participating labs (CalTest). It was measured on four different days using two different motors.



|  | CalTest1<br>IE2 | CalTest2<br>IE2 | CalTest3<br>IE2 | CalTest4<br>IE2 | Mean value | Max/Min span |
|---|---|---|---|---|---|---|
| Equations | 0,12 | 0,12 | 0,13 | 0,13 |  |  |
|  | 7,01 | 6,99 | 6,87 | 6,89 |  |  |
| Absolute Current | 15,30 | 15,18 | 15,29 | 15,09 |  |  |
|  | 1,00 | 1,00 | 1,00 | 1,00 |  |  |
| 10,00 | 97,4 | 97,1 | 96,9 | 97,0 | 97 W | ± 0,2 W |
| 10,60 | 103,1 | 102,8 | 102,7 | 102,7 | 103 W | ± 0,2 W |
| 11,20 | 108,8 | 108,6 | 108,5 | 108,5 | 109 W | ± 0,2 W |
| 11,80 | 114,7 | 114,4 | 114,4 | 114,5 | 114 W | ± 0,2 W |
| 12,40 | 120,6 | 120,4 | 120,4 | 120,5 | 120 W | ± 0,1 W |
| 13,00 | 126,7 | 126,4 | 126,5 | 126,6 | 127 W | ± 0,1 W |
| 13,60 | 132,8 | 132,5 | 132,7 | 132,8 | 133 W | ± 0,1 W |
| 14,20 | 139,0 | 138,7 | 138,9 | 139,1 | 139 W | ± 0,2 W |
| 14,80 | 145,3 | 145,0 | 145,3 | 145,5 | 145 W | ± 0,2 W |
| 15,40 | 151,7 | 151,4 | 151,8 | 152,0 | 152 W | ± 0,3 W |
| 16,00 | 158,1 | 157,9 | 158,3 | 158,5 | 158 W | ± 0,3 W |
| 16,60 | 164,7 | 164,4 | 165,0 | 165,2 | 165 W | ± 0,4 W |
| 17,20 | 171,3 | 171,0 | 171,7 | 172,0 | 172 W | ± 0,5 W |
| 17,80 | 178,0 | 177,8 | 178,6 | 178,8 | 178 W | ± 0,5 W |
| 18,40 | 184,9 | 184,6 | 185,5 | 185,8 | 185 W | ± 0,6 W |
| 19,00 | 191,7 | 191,5 | 192,5 | 192,8 | 192 W | ± 0,7 W |
| 19,60 | 198,7 | 198,4 | 199,6 | 200,0 | 199 W | ± 0,8 W |
| 20,20 | 205,8 | 205,5 | 206,8 | 207,2 | 206 W | ± 0,8 W |
| 20,80 | 213,0 | 212,7 | 214,1 | 214,5 | 214 W | ± 0,9 W |
| 21,40 | 220,2 | 219,9 | 221,5 | 221,9 | 221 W | ± 1,0 W |
| 22,00 | 227,5 | 227,2 | 229,0 | 229,5 | 228 W | ± 1,1 W |
| 22,60 | 234,9 | 234,6 | 236,6 | 237,1 | 236 W | ± 1,2 W |

**Figure 11** Collected results of converter No. 01B – ABB 11 kW

The losses at 21.4 A, the defined “nominal” output current corresponding to a standard 11 kW 4-pole motor, shows very good agreement.

The statistics at this load point are as follows:

Mean value: **221** W with a standard deviation of **0.86** W

The averaged efficiency of the converter at this operating point was measured to **98.2%.**

For reference it should be noted that the testing standard for converters IEC 61800-9-2, edition 1 have a suggested reference IE1 loss for a 14.4 kVA unit (11 kW informative) of 781 W.

This would lead to a relative value of 221/781 ≈ 0.28.

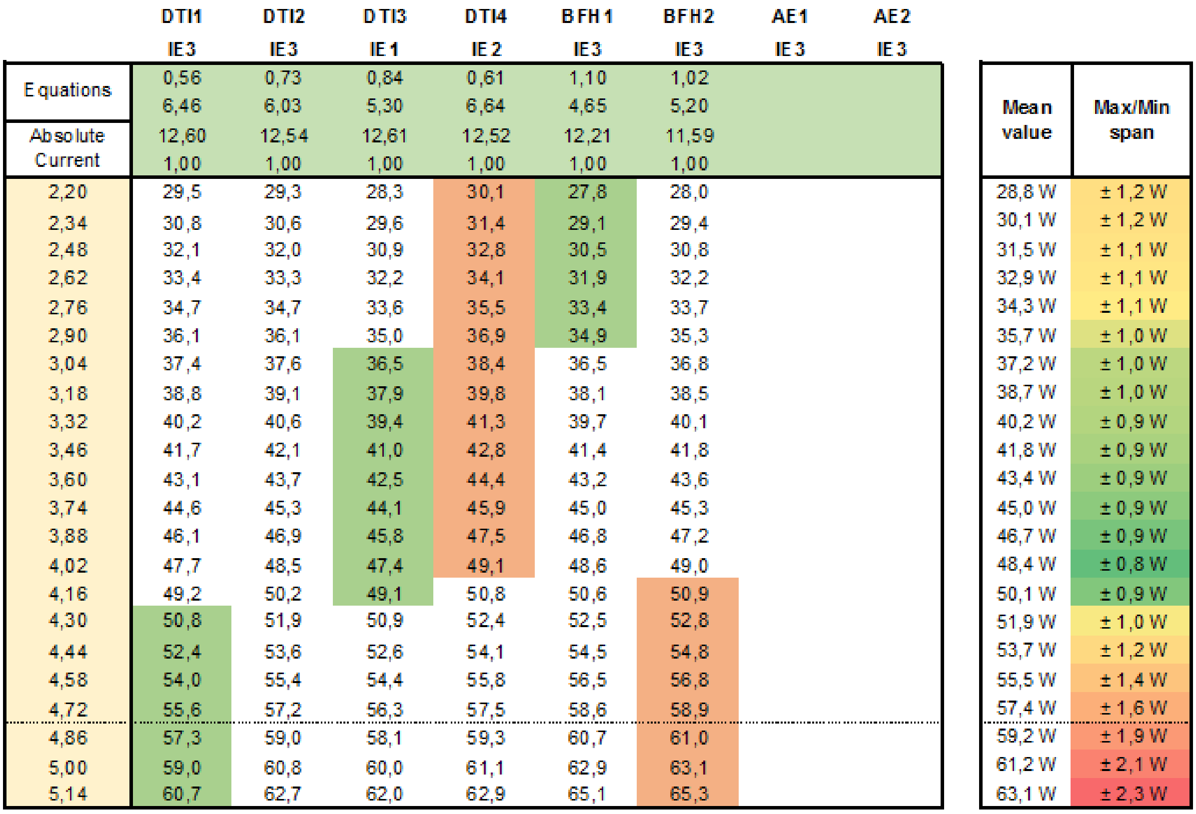
In the specific case with this converter, the reference becomes higher.
The calculated rated apparent power of this converter is: $S_R = \sqrt{3} \cdot U_R \cdot I_R = 1.73 \cdot 400 \cdot 21.4 = 14.8$ kVA.

The reference losses would then amount to 1.01 kW corresponding to a relative value of 0.22.

### 3.2.3 Converter No. 02A: Schneider 2.2 kW, nominal output 5.8 Amps – 3 phase supply

Below, in Figure 12, are the collected results of the tests performed by three labs on the Schneider 2.2 kW converter No. 02A.

The measurements from Advanced Energy have been removed, as the load motor used here was a 3.7 kW machine resulting in very high deviations.



| | DTI1 IE3 | DTI2 IE3 | DTI3 IE1 | DTI4 IE2 | BFH1 IE3 | BFH2 IE3 | AE1 IE3 | AE2 IE3 | Mean value | Max/Min span |
|---|---|---|---|---|---|---|---|---|---|---|
| Equations | 0,56 | 0,73 | 0,84 | 0,61 | 1,10 | 1,02 | | | | |
| | 6,46 | 6,03 | 5,30 | 6,64 | 4,65 | 5,20 | | | | |
| Absolute Current | 12,60 | 12,54 | 12,61 | 12,52 | 12,21 | 11,59 | | | | |
| | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 | | | | |
| 2,20 | 29,5 | 29,3 | 28,3 | 30,1 | 27,8 | 28,0 | | | 28,8 W | ± 1,2 W |
| 2,34 | 30,8 | 30,6 | 29,6 | 31,4 | 29,1 | 29,4 | | | 30,1 W | ± 1,2 W |
| 2,48 | 32,1 | 32,0 | 30,9 | 32,8 | 30,5 | 30,8 | | | 31,5 W | ± 1,1 W |
| 2,62 | 33,4 | 33,3 | 32,2 | 34,1 | 31,9 | 32,2 | | | 32,9 W | ± 1,1 W |
| 2,76 | 34,7 | 34,7 | 33,6 | 35,5 | 33,4 | 33,7 | | | 34,3 W | ± 1,1 W |
| 2,90 | 36,1 | 36,1 | 35,0 | 36,9 | 34,9 | 35,3 | | | 35,7 W | ± 1,0 W |
| 3,04 | 37,4 | 37,6 | 36,5 | 38,4 | 36,5 | 36,8 | | | 37,2 W | ± 1,0 W |
| 3,18 | 38,8 | 39,1 | 37,9 | 39,8 | 38,1 | 38,5 | | | 38,7 W | ± 1,0 W |
| 3,32 | 40,2 | 40,6 | 39,4 | 41,3 | 39,7 | 40,1 | | | 40,2 W | ± 0,9 W |
| 3,46 | 41,7 | 42,1 | 41,0 | 42,8 | 41,4 | 41,8 | | | 41,8 W | ± 0,9 W |
| 3,60 | 43,1 | 43,7 | 42,5 | 44,4 | 43,2 | 43,6 | | | 43,4 W | ± 0,9 W |
| 3,74 | 44,6 | 45,3 | 44,1 | 45,9 | 45,0 | 45,3 | | | 45,0 W | ± 0,9 W |
| 3,88 | 46,1 | 46,9 | 45,8 | 47,5 | 46,8 | 47,2 | | | 46,7 W | ± 0,9 W |
| 4,02 | 47,7 | 48,5 | 47,4 | 49,1 | 48,6 | 49,0 | | | 48,4 W | ± 0,8 W |
| 4,16 | 49,2 | 50,2 | 49,1 | 50,8 | 50,6 | 50,9 | | | 50,1 W | ± 0,9 W |
| 4,30 | 50,8 | 51,9 | 50,9 | 52,4 | 52,5 | 52,8 | | | 51,9 W | ± 1,0 W |
| 4,44 | 52,4 | 53,6 | 52,6 | 54,1 | 54,5 | 54,8 | | | 53,7 W | ± 1,2 W |
| 4,58 | 54,0 | 55,4 | 54,4 | 55,8 | 56,5 | 56,8 | | | 55,5 W | ± 1,4 W |
| 4,72 | 55,6 | 57,2 | 56,3 | 57,5 | 58,6 | 58,9 | | | 57,4 W | ± 1,6 W |
| 4,86 | 57,3 | 59,0 | 58,1 | 59,3 | 60,7 | 61,0 | | | 59,2 W | ± 1,9 W |
| 5,00 | 59,0 | 60,8 | 60,0 | 61,1 | 62,9 | 63,1 | | | 61,2 W | ± 2,1 W |
| 5,14 | 60,7 | 62,7 | 62,0 | 62,9 | 65,1 | 65,3 | | | 63,1 W | ± 2,3 W |

**Figure 12** Collected results of converter No. 02A – Schneider 2.2. kW

The losses at 4.75 A, the defined “nominal” output current corresponding to a standard 2.2 kW 4-pole motor, shows good agreement.

The statistics at this load point are as follows:

Mean value: **57.4** W with a standard deviation of **1.17** W

The averaged efficiency of the converter at this operating point was measured to **97.7%.**

For reference it should be noted that the testing standard for converters IEC 61800-9-2, edition 1 have a suggested reference IE1 loss for a 3.3 kVA unit (2.2 kW informative) of 237 W.

This would lead to a relative value of 57.4/237 ≈ 0.24.

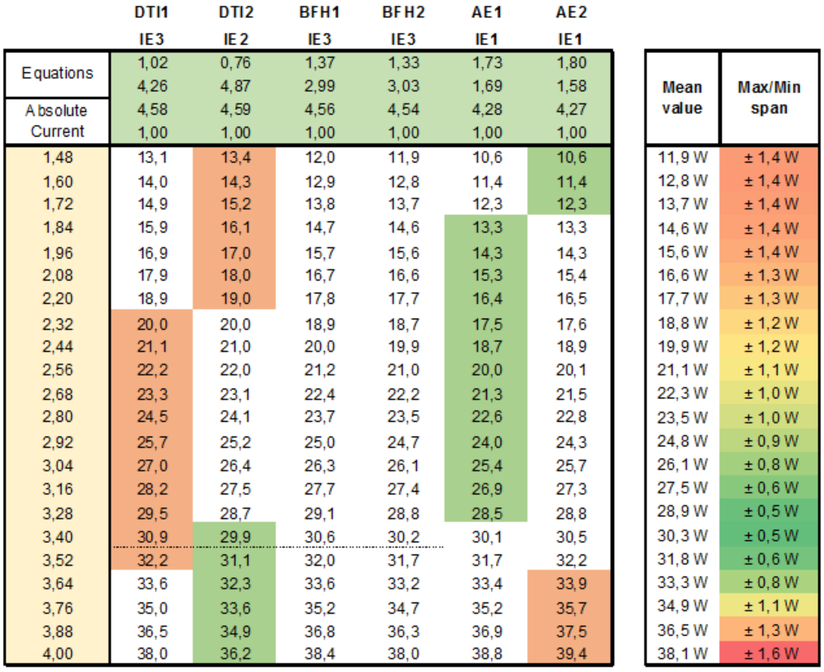
In the specific case with this converter, the UTP reference equals the reference suggested by IEC 61800-9-2, edition 1 although it is right on the limit:

The calculated rated apparent power of this converter is: $S_R = \sqrt{3} \cdot U_R \cdot I_R = 1.73 \cdot 400 \cdot 4.75 = 3.3$ kVA

### 3.2.4 Converter No. 02B: Parker 0.75 kW, nominal output 4.0 Amps – 1 phase supply

Below, in Figure 13, are the collected results of the tests performed by three labs on the Parker 0.75 kW converter No. 02B.

All measurements were made with 0.75 kW motors. In US with Advanced Energy the maximum measured current was 4.0 A, all others it was 3.4 A.



|  | DTI1 | DTI2 | BFH1 | BFH2 | AE1 | AE2 | Mean value | Max/Min span |
|---|---|---|---|---|---|---|---|---|
|  | IE3 | IE2 | IE3 | IE3 | IE1 | IE1 |  |  |
| Equations | 1,02 | 0,76 | 1,37 | 1,33 | 1,73 | 1,80 |  |  |
|  | 4,26 | 4,87 | 2,99 | 3,03 | 1,69 | 1,58 |  |  |
| Absolute Current | 4,58 | 4,59 | 4,56 | 4,54 | 4,28 | 4,27 |  |  |
|  | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 |  |  |
| 1,48 | 13,1 | 13,4 | 12,0 | 11,9 | 10,6 | 10,6 | 11,9 W | ± 1,4 W |
| 1,60 | 14,0 | 14,3 | 12,9 | 12,8 | 11,4 | 11,4 | 12,8 W | ± 1,4 W |
| 1,72 | 14,9 | 15,2 | 13,8 | 13,7 | 12,3 | 12,3 | 13,7 W | ± 1,4 W |
| 1,84 | 15,9 | 16,1 | 14,7 | 14,6 | 13,3 | 13,3 | 14,6 W | ± 1,4 W |
| 1,96 | 16,9 | 17,0 | 15,7 | 15,6 | 14,3 | 14,3 | 15,6 W | ± 1,4 W |
| 2,08 | 17,9 | 18,0 | 16,7 | 16,6 | 15,3 | 15,4 | 16,6 W | ± 1,3 W |
| 2,20 | 18,9 | 19,0 | 17,8 | 17,7 | 16,4 | 16,5 | 17,7 W | ± 1,3 W |
| 2,32 | 20,0 | 20,0 | 18,9 | 18,7 | 17,5 | 17,6 | 18,8 W | ± 1,2 W |
| 2,44 | 21,1 | 21,0 | 20,0 | 19,9 | 18,7 | 18,9 | 19,9 W | ± 1,2 W |
| 2,56 | 22,2 | 22,0 | 21,2 | 21,0 | 20,0 | 20,1 | 21,1 W | ± 1,1 W |
| 2,68 | 23,3 | 23,1 | 22,4 | 22,2 | 21,3 | 21,5 | 22,3 W | ± 1,0 W |
| 2,80 | 24,5 | 24,1 | 23,7 | 23,5 | 22,6 | 22,8 | 23,5 W | ± 1,0 W |
| 2,92 | 25,7 | 25,2 | 25,0 | 24,7 | 24,0 | 24,3 | 24,8 W | ± 0,9 W |
| 3,04 | 27,0 | 26,4 | 26,3 | 26,1 | 25,4 | 25,7 | 26,1 W | ± 0,8 W |
| 3,16 | 28,2 | 27,5 | 27,7 | 27,4 | 26,9 | 27,3 | 27,5 W | ± 0,6 W |
| 3,28 | 29,5 | 28,7 | 29,1 | 28,8 | 28,5 | 28,8 | 28,9 W | ± 0,5 W |
| 3,40 | 30,9 | 29,9 | 30,6 | 30,2 | 30,1 | 30,5 | 30,3 W | ± 0,5 W |
| 3,52 | 32,2 | 31,1 | 32,0 | 31,7 | 31,7 | 32,2 | 31,8 W | ± 0,6 W |
| 3,64 | 33,6 | 32,3 | 33,6 | 33,2 | 33,4 | 33,9 | 33,3 W | ± 0,8 W |
| 3,76 | 35,0 | 33,6 | 35,2 | 34,7 | 35,2 | 35,7 | 34,9 W | ± 1,1 W |
| 3,88 | 36,5 | 34,9 | 36,8 | 36,3 | 36,9 | 37,5 | 36,5 W | ± 1,3 W |
| 4,00 | 38,0 | 36,2 | 38,4 | 38,0 | 38,8 | 39,4 | 38,1 W | ± 1,6 W |

**Figure 13** **Collected results of converter No. 02B – Parker 0.75 kW**

The losses at 3.4 A, the defined “nominal” output current corresponding to a standard 0.75 kW 4-pole motor, shows very good agreement.

The statistics at this load point are as follows:

Mean value: **30.3** W with a standard deviation of **0.33** W

The averaged efficiency of the converter at this operating point was measured to **96.5%.**

For reference it should be noted that the testing standard for converters IEC 61800-9-2, edition 1 have a suggested reference IE1 loss for a 1.29 kVA unit (0.75 kW informative) of 142 W.

This would lead to a relative value of 30.3/142 ≈ 0.21.

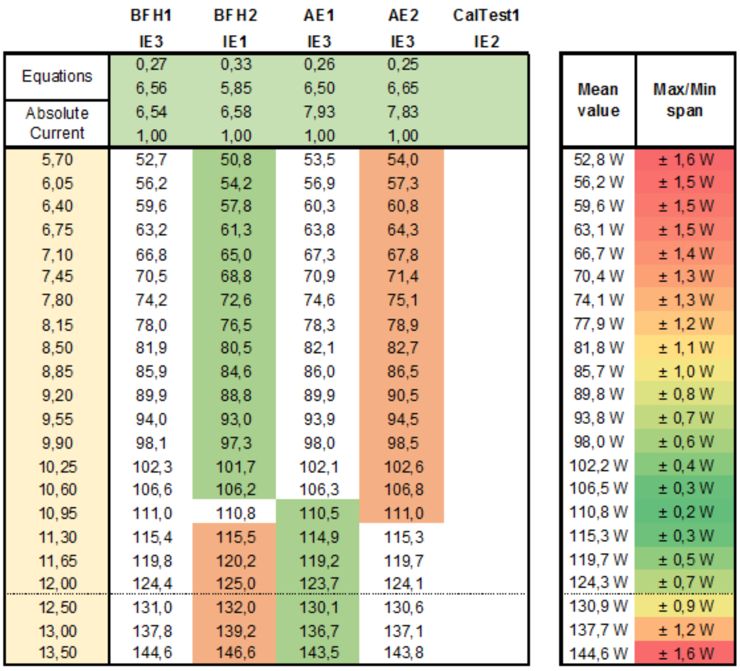
In the specific case with this converter, the reference becomes higher.
The calculated rated apparent power of this converter is: $S_R = \sqrt{3} \cdot U_R \cdot I_R = 1.73 \cdot 230 \cdot 3.4 = 1.354$ VA.

The reference losses would then amount to 163 W corresponding to a relative value of 0.19.

### 3.2.5 Converter No. 03A: Lenze 5.5 kW, nominal output 13 Amps – 3 phase supply

Below, in Figure 14, are the collected results of the tests performed by three labs on the Lenze 5.5 kW converter No. 03A.

The measurement from CalTest have been removed as this, for so far unexplainable reasons, resulted in very high deviation.



|  | BFH1 | BFH2 | AE1 | AE2 | CalTest1 | Mean value | Max/Min span |
|---|---|---|---|---|---|---|---|
|  | IE3 | IE1 | IE3 | IE3 | IE2 |  |  |
| Equations | 0,27 | 0,33 | 0,26 | 0,25 |  |  |  |
|  | 6,56 | 5,85 | 6,50 | 6,65 |  |  |  |
| Absolute Current | 6,54 | 6,58 | 7,93 | 7,83 |  |  |  |
|  | 1,00 | 1,00 | 1,00 | 1,00 |  |  |  |
| 5,70 | 52,7 | 50,8 | 53,5 | 54,0 |  | 52,8 W | ± 1,6 W |
| 6,05 | 56,2 | 54,2 | 56,9 | 57,3 |  | 56,2 W | ± 1,5 W |
| 6,40 | 59,6 | 57,8 | 60,3 | 60,8 |  | 59,6 W | ± 1,5 W |
| 6,75 | 63,2 | 61,3 | 63,8 | 64,3 |  | 63,1 W | ± 1,5 W |
| 7,10 | 66,8 | 65,0 | 67,3 | 67,8 |  | 66,7 W | ± 1,4 W |
| 7,45 | 70,5 | 68,8 | 70,9 | 71,4 |  | 70,4 W | ± 1,3 W |
| 7,80 | 74,2 | 72,6 | 74,6 | 75,1 |  | 74,1 W | ± 1,3 W |
| 8,15 | 78,0 | 76,5 | 78,3 | 78,9 |  | 77,9 W | ± 1,2 W |
| 8,50 | 81,9 | 80,5 | 82,1 | 82,7 |  | 81,8 W | ± 1,1 W |
| 8,85 | 85,9 | 84,6 | 86,0 | 86,5 |  | 85,7 W | ± 1,0 W |
| 9,20 | 89,9 | 88,8 | 89,9 | 90,5 |  | 89,8 W | ± 0,8 W |
| 9,55 | 94,0 | 93,0 | 93,9 | 94,5 |  | 93,8 W | ± 0,7 W |
| 9,90 | 98,1 | 97,3 | 98,0 | 98,5 |  | 98,0 W | ± 0,6 W |
| 10,25 | 102,3 | 101,7 | 102,1 | 102,6 |  | 102,2 W | ± 0,4 W |
| 10,60 | 106,6 | 106,2 | 106,3 | 106,8 |  | 106,5 W | ± 0,3 W |
| 10,95 | 111,0 | 110,8 | 110,5 | 111,0 |  | 110,8 W | ± 0,2 W |
| 11,30 | 115,4 | 115,5 | 114,9 | 115,3 |  | 115,3 W | ± 0,3 W |
| 11,65 | 119,8 | 120,2 | 119,2 | 119,7 |  | 119,7 W | ± 0,5 W |
| 12,00 | 124,4 | 125,0 | 123,7 | 124,1 |  | 124,3 W | ± 0,7 W |
| 12,50 | 131,0 | 132,0 | 130,1 | 130,6 |  | 130,9 W | ± 0,9 W |
| 13,00 | 137,8 | 139,2 | 136,7 | 137,1 |  | 137,7 W | ± 1,2 W |
| 13,50 | 144,6 | 146,6 | 143,5 | 143,8 |  | 144,6 W | ± 1,6 W |

**Figure 14** **Collected results of converter No. 03A – Lenze 5.5 kW**

The losses at 12 A, the defined “nominal” output current corresponding to a standard 5.5 kW 4-pole motor, shows very high agreement.

The statistics at this load point are as follows:

Mean value: **124.3** W with a standard deviation of **0.48** W

The averaged efficiency of the converter at this operating point was measured to **98.0%.**

For reference it should be noted that the testing standard for converters IEC 61800-9-2, edition 1 have a suggested reference IE1 loss for a 7.94 kVA unit (5.5 kW informative) of 477 W.

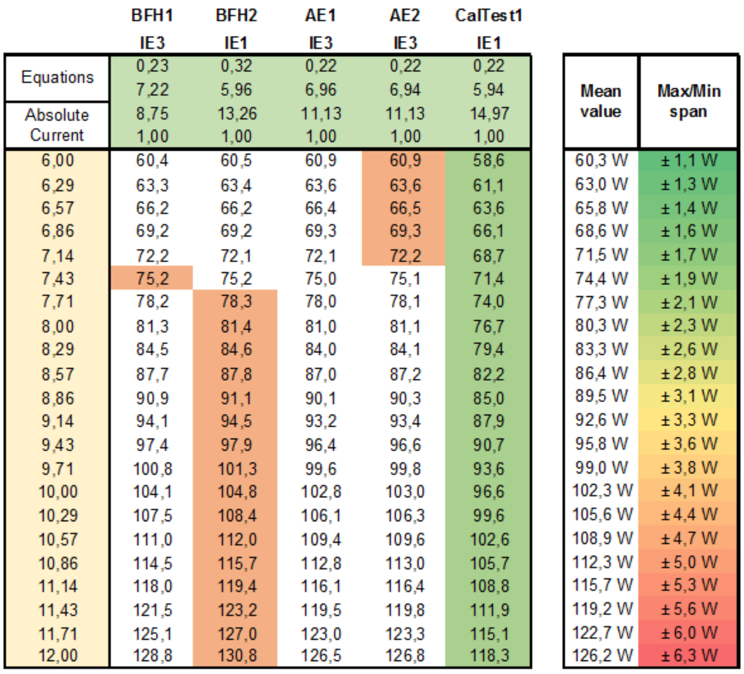
This would lead to a relative value of 124.3/477 ≈ 0.26.

In the specific case with this converter, the reference becomes even higher.
The calculated rated apparent power of this converter is: $S_R = \sqrt{3} \cdot U_R \cdot I_R = 1.73 \cdot 400 \cdot 12 = 8.31$ kVA.

The reference losses would then amount to 581 W corresponding to a relative value of 0.21.

### 3.2.6 Converter No. 03B: ABB 5.5 kW, nominal output 12 Amps – 3 phase supply

Below, in Figure 15, are the collected results of the tests performed by three labs on the ABB 5.5 kW converter No. 03B.



| | BFH1 IE3 | BFH2 IE1 | AE1 IE3 | AE2 IE3 | CalTest1 IE1 | Mean value | Max/Min span |
|---|---|---|---|---|---|---|---|
| Equations | 0,23 | 0,32 | 0,22 | 0,22 | 0,22 | | |
| | 7,22 | 5,96 | 6,96 | 6,94 | 5,94 | | |
| Absolute Current | 8,75 | 13,26 | 11,13 | 11,13 | 14,97 | | |
| | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 | | |
| 6,00 | 60,4 | 60,5 | 60,9 | 60,9 | 58,6 | 60,3 W | ± 1,1 W |
| 6,29 | 63,3 | 63,4 | 63,6 | 63,6 | 61,1 | 63,0 W | ± 1,3 W |
| 6,57 | 66,2 | 66,2 | 66,4 | 66,5 | 63,6 | 65,8 W | ± 1,4 W |
| 6,86 | 69,2 | 69,2 | 69,3 | 69,3 | 66,1 | 68,6 W | ± 1,6 W |
| 7,14 | 72,2 | 72,1 | 72,1 | 72,2 | 68,7 | 71,5 W | ± 1,7 W |
| 7,43 | 75,2 | 75,2 | 75,0 | 75,1 | 71,4 | 74,4 W | ± 1,9 W |
| 7,71 | 78,2 | 78,3 | 78,0 | 78,1 | 74,0 | 77,3 W | ± 2,1 W |
| 8,00 | 81,3 | 81,4 | 81,0 | 81,1 | 76,7 | 80,3 W | ± 2,3 W |
| 8,29 | 84,5 | 84,6 | 84,0 | 84,1 | 79,4 | 83,3 W | ± 2,6 W |
| 8,57 | 87,7 | 87,8 | 87,0 | 87,2 | 82,2 | 86,4 W | ± 2,8 W |
| 8,86 | 90,9 | 91,1 | 90,1 | 90,3 | 85,0 | 89,5 W | ± 3,1 W |
| 9,14 | 94,1 | 94,5 | 93,2 | 93,4 | 87,9 | 92,6 W | ± 3,3 W |
| 9,43 | 97,4 | 97,9 | 96,4 | 96,6 | 90,7 | 95,8 W | ± 3,6 W |
| 9,71 | 100,8 | 101,3 | 99,6 | 99,8 | 93,6 | 99,0 W | ± 3,8 W |
| 10,00 | 104,1 | 104,8 | 102,8 | 103,0 | 96,6 | 102,3 W | ± 4,1 W |
| 10,29 | 107,5 | 108,4 | 106,1 | 106,3 | 99,6 | 105,6 W | ± 4,4 W |
| 10,57 | 111,0 | 112,0 | 109,4 | 109,6 | 102,6 | 108,9 W | ± 4,7 W |
| 10,86 | 114,5 | 115,7 | 112,8 | 113,0 | 105,7 | 112,3 W | ± 5,0 W |
| 11,14 | 118,0 | 119,4 | 116,1 | 116,4 | 108,8 | 115,7 W | ± 5,3 W |
| 11,43 | 121,5 | 123,2 | 119,5 | 119,8 | 111,9 | 119,2 W | ± 5,6 W |
| 11,71 | 125,1 | 127,0 | 123,0 | 123,3 | 115,1 | 122,7 W | ± 6,0 W |
| 12,00 | 128,8 | 130,8 | 126,5 | 126,8 | 118,3 | 126,2 W | ± 6,3 W |

**Figure 15 Collected results of converter No. 03B – ABB 5.5 kW**

The losses at 12 A, the defined “nominal” output current corresponding to a standard 5.5 kW 4-pole motor, shows good agreement between four of the measurements. The CalTest measurement are distinctly lower than the others.

The statistics at this load point are as follows:

Mean value: **126.2** W with a standard deviation of **4.3** W

The averaged efficiency of the converter at this operating point was measured to **98.1%.**

For reference it should be noted that the testing standard for converters IEC 61800-9-2, edition 1 have a suggested reference IE1 loss for a 7.94 kVA unit (5.5 kW informative) of 477 W.

This would lead to a relative value of 124.7/477 ≈ 0.26

In the specific case with this converter, the reference becomes even higher.
The calculated rated apparent power of this converter is: $S_R = \sqrt{3} \cdot U_R \cdot I_R = 1.73 \cdot 400 \cdot 12 = 8.31$ kVA.

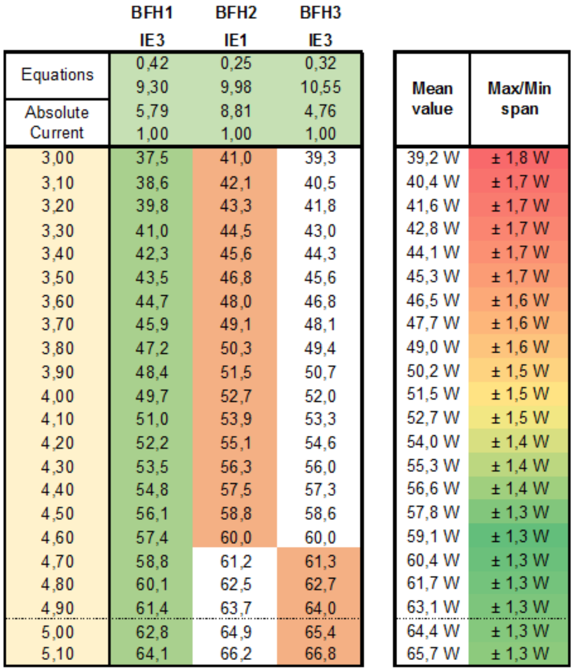
The reference losses would then amount to 581 W corresponding to a relative value of 0.21.

It’s worth noting that this 5.5 kW converter has been measured to the exact same losses as 03A.

### 3.2.7 Converter No. 03C: ABB 2.2 kW, nominal output 5.3 Amps – 3 phase supply

Below, in Figure 16, are the collected results of the tests performed on the ABB 2.2 kW converter No. 03C.

This converter was only measured in Switzerland by BFH.



|  | BFH1 | BFH2 | BFH3 | Mean value | Max/Min span |
|---|---|---|---|---|---|
|  | IE3 | IE1 | IE3 |  |  |
| Equations | 0,42 | 0,25 | 0,32 |  |  |
|  | 9,30 | 9,98 | 10,55 |  |  |
| Absolute Current | 5,79 | 8,81 | 4,76 |  |  |
|  | 1,00 | 1,00 | 1,00 |  |  |
| 3,00 | 37,5 | 41,0 | 39,3 | 39,2 W | ± 1,8 W |
| 3,10 | 38,6 | 42,1 | 40,5 | 40,4 W | ± 1,7 W |
| 3,20 | 39,8 | 43,3 | 41,8 | 41,6 W | ± 1,7 W |
| 3,30 | 41,0 | 44,5 | 43,0 | 42,8 W | ± 1,7 W |
| 3,40 | 42,3 | 45,6 | 44,3 | 44,1 W | ± 1,7 W |
| 3,50 | 43,5 | 46,8 | 45,6 | 45,3 W | ± 1,7 W |
| 3,60 | 44,7 | 48,0 | 46,8 | 46,5 W | ± 1,6 W |
| 3,70 | 45,9 | 49,1 | 48,1 | 47,7 W | ± 1,6 W |
| 3,80 | 47,2 | 50,3 | 49,4 | 49,0 W | ± 1,6 W |
| 3,90 | 48,4 | 51,5 | 50,7 | 50,2 W | ± 1,5 W |
| 4,00 | 49,7 | 52,7 | 52,0 | 51,5 W | ± 1,5 W |
| 4,10 | 51,0 | 53,9 | 53,3 | 52,7 W | ± 1,5 W |
| 4,20 | 52,2 | 55,1 | 54,6 | 54,0 W | ± 1,4 W |
| 4,30 | 53,5 | 56,3 | 56,0 | 55,3 W | ± 1,4 W |
| 4,40 | 54,8 | 57,5 | 57,3 | 56,6 W | ± 1,4 W |
| 4,50 | 56,1 | 58,8 | 58,6 | 57,8 W | ± 1,3 W |
| 4,60 | 57,4 | 60,0 | 60,0 | 59,1 W | ± 1,3 W |
| 4,70 | 58,8 | 61,2 | 61,3 | 60,4 W | ± 1,3 W |
| 4,80 | 60,1 | 62,5 | 62,7 | 61,7 W | ± 1,3 W |
| 4,90 | 61,4 | 63,7 | 64,0 | 63,1 W | ± 1,3 W |
| 5,00 | 62,8 | 64,9 | 65,4 | 64,4 W | ± 1,3 W |
| 5,10 | 64,1 | 66,2 | 66,8 | 65,7 W | ± 1,3 W |

**Figure 16 Collected results of converter No. 03C – ABB 2.2 kW**

The losses at 4.9 A, the defined “nominal” output current corresponding to a standard 2.2 kW 4-pole motor, show very good agreement. The first measurement was lower than the others.

The statistics at this load point are as follows:

Mean value: **63.1** W with a standard deviation of **1.16** W

The averaged efficiency of the converter at this operating point was measured to **97.5%.**

For reference it should be noted that the testing standard for converters IEC 61800-9-2, edition 1 have a suggested reference IE1 loss for a 3.3 kVA unit (2.2 kW informative) of 237 W.

This would lead to a relative value of 63.1/237 ≈ 0.27.

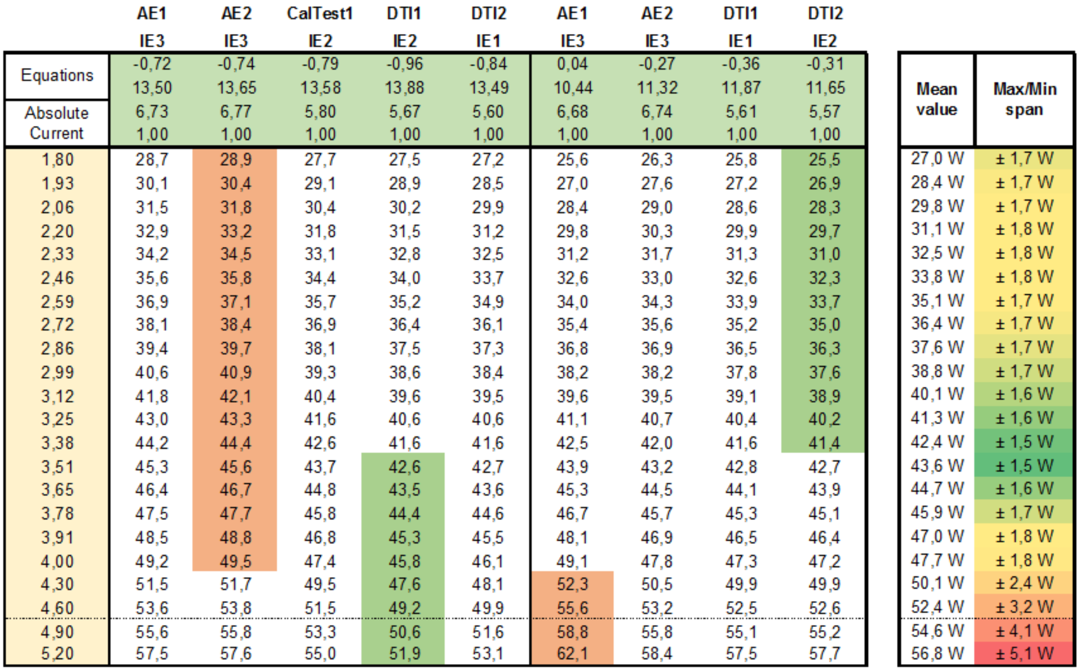
In the specific case with this converter, the reference becomes even higher.
The calculated rated apparent power of this converter is: $S_R = \sqrt{3}\cdot U_R\cdot I_R = 1.73\cdot 400\cdot 4.9 = 3.39$ kVA.

The reference losses would then amount to 299 W corresponding to a relative value of 0.21.

### 3.2.8 Converter No. 04A: Schneider 2.2 kW, nominal output 5.1 Amps – 3 phase supply

Below, in Figure 17, are the collected results of the tests performed by four labs on the Schneider 2.2 kW converter No. 04A.

This converter was tested both at 3.91 A and 5.1 A nominal using different load motors.



| | AE1<br>IE3 | AE2<br>IE3 | CalTest1<br>IE2 | DTI1<br>IE2 | DTI2<br>IE1 | AE1<br>IE3 | AE2<br>IE3 | DTI1<br>IE1 | DTI2<br>IE2 | Mean value | Max/Min span |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Equations | -0,72 | -0,74 | -0,79 | -0,96 | -0,84 | 0,04 | -0,27 | -0,36 | -0,31 | | |
| | 13,50 | 13,65 | 13,58 | 13,88 | 13,49 | 10,44 | 11,32 | 11,87 | 11,65 | | |
| Absolute Current | 6,73 | 6,77 | 5,80 | 5,67 | 5,60 | 6,68 | 6,74 | 5,61 | 5,57 | | |
| | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 | | |
| 1,80 | 28,7 | 28,9 | 27,7 | 27,5 | 27,2 | 25,6 | 26,3 | 25,8 | 25,5 | 27,0 W | ± 1,7 W |
| 1,93 | 30,1 | 30,4 | 29,1 | 28,9 | 28,5 | 27,0 | 27,6 | 27,2 | 26,9 | 28,4 W | ± 1,7 W |
| 2,06 | 31,5 | 31,8 | 30,4 | 30,2 | 29,9 | 28,4 | 29,0 | 28,6 | 28,3 | 29,8 W | ± 1,7 W |
| 2,20 | 32,9 | 33,2 | 31,8 | 31,5 | 31,2 | 29,8 | 30,3 | 29,9 | 29,7 | 31,1 W | ± 1,8 W |
| 2,33 | 34,2 | 34,5 | 33,1 | 32,8 | 32,5 | 31,2 | 31,7 | 31,3 | 31,0 | 32,5 W | ± 1,8 W |
| 2,46 | 35,6 | 35,8 | 34,4 | 34,0 | 33,7 | 32,6 | 33,0 | 32,6 | 32,3 | 33,8 W | ± 1,8 W |
| 2,59 | 36,9 | 37,1 | 35,7 | 35,2 | 34,9 | 34,0 | 34,3 | 33,9 | 33,7 | 35,1 W | ± 1,7 W |
| 2,72 | 38,1 | 38,4 | 36,9 | 36,4 | 36,1 | 35,4 | 35,6 | 35,2 | 35,0 | 36,4 W | ± 1,7 W |
| 2,86 | 39,4 | 39,7 | 38,1 | 37,5 | 37,3 | 36,8 | 36,9 | 36,5 | 36,3 | 37,6 W | ± 1,7 W |
| 2,99 | 40,6 | 40,9 | 39,3 | 38,6 | 38,4 | 38,2 | 38,2 | 37,8 | 37,6 | 38,8 W | ± 1,7 W |
| 3,12 | 41,8 | 42,1 | 40,4 | 39,6 | 39,5 | 39,6 | 39,5 | 39,1 | 38,9 | 40,1 W | ± 1,6 W |
| 3,25 | 43,0 | 43,3 | 41,6 | 40,6 | 40,6 | 41,1 | 40,7 | 40,4 | 40,2 | 41,3 W | ± 1,6 W |
| 3,38 | 44,2 | 44,4 | 42,6 | 41,6 | 41,6 | 42,5 | 42,0 | 41,6 | 41,4 | 42,4 W | ± 1,5 W |
| 3,51 | 45,3 | 45,6 | 43,7 | 42,6 | 42,7 | 43,9 | 43,2 | 42,8 | 42,7 | 43,6 W | ± 1,5 W |
| 3,65 | 46,4 | 46,7 | 44,8 | 43,5 | 43,6 | 45,3 | 44,5 | 44,1 | 43,9 | 44,7 W | ± 1,6 W |
| 3,78 | 47,5 | 47,7 | 45,8 | 44,4 | 44,6 | 46,7 | 45,7 | 45,3 | 45,1 | 45,9 W | ± 1,7 W |
| 3,91 | 48,5 | 48,8 | 46,8 | 45,3 | 45,5 | 48,1 | 46,9 | 46,5 | 46,4 | 47,0 W | ± 1,8 W |
| 4,00 | 49,2 | 49,5 | 47,4 | 45,8 | 46,1 | 49,1 | 47,8 | 47,3 | 47,2 | 47,7 W | ± 1,8 W |
| 4,30 | 51,5 | 51,7 | 49,5 | 47,6 | 48,1 | 52,3 | 50,5 | 49,9 | 49,9 | 50,1 W | ± 2,4 W |
| 4,60 | 53,6 | 53,8 | 51,5 | 49,2 | 49,9 | 55,6 | 53,2 | 52,5 | 52,6 | 52,4 W | ± 3,2 W |
| 4,90 | 55,6 | 55,8 | 53,3 | 50,6 | 51,6 | 58,8 | 55,8 | 55,1 | 55,2 | 54,6 W | ± 4,1 W |
| 5,20 | 57,5 | 57,6 | 55,0 | 51,9 | 53,1 | 62,1 | 58,4 | 57,5 | 57,7 | 56,8 W | ± 5,1 W |

**Figure 17 Collected results of converter No. 04A – Schneider 2.2 kW**

The losses at 4.6 A, the defined "nominal" output current corresponding to a standard 2.2 kW 4-pole motor, shows very good agreement.

The statistics at this load point are as follows:

Mean value: **52.4** W with a standard deviation of **1.87** W

The averaged efficiency of the converter at this operating point was measured to **98.0%.**

For reference it should be noted that the testing standard for converters IEC 61800-9-2, edition 1 have a suggested reference IE1 loss for a 3.3 kVA unit (2.2 kW informative) of 237 W.

This would lead to a relative value of 52.4/237 ≈ 0.22.

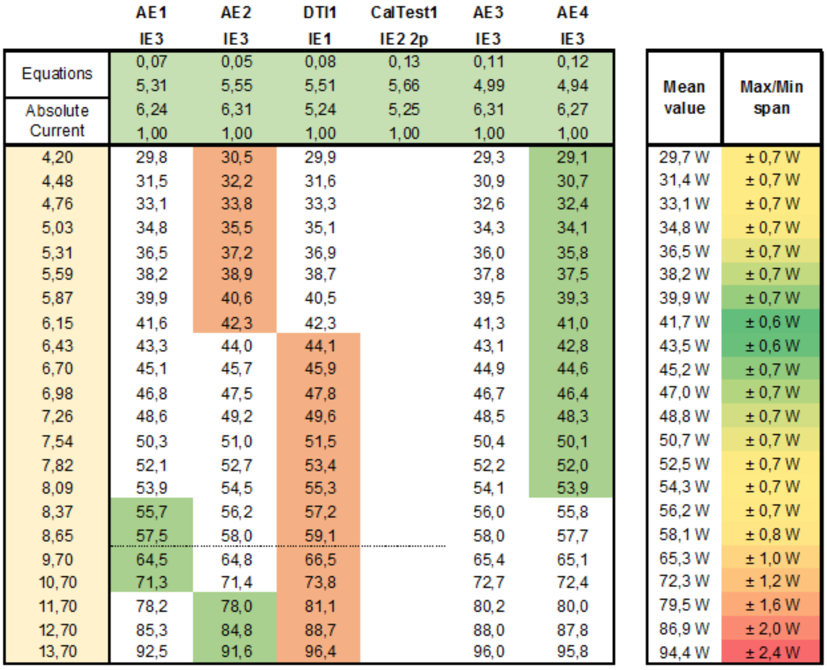
In the specific case with this converter, the reference becomes even higher.
The calculated rated apparent power of this converter is: $S_R = \sqrt{3} \cdot U_R \cdot I_R = 1.73 \cdot 460 \cdot 4.6 = 3.66$ kVA.

The reference losses would then amount to 299 W corresponding to a relative value of 0.18.

### 3.2.9 Converter No. 04B: Schneider 3.0 kW, nominal output 13.7 Amps – 3 phase supply

Below, in Figure 18, are the collected results of the tests performed by three labs on the Schneider 3.0 kW converter No. 04B.

This converter was tested by three labs both at 8.65 A and 13.7 A nominal using different load motors. The measurement from CalTest have been removed, as the load motor used here was a 2-pole machine resulting in very high deviations.



| | AE1 | AE2 | DTI1 | CalTest1 | AE3 | AE4 | Mean value | Max/Min span |
|---|---|---|---|---|---|---|---|---|
| | IE3 | IE3 | IE1 | IE2 2p | IE3 | IE3 | | |
| Equations | 0,07 | 0,05 | 0,08 | 0,13 | 0,11 | 0,12 | | |
| | 5,31 | 5,55 | 5,51 | 5,66 | 4,99 | 4,94 | | |
| Absolute Current | 6,24 | 6,31 | 5,24 | 5,25 | 6,31 | 6,27 | | |
| | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 | 1,00 | | |
| 4,20 | 29,8 | 30,5 | 29,9 | | 29,3 | 29,1 | 29,7 W | ± 0,7 W |
| 4,48 | 31,5 | 32,2 | 31,6 | | 30,9 | 30,7 | 31,4 W | ± 0,7 W |
| 4,76 | 33,1 | 33,8 | 33,3 | | 32,6 | 32,4 | 33,1 W | ± 0,7 W |
| 5,03 | 34,8 | 35,5 | 35,1 | | 34,3 | 34,1 | 34,8 W | ± 0,7 W |
| 5,31 | 36,5 | 37,2 | 36,9 | | 36,0 | 35,8 | 36,5 W | ± 0,7 W |
| 5,59 | 38,2 | 38,9 | 38,7 | | 37,8 | 37,5 | 38,2 W | ± 0,7 W |
| 5,87 | 39,9 | 40,6 | 40,5 | | 39,5 | 39,3 | 39,9 W | ± 0,7 W |
| 6,15 | 41,6 | 42,3 | 42,3 | | 41,3 | 41,0 | 41,7 W | ± 0,6 W |
| 6,43 | 43,3 | 44,0 | 44,1 | | 43,1 | 42,8 | 43,5 W | ± 0,6 W |
| 6,70 | 45,1 | 45,7 | 45,9 | | 44,9 | 44,6 | 45,2 W | ± 0,7 W |
| 6,98 | 46,8 | 47,5 | 47,8 | | 46,7 | 46,4 | 47,0 W | ± 0,7 W |
| 7,26 | 48,6 | 49,2 | 49,6 | | 48,5 | 48,3 | 48,8 W | ± 0,7 W |
| 7,54 | 50,3 | 51,0 | 51,5 | | 50,4 | 50,1 | 50,7 W | ± 0,7 W |
| 7,82 | 52,1 | 52,7 | 53,4 | | 52,2 | 52,0 | 52,5 W | ± 0,7 W |
| 8,09 | 53,9 | 54,5 | 55,3 | | 54,1 | 53,9 | 54,3 W | ± 0,7 W |
| 8,37 | 55,7 | 56,2 | 57,2 | | 56,0 | 55,8 | 56,2 W | ± 0,7 W |
| 8,65 | 57,5 | 58,0 | 59,1 | | 58,0 | 57,7 | 58,1 W | ± 0,8 W |
| 9,70 | 64,5 | 64,8 | 66,5 | | 65,4 | 65,1 | 65,3 W | ± 1,0 W |
| 10,70 | 71,3 | 71,4 | 73,8 | | 72,7 | 72,4 | 72,3 W | ± 1,2 W |
| 11,70 | 78,2 | 78,0 | 81,1 | | 80,2 | 80,0 | 79,5 W | ± 1,6 W |
| 12,70 | 85,3 | 84,8 | 88,7 | | 88,0 | 87,8 | 86,9 W | ± 2,0 W |
| 13,70 | 92,5 | 91,6 | 96,4 | | 96,0 | 95,8 | 94,4 W | ± 2,4 W |

**Figure 18** Collected results of converter No. 04B – Schneider 3.0 kW

The losses at 8.65 A, the defined “nominal” output current corresponding to a standard 3.0 kW 4-pole motor, shows very good agreement.

The statistics at this load point are as follows:

Mean value: **58.1** W with a standard deviation of **0.56** W

The averaged efficiency of the converter at this operating point was measured to **97.5%.**

For reference it should be noted that the testing standard for converters IEC 61800-9-2, edition 1 have a suggested reference IE1 loss for a 4.44 kVA unit (3.0 kW informative) of 299 W.

This would lead to a relative value of 58.1/299 ≈ 0.19.

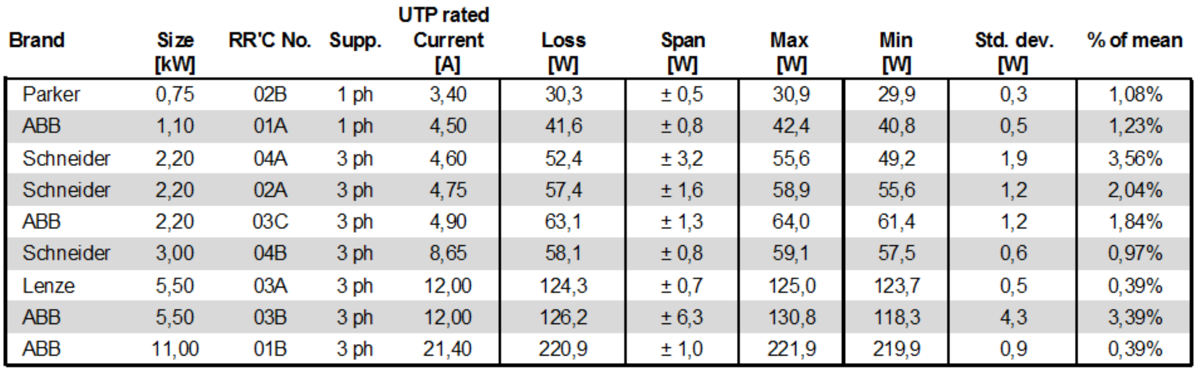
In the specific case with this converter, the reference becomes lower.
The calculated rated apparent power of this converter is: $S_R = \sqrt{3} \cdot U_R \cdot I_R = 1.73 \cdot 208 \cdot 8.65 = 3.12$ kVA.

The reference losses would then amount to 237 W corresponding to a relative value of 0.25.

## 3.3 Consolidated results for the 9 converters together

### 3.3.1 Tabled overview of tests with UTP in phase 1

When compiling all the test results above, the table in Figure 19 is generated. The table is sorted by UTP defined output current which in most cases are much lower than the nominal output current on the nameplate of the converters respectively.



| 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% |

**Figure 19** **Overview of phase 1 test results**

The results show very good repeatability in most cases. Only two examples show a standard deviation that differs significantly from the others.

For the worst case, converter No. 04A - the standard deviation constitutes 3.56% of the mean value. In this case the converter was measured several times as both 3.91 A & 5.1 A UTP nominal output current and the statistical presentation above includes therefore both extrapolation as well as 50/60 Hz frequency testing. Considering this, the result is acceptable. It is more than likely that if one agreed output current had been present (as planned in forthcoming UTP version), the result would have been with a much smaller standard deviation.

In the case of converter No. 03B there is, at this point, no plausible explanation for the deviation. The converter has been tested five times with four different motors in three different labs. Four of the test results agree smoothly and one of the tests shows significantly lower losses hence the high standard deviation. Should this test be excluded in the statistics, the new calculated standard deviation based on four labs instead would be 1.68 W (1.35%). There is, however, no plausible reason for this at this point in time. The UTP phase 2 shall include further testing of this device to enlighten the issues with this device.

In conclusion the repeatability and reproducibility of the 58 tests performed in four laboratories using 24 different motors in efficiency classes of IE1, IE2 and IE3 from 13 different manufacturers are remarkable. Even across 50 & 60 Hz supply worlds the results agree impressively.

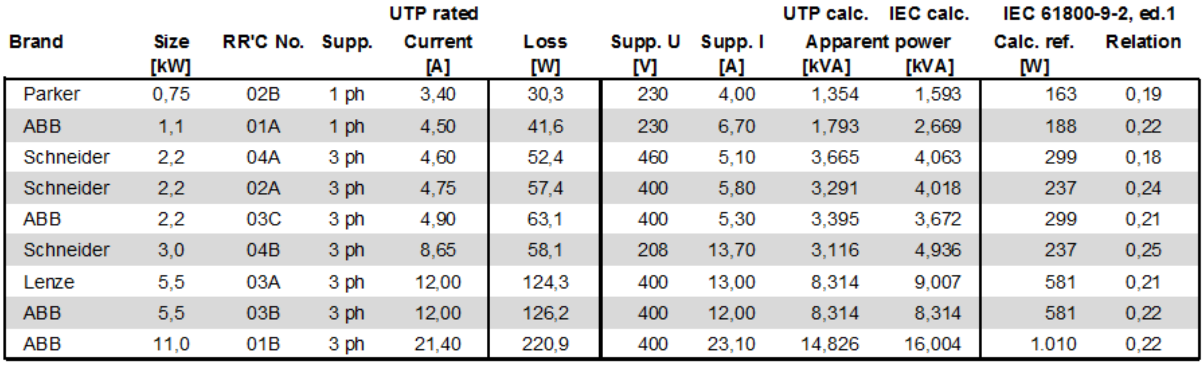
### 3.3.2 Relation to current values of nominal losses in IEC 61800-9-2, edition 1

When comparing the losses of the measured converters to the reference losses in the current IEC 61800-9-2, edition 1 standard, a clear tendency emerges. All of the tested converters were measured at losses less than one third of the reference losses.

The first table below, Figure 20, shows the calculated UTP kVA values using the UTP defined output currents, which is used to find the related kW losses for an IE1 reference.

The relation in the last column express the IE level (IE1 > 0.75; IE2 < 0.75).

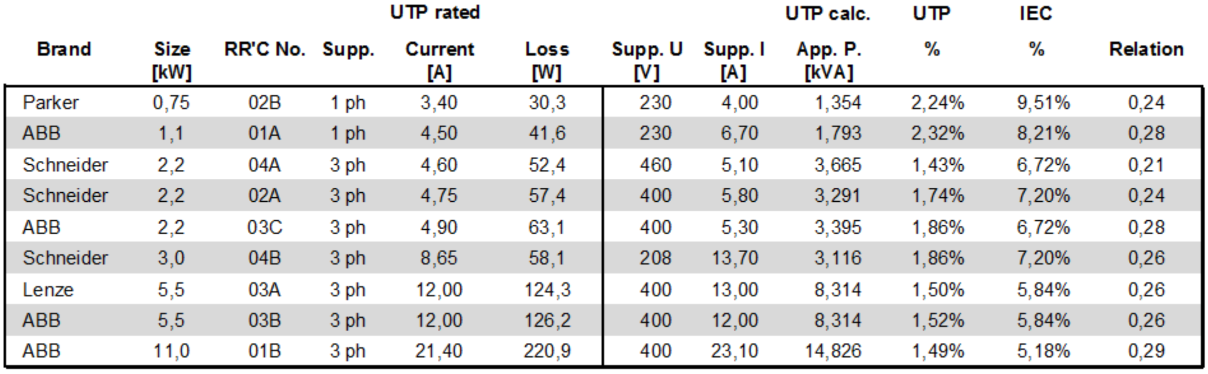
In this case it is calculated in absolute W values:



| 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] | IEC 61800-9-2, ed.1 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 |

**Figure 20** Comparing measured losses to reference W vs. W

Following the methodology of the IEC 61800-9-2, edition 1 this evaluation is to be performed in relative loss values. When applying this to Figure 20 above the result in Figure 21 becomes equally clear although a fraction higher in absolute values:



| Brand | Size [kW] | RR'C No. | Supp. | UTP rated Current [A] | Loss [W] | Supp. U [V] | Supp. I [A] | UTP calc. App. P. [kVA] | UTP % | IEC % | Relation |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Parker | 0,75 | 02B | 1 ph | 3,40 | 30,3 | 230 | 4,00 | 1,354 | 2,24% | 9,51% | 0,24 |
| ABB | 1,1 | 01A | 1 ph | 4,50 | 41,6 | 230 | 6,70 | 1,793 | 2,32% | 8,21% | 0,28 |
| Schneider | 2,2 | 04A | 3 ph | 4,60 | 52,4 | 460 | 5,10 | 3,665 | 1,43% | 6,72% | 0,21 |
| Schneider | 2,2 | 02A | 3 ph | 4,75 | 57,4 | 400 | 5,80 | 3,291 | 1,74% | 7,20% | 0,24 |
| ABB | 2,2 | 03C | 3 ph | 4,90 | 63,1 | 400 | 5,30 | 3,395 | 1,86% | 6,72% | 0,28 |
| Schneider | 3,0 | 04B | 3 ph | 8,65 | 58,1 | 208 | 13,70 | 3,116 | 1,86% | 7,20% | 0,26 |
| Lenze | 5,5 | 03A | 3 ph | 12,00 | 124,3 | 400 | 13,00 | 8,314 | 1,50% | 5,84% | 0,26 |
| ABB | 5,5 | 03B | 3 ph | 12,00 | 126,2 | 400 | 12,00 | 8,314 | 1,52% | 5,84% | 0,26 |
| ABB | 11,0 | 01B | 3 ph | 21,40 | 220,9 | 400 | 23,10 | 14,826 | 1,49% | 5,18% | 0,29 |

**Figure 21** Comparing measured losses to reference percentages

For phase 2 of the UTP study it is planned to include converters with all available accessories, filters, Four-quadrant power converter (4Q), etc. to evaluate the influence of these factors on the losses. One potential idea could be to include a compensation factor when evaluating the energy efficiency class.

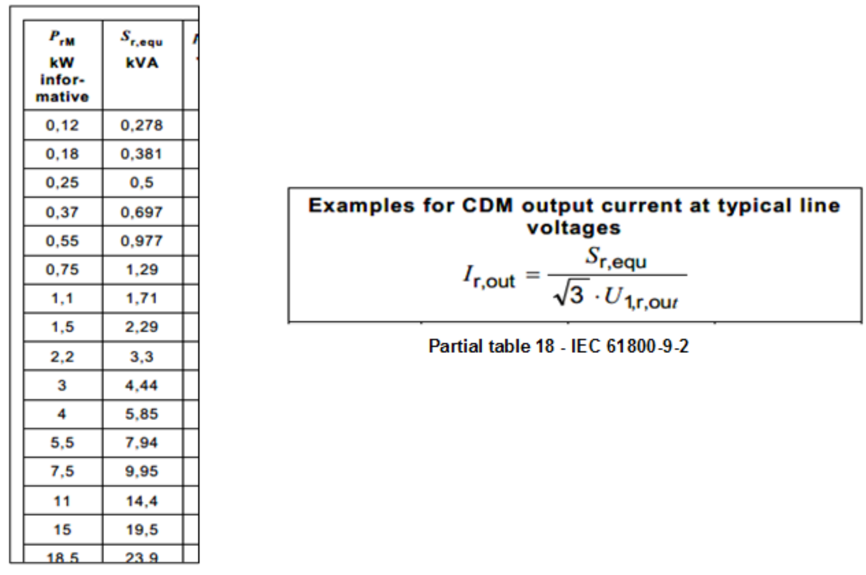
### 3.4 Recommendation for future tests

Based on the findings described earlier in this chapter a few details have been narrowed in for the up-coming RR'C phase 2 of the UTP project.

### 3.4.1 A reference output current table

It has been shown that for the best comparability a well-defined output current table is needed for the specific converter sizes. This table needs to be differentiated in terms of input voltage.

For UTP phase 2, it is suggested to use table A1 in IEC 61800-9-2, edition 1, as inspiration for a new “nominal” output current of a given converter as it has a column of informative kW. If this is combined with the “Examples for CDM output current” equation in table 18, a relatively uniform output current can be defined for any converter.



| $P_{rM}$ kW informative | $S_{r,equ}$ kVA |
|---|---|
| 0,12 | 0,278 |
| 0,18 | 0,381 |
| 0,25 | 0,5 |
| 0,37 | 0,697 |
| 0,55 | 0,977 |
| 0,75 | 1,29 |
| 1,1 | 1,71 |
| 1,5 | 2,29 |
| 2,2 | 3,3 |
| 3 | 4,44 |
| 4 | 5,85 |
| 5,5 | 7,94 |
| 7,5 | 9,95 |
| 11 | 14,4 |
| 15 | 19,5 |
| 18,5 | 23,9 |

Partial table A1 - IEC 61800-9-2

**Examples for CDM output current at typical line voltages**

$$I_{r,out} = \frac{S_{r,equ}}{\sqrt{3} \cdot U_{1,r,out}}$$

Partial table 18 - IEC 61800-9-2

**Figure 22 Table extracts from IEC 61800-9-2, edition 1**

Had this idea been used in phase 1, the nominal currents would look like Figure 23 below giving a fine match to the selected. The method could even be refined to round up to nearest 0.5 A:

| Brand | Size [kW] | RR'C No. | Supp. | UTP rated Current [A] | Loss [W] | Supp. U [V] | Supp. I [A] | IEC 61800-9-2, ed.1 Table A1 [kVA] | Calculated A [A] | Rounded [A] |
|---|---|---|---|---|---|---|---|---|---|---|
| Parker | 0,75 | 02B | 1 ph | 3,40 | 30,3 | 230 | 4,00 | 1,29 | 3,24 | 3,5 |
| ABB | 1,1 | 01A | 1 ph | 4,50 | 41,6 | 230 | 6,70 | 1,71 | 4,29 | 4,5 |
| Schneider | 2,2 | 04A | 3 ph | 4,60 | 52,4 | 460 | 5,10 | 3,30 | 4,14 | 4,5 |
| Schneider | 2,2 | 02A | 3 ph | 4,75 | 57,4 | 400 | 5,80 | 3,30 | 4,76 | 5,0 |
| ABB | 2,2 | 03C | 3 ph | 4,90 | 63,1 | 400 | 5,30 | 3,30 | 4,76 | 5,0 |
| Schneider | 3,0 | 04B | 3 ph | 8,65 | 58,1 | 208 | 13,70 | 4,44 | 12,32 | 12,5 |
| Lenze | 5,5 | 03A | 3 ph | 12,00 | 124,3 | 400 | 13,00 | 7,94 | 11,46 | 12,0 |
| ABB | 5,5 | 03B | 3 ph | 12,00 | 126,2 | 400 | 12,00 | 7,94 | 11,46 | 12,0 |
| ABB | 11,0 | 01B | 3 ph | 21,40 | 220,9 | 400 | 23,10 | 14,40 | 20,78 | 21,0 |

**Figure 23 Phase 1 converters calculated output current**

### 3.4.2 Use only IE2 or IE3 motors

In phase 1 of the UTP it has been shown that the energy class of the load motor used is of less importance for the measured power loss result.

It is however recommended to use at least IE2 motors as these are the minimum performance standard requirement in many parts of the world and are likely to be present in many laboratories.

It has also been shown that for repeatability only 4-pole motors shall be used as load and that these motors must match the converter evaluated in nominal kW.

The UTP phase 1 participants were aware, that converters are sized in kVA and output A, but it has been shown during phase 1 that almost all converters also have a kW rating for the motor intended.

Should everything else fail the reference in Figure 22 above can be used to calculate a nominal motor size.

### 3.4.3 Stay with 13-point UTP measurement in phase 2

Phase 1 of the UTP has shown that the potential operating points 13, 14, 15 & 16 were not needed to make a proper evaluation and creation of the quadratic equation.

Furthermore, it has been shown that especially on the smaller motors it is very hard to achieve these relatively small currents and that magnetizing current takes control consequently making it very difficult to measure in a stable condition.

The final discussion on how many and which operating points will eventually be included in the standard will be held later.

# 4. Proposed testing method

## 4.1 2019 UTP measurement method

Choice of loading motor: The RR'C phase 1 specified that the loading motor for a given converter should be a 4-pole IE2 machine with a rated output mechanical power matching that of the converter's rated output power. It was found, however, that both IE2 and IE3 efficiency rated motors produced closely comparable measured converter loss and efficiency figures.

Per unit (100%) rated converter current, for the purpose of the measurements made in this study, will be defined as the average rated full load current drawn by (4-pole) motors of the above type. Any future standard based on this study would include a table of such current values. Converter losses for the slightly higher currents drawn by motors with higher or lower pole numbers would be determined by extrapolation.

Converters in the RR'C phase 1 were exclusively of the 'DC link' type, as these are the most common in the market place. Attention is drawn, however, to converters with other topologies, such as the matrix type, in which the output is generated (in 3-phase systems) by a matrix of nine bilateral solid-state switches, connected directly to the in-coming supply and converter output terminals. Such converters have advantages over the DC link type, including lack of need for DC link capacitors, fewer semi-conductor junctions in the main current paths and intrinsically bilateral (regenerative) power flow capability. Converters of this and any other types will be included in RR'C phase 2 study.

Converters for the forthcoming study should have output ratings which range as widely as possible, as the RR'C phase 1 provided comparison figures for converters with ratings limited to the range 0.75 to 5.5 kW. For the RR'C phase 2 to be effective, it is suggested that the converter ratings range up to at least 110 kW, and beyond, if possible.

Concern was expressed at the RR'C Workshop on 13 November 2019 at the Motor Summit 2018 in Zurich that by including measurements of 'standby power' in assessing a given converter, equipment with greater internal computational and communications capacity would be penalized. This is not the intention, however, and higher standby power consumptions should be accommodated by regulatory standards by assigning increased standby power limits for more sophisticated converter equipment (e.g. those incorporating PLC and related capabilities). It will thus be important to include converters with such advanced capabilities in the RR'C phase 2.

The RR'C phase 1 was limited to air-cooled converters. The inclusion of water-cooled converters in phase 2 will enhance the value of the project. In such cases, it is suggested that for water-cooled converter loss measurements, cooling water be provided at the maximum temperature and minimum flow rate of the coolant as specified by the manufacturer.

Because converter efficiency is generally quite high, efficiency measurements using input-output methods require very high-quality instrumentation, primarily in the form of a multi-input electrical 'power analyzer'. The 'state-of-the art' for such equipment is a nominal (power measurement) accuracy of around 0.02%, and such instruments should be used for the RR'C phase 2.

Figure 4, shows the 17 operating points used for RR'C phase 1. It was found, however, that in many cases the 25% motor load current was unachievable, as motor no-load current in many instances exceeded that value. In any case, converter losses at such low load currents are much less important than those at higher fractions of rated motor current. For that reason, it is suggested that the converter operating conditions at which losses are measured be limited to points no.1 to no.12, (as in Figure 4) and then no.17, i.e., omitting those at 25% load current, namely points no.13 to no.16. Note that for small motors, no-load current may exceed 50%, in which case, converter losses would be measured at that current. Omission of points no.13 to no.16, as above, significantly shortens the time required to make the necessary measurements.

*A note on operating point no.1 (as in Figure 4):*

*In instances where the supply voltage to a converter (e.g. 400 V) is equal to the motor rated voltage, the top (100% frequency), as is often the case in practice, a converter is unable to provide the required motor voltage at the 100% frequency, 100% load point because of unavoidable voltage drop within the converter. In this case, the PWM process within the converter raises the (rms) value of output voltage by omission of output voltage pulses, a process described in IEC 61800-9-2, edition 1, as 'over-modulation'. The effect of this is to both lower the peak flux levels in the driven motor, and to introduce low order harmonics into the motor supply voltage. The reduction of effective motor supply voltage requires that the motor draw higher current at full load, and increased motor losses are the result. The converter, on the other hand, experiences decreased losses, as the losses in the (d.c.-link type) converter output stage drop on account of the reduced number of switching transitions. The result is that the converter loss curve for 100% output (fundamental) frequency departs from its essentially quadratic shape, and is bent downwards at the top end.*

*It appears that the reason IEC 61800-9-2, edition 1, does not require performance figures at 100% of rated (motor) frequency to be determined appears to relate to the likelihood of PWM 'over-modulation' when rated voltage is required at the motor terminals. This 'over-modulation' in no way prevents the converter delivering rated (fundamental) frequency to the motor, however, and a motor must be able to run satisfactorily at its rated frequency.*

*Any reduction in PWM losses at the 100% load, 100% frequency point, will tend to be accompanied by a small increase in motor losses, and these two phenomena will tend to compensate for each other in a practical converter-motor combination (resulting in a decrease in converter losses because there are fewer switching transitions. On the other hand, the driven motor is likely to suffer a small increase in (iron) losses because of the increased (low order) harmonic content of its supply voltage. These two phenomena tend to compensate for each other in a practical power drive system (PDS).*

*The UTP V2 in separate attachment to this paper provides specific details for the RR'C phase 2, including choice of instrumentation, choice of operating points and measurement sequence, and tabulation of measured results.*

### 4.2 Presentation format with second order polynomial

When applying the UTP methodology and the automatized spreadsheet following the protocol (Figure 25), the result presents itself as a second order polynomial, i.e. an essentially quadratic relationship between converter losses and the current delivered to a motor. This exercise has been predicated on the idea that converters are simply power supplies, with electrical inputs and outputs, but producing neither torque nor speed directly.

Converter losses are produced in

4.2.1: output-end semiconductors as result of voltage drop, with current distribution between active and passive elements dependent on the output power factor.

4.2.2: output-end semiconductors due to switching

4.2.3: mains-end diode rectifiers, with magnitude dependent on the active power delivered to the (motor) load

4.2.4: wiring, busbars and capacitor voltage-sharing and discharge resistors (for example)

4.2.5: cooling systems, including fans, (for example)

4.2.6: control and communication electronics – 'standby losses'

The above suggests that it should be possible to characterize converter losses by means of a simple quadratic relationship between total losses and output current, for a given fundamental converter output frequency. Small differences will inevitably exist between such curves for different fundamental output frequencies, since as motor speed drops, so too does the power which is delivered, via the mains-end rectifier system, resulting in reduced losses in the latter.

Figure 24, below, shows the relationship between losses and converter load:

| Origin of loss | Dependency |
|---|---|
| Control electronics, d.c. link capacitor discharge and voltage sharing resistors | Load independent |
| Permanently energised, fixed speed cooling fans | Load independent |
| Thermostatically controlled cooling fans | Load dependent |
| $I^2R$ losses due to load current in all ‘ohmic’ conductors, including busbars, wiring, inductor windings etc. | Load dependent, and proportional to current squared |
| Losses due to semiconductor junctions exhibiting ‘threshold’ voltages | Load dependent, proportional to current<br>(approximately) |
| Switching losses in output stage semiconductors | Essentially proportional to load current |

**Figure 24 Converter power loss components**

There are thus three types of loss dependency, namely loss which is load independent, loss which is proportional to load current, and loss which is proportional to load current squared.

It is therefore possible to characterise total converter losses by means of a quadratic equation in load current, with the constant term representing standby losses:

$$P = AI^2 + BI + C$$

where P is the total converter power loss in W

I is the output current in A and

C is the standby power in W

### 4.3 UTP relation to IEC 61800-9, edition 1 operating points

When applying the UTP methodology and the automatized spreadsheet following the protocol, the result presents itself as a second order polynomial. A squared relation between output current and losses.

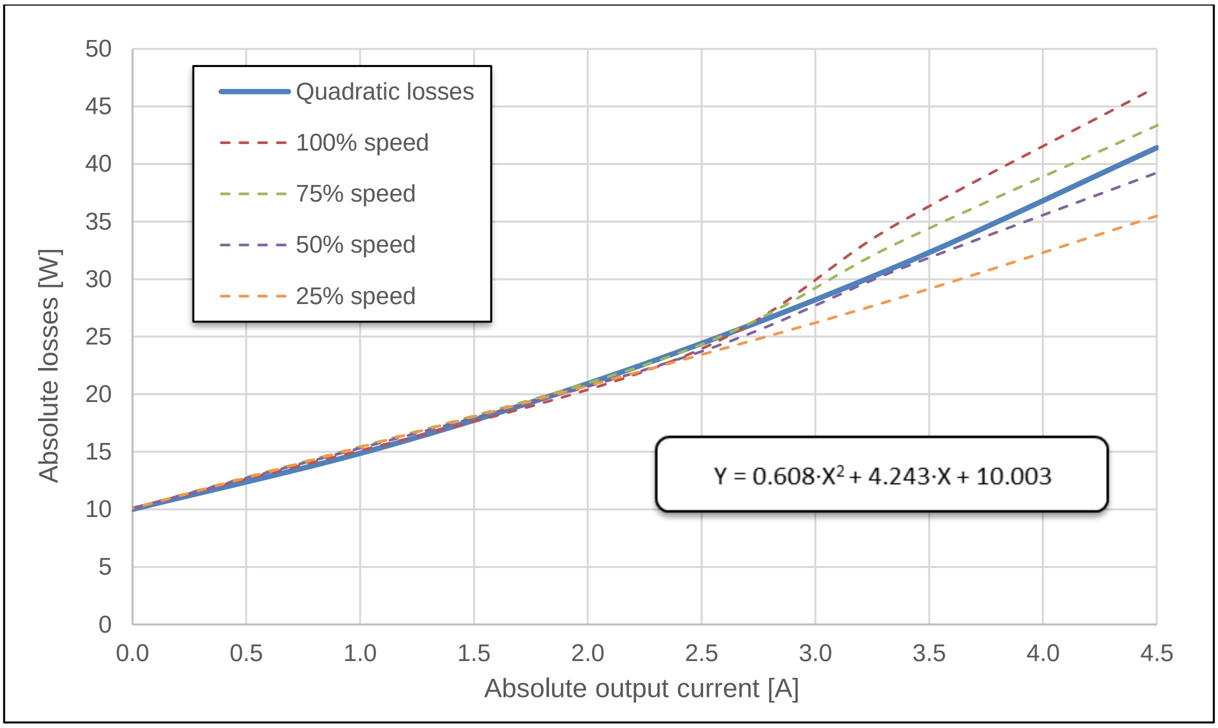


**Figure 25** **Squared relation between output current and losses**

The specific example illustrated above comes from a small 50 Hz, 230 V, 1 phase supplied converter, 1.1 kW which have a nameplate maximum current of 6.7 A. After applying the UTP methodology to this converter it is simple to “convert” any output current into (averaged) losses.

It this therefore possible to relate the UTP result to the existing IEC 61800-9-2, edition 1 standard and the suggested 8 operating points from that. The operating point (1) is used for energy classification of the converter.

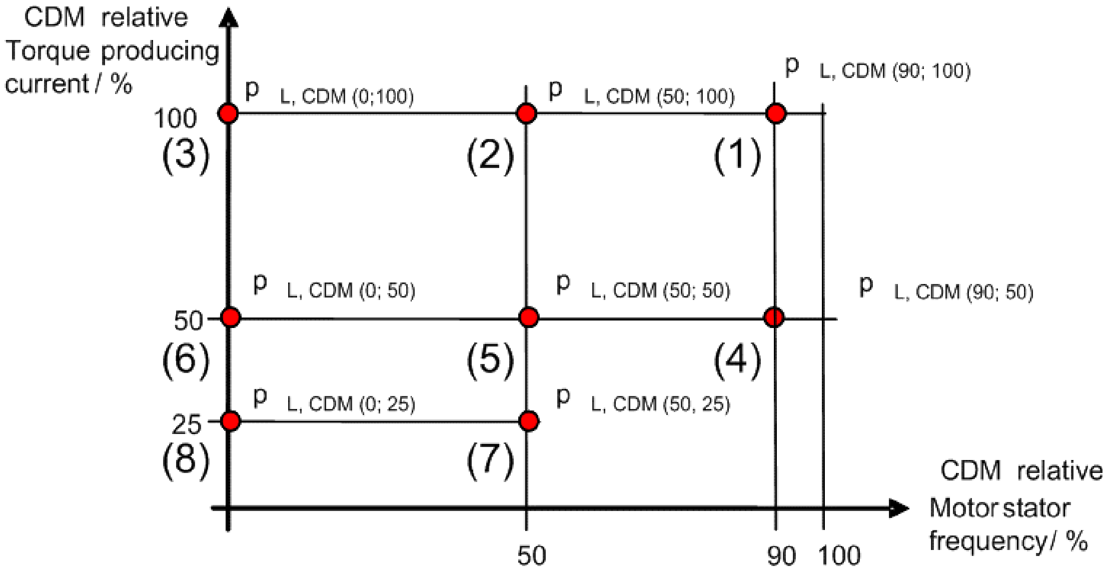
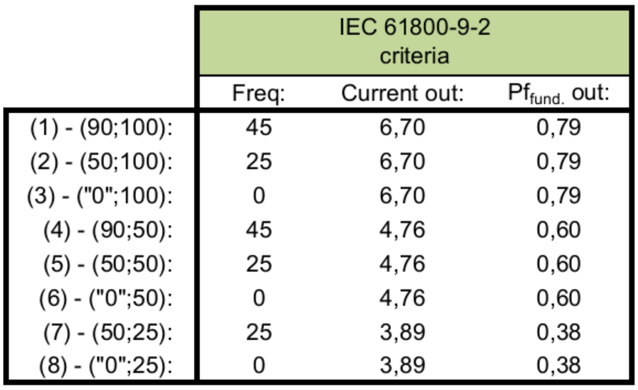


**Figure 26** **8 standardized CDM operating points from IEC 61800-9-2, edition 1**

The IEC 61800-9-2, edition 1 standard introduced a concept called "torque producing current" which dictates a certain power factor at a certain current level to ensure the work performed is sufficient and comparable. From table 1 & 2 in IEC 61800-9-2, edition 1 the specific requirements to the example at hand can be deducted:



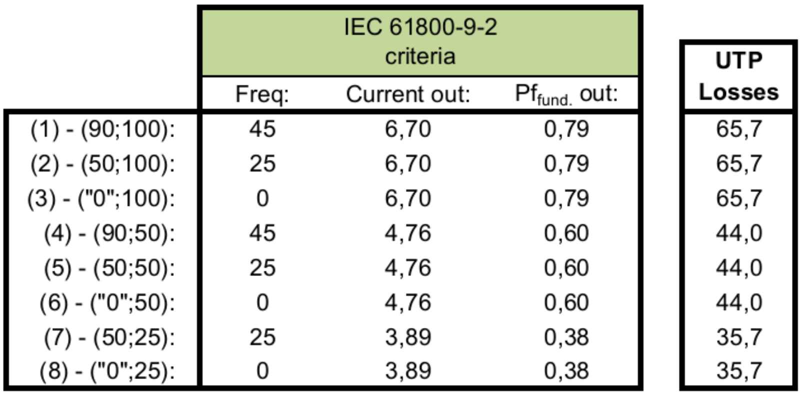
| | IEC 61800-9-2 criteria | | |
|---|---|---|---|
| | Freq: | Current out: | $Pf_{fund.}$ out: |
| (1) - (90;100): | 45 | 6,70 | 0,79 |
| (2) - (50;100): | 25 | 6,70 | 0,79 |
| (3) - ("0";100): | 0 | 6,70 | 0,79 |
| (4) - (90;50): | 45 | 4,76 | 0,60 |
| (5) - (50;50): | 25 | 4,76 | 0,60 |
| (6) - ("0";50): | 0 | 4,76 | 0,60 |
| (7) - (50;25): | 25 | 3,89 | 0,38 |
| (8) - ("0";25): | 0 | 3,89 | 0,38 |

**Figure 27** **Criteria deducted from IEC 61800-9-2, edition 1**

From the UTP squared relation methodology the absolute values of current can be calculated to losses as follows:

6.70 A = 65.7 W
4.76 A = 44.0 W
3.89 A = 35.7 W

Giving a suggested result to the 8 points:



| | IEC 61800-9-2 criteria | | | |
|---|---|---|---|---|
| | Freq: | Current out: | $Pf_{fund.}$ out: | **UTP Losses** |
| (1) - (90;100): | 45 | 6,70 | 0,79 | 65,7 |
| (2) - (50;100): | 25 | 6,70 | 0,79 | 65,7 |
| (3) - ("0";100): | 0 | 6,70 | 0,79 | 65,7 |
| (4) - (90;50): | 45 | 4,76 | 0,60 | 44,0 |
| (5) - (50;50): | 25 | 4,76 | 0,60 | 44,0 |
| (6) - ("0";50): | 0 | 4,76 | 0,60 | 44,0 |
| (7) - (50;25): | 25 | 3,89 | 0,38 | 35,7 |
| (8) - ("0";25): | 0 | 3,89 | 0,38 | 35,7 |

**Figure 28** **Criteria deducted from IEC 61800-9-2, edition 1 incl. calculated UTP losses**

If compared directly to the 8 IEC 61800-9-2, edition 1 points this would correspond to an averaging of the losses in point (2), (5) & (7):

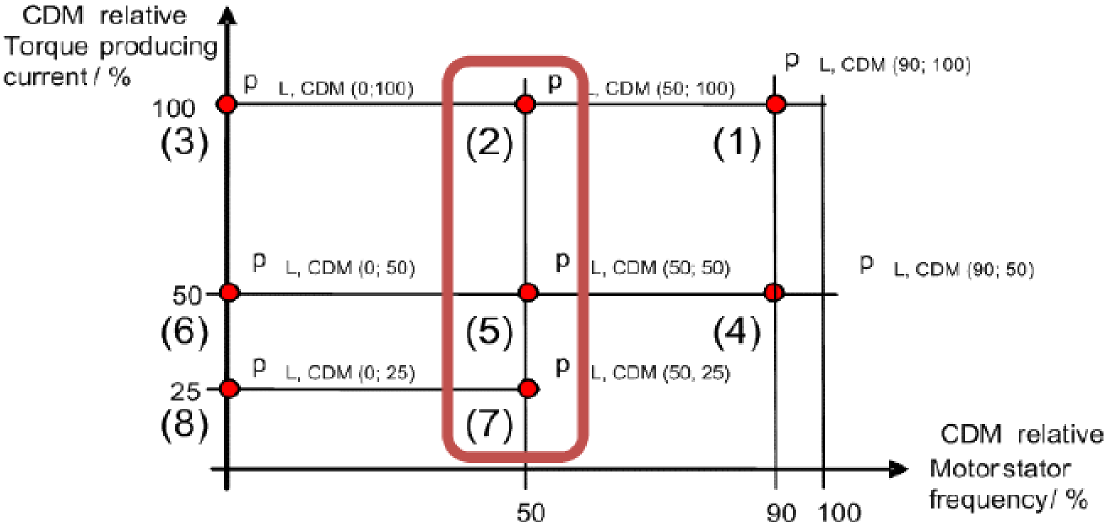


**Figure 29** Three averaged CDM operating points from IEC 61800-9-2, edition 1

# 5. Next steps for RR'C phase 2

## 5.1 Goal

The main goals of an international Round Robin test for converters (RR'C) Phase 2 are:

- The test method described in IEC 61800-9-2:2017 (edition 1) for converters (and in IEC TS 60034-2-3:2013[4] for motors driven by converters) have not been used for sufficient time to know their accuracy and repeatability. ►Clarify and verify test method.
- The test laboratories around the world using this test method are not yet familiar with it. ►Check laboratory performance
- The performance of the converters and their losses need to be verified vs. the catalogue data. ► Provide scientifically based and documented evidence.
- Different products from different manufacturers need to be tested as to defining the reference and IE1/IE2 or eventual higher levels. ►Clarify spread of product performance by different manufacturers.

The results of the Round Robin test will build the key evidence for the revision of IEC 61800-9-2 → ed. 2, especially the design of an updated and solid testing procedure which in the current version is often referred to as being vague and ambiguous, and also the provision of sufficient solid and impartial measured background data for a potential correction of the current level of the reference values for losses inside converters.

### 5.1.1 Preparation

The RR'C workshop on 13 November 2018 at the Motor Summit in Zurich has served as a first opportunity for an interim report on the results of the RR'C Phase 1 and the clarification of the plan for Phase 2. Also, the IEC SC 22G WG18 meeting on 18-22 February 2019 in Australia will serve both for the final reporting of the results of the RR'C Phase 1 and the launch of RR'C Phase 2. The timeline of Phase 2 has already been synchronized with the preparation of IEC 61800-9-2, edition 2.

The preparation phase for RR’C Phase 2 includes the following tasks:

- Product definition and selection to include a representative sample of typical converter types, sizes, frequencies and phases, etc. The goal is to select a sufficient number of products in the entire range of 0.12 kW up to 1000 kW to get the necessary information on reviewing the reference losses and the IE-classes.
- Workshop regarding organizational issues as well as testing procedures (UTP)
- Discussion with IEC WG18 to include the results in IEC 61800-9-2, edition 2 (next WG18 meeting in February 2019 in Australia).

### 5.1.2 Phase 2

Phase 2 includes the following tasks:

- Full converter testing campaign in about 6 - 7 testing labs with some 60 products based on the UTP, edition 2.
- Analysis and report of the results.
- Publication of results.

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[4] IEC 60034--2-3:2013: Rotating electrical machines - Part 2-3: Specific test methods for determining losses and efficiency of converter-fed AC induction motors

The bulk of the testing work in Phase 2 will be between spring of 2019 and summer of 2020. After that, the evaluation and reporting in the fall of 2020 will take the rest of the program's time. For budgetary reasons the testing might be continued in 2021.

### 5.1.3 Timeline

1 March 2019 - 31 October 2020 (full testing phase)

- Phase 2: start March 2019
- Phase 2: final report to EMSA/WG18 October 2020

## 5.2 Choice of products for tests (2-poleages)

The product selection will be decided by the following criteria:

- Converter type: hardware and software
- Grid feeding phases, frequency
- Converter power range, general purpose products
- Number of relevant manufacturers
- Number of products per size.

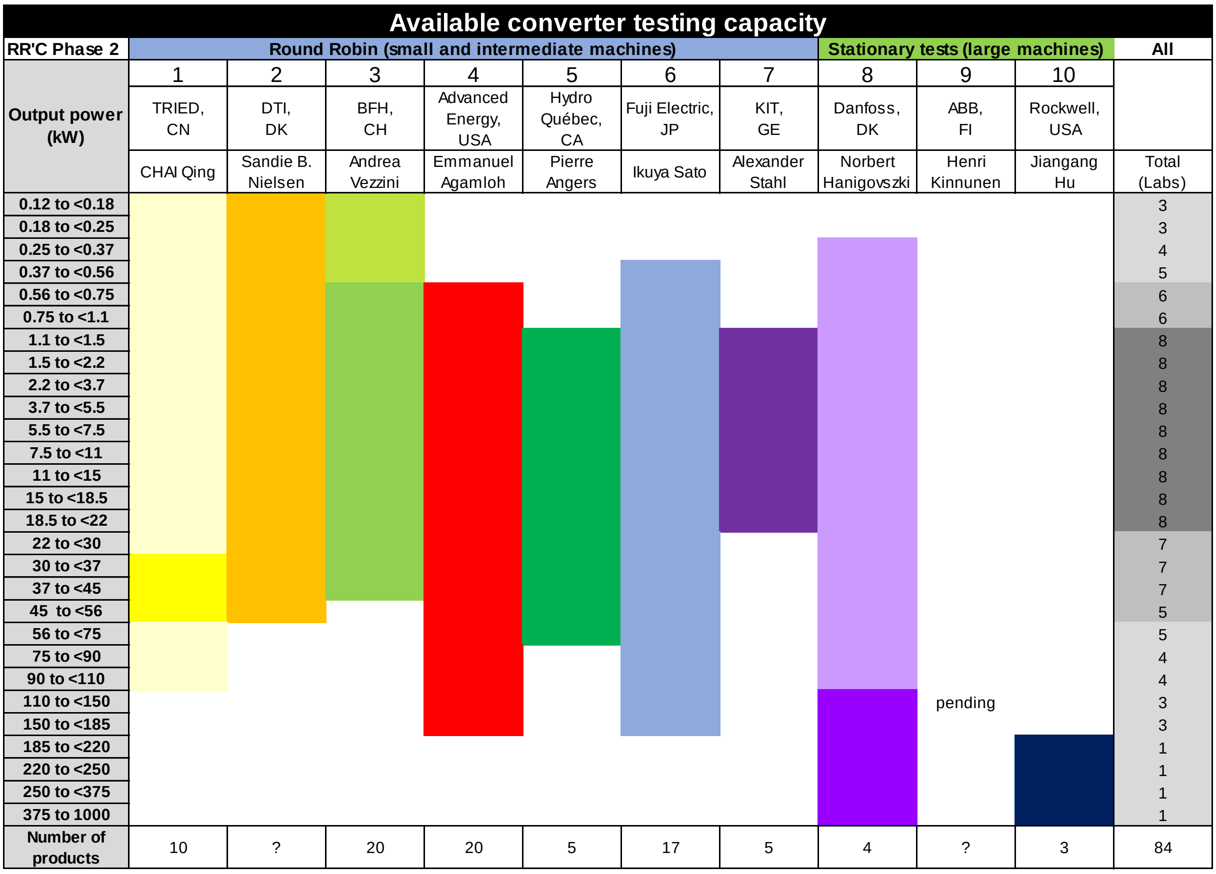
Phase 2 includes a total of circa 60 converters in the power range of from 0.12 - 1000 kW from 5 to 8 manufacturers to form a representative sample of converters actually used in the global market for motor driven units.

| **RR'C Budget Phase 2 Details by size** | Converter tests | Output power range | | Number of products under test |
|---|---|---|---|---|
| | Products size | kW | kW | |
| 1 | small | 0.12 | 5 | 18 |
| 2 | medium | 11 | 30 | 21 |
| 3 | large | 37 | 110 | 15 |
| 4 | very large | 200 | 1000 | 6 |
| | **Total** *(average)* | | | 60 |

**Figure 30 Proposed selection of converters for tests, by size (preliminary)**

The total number of products to be tested is dependent on the availability of the products, the capability of the test laboratories, the cost and available resources to cover the cost. The four classes of converter sizes are chosen to reflect the power and the market share of the respective groups.

The estimate is for about 60 converters between 0.12 and 1000 kW to be tested and evaluated in about 6 to 8 countries and their respective independent laboratories plus some industry laboratories. The converter sizes will be distributed between the labs according to their available capacity and testing equipment (see Figure 31).



**Available converter testing capacity**

| RR'C Phase 2 | Round Robin (small and intermediate machines) | | | | | | | Stationary tests (large machines) | | | All |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Output power (kW) | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
| | TRIED, CN | DTI, DK | BFH, CH | Advanced Energy, USA | Hydro Québec, CA | Fuji Electric, JP | KIT, GE | Danfoss, DK | ABB, FI | Rockwell, USA | |
| | CHAI Qing | Sandie B. Nielsen | Andrea Vezzini | Emmanuel Agamloh | Pierre Angers | Ikuya Sato | Alexander Stahl | Norbert Hanigovszki | Henri Kinnunen | Jiangang Hu | Total (Labs) |
| 0.12 to <0.18 | ■ | ■ | ■ | | | | | | | | 3 |
| 0.18 to <0.25 | ■ | ■ | ■ | | | | | | | | 3 |
| 0.25 to <0.37 | ■ | ■ | ■ | | | | | ■ | | | 4 |
| 0.37 to <0.56 | ■ | ■ | ■ | | | ■ | | ■ | | | 5 |
| 0.56 to <0.75 | ■ | ■ | ■ | ■ | | ■ | | ■ | | | 6 |
| 0.75 to <1.1 | ■ | ■ | ■ | ■ | | ■ | | ■ | | | 6 |
| 1.1 to <1.5 | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | | 8 |
| 1.5 to <2.2 | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | | 8 |
| 2.2 to <3.7 | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | | 8 |
| 3.7 to <5.5 | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | | 8 |
| 5.5 to <7.5 | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | | 8 |
| 7.5 to <11 | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | | 8 |
| 11 to <15 | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | | 8 |
| 15 to <18.5 | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | | 8 |
| 18.5 to <22 | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | | 8 |
| 22 to <30 | ■ | ■ | ■ | ■ | ■ | ■ | | ■ | | | 7 |
| 30 to <37 | ■ | ■ | ■ | ■ | ■ | ■ | | ■ | | | 7 |
| 37 to <45 | ■ | ■ | ■ | ■ | ■ | ■ | | ■ | | | 7 |
| 45 to <56 | ■ | ■ | | ■ | ■ | ■ | | ■ | | | 5 |
| 56 to <75 | ■ | | | ■ | ■ | ■ | | ■ | | | 5 |
| 75 to <90 | ■ | | | ■ | | ■ | | ■ | | | 4 |
| 90 to <110 | ■ | | | ■ | | ■ | | ■ | | | 4 |
| 110 to <150 | | | | ■ | | ■ | | ■ | pending | | 3 |
| 150 to <185 | | | | ■ | | ■ | | ■ | | | 3 |
| 185 to <220 | | | | | | | | ■ | | ■ | 1 |
| 220 to <250 | | | | | | | | ■ | | ■ | 1 |
| 250 to <375 | | | | | | | | ■ | | ■ | 1 |
| 375 to 1000 | | | | | | | | ■ | | ■ | 1 |
| Number of products | 10 | ? | 20 | 20 | 5 | 17 | 5 | 4 | ? | 3 | 84 |

**Figure 31 Testing capacity: Converter size (results from questionnaire, September 2018)**

In order to satisfy the rules of a Round Robin (and to save money and time) the current plan is not to have all products go through tests in all the 7 labs. All products between 0.12 kW and 110 kW (around 50) are to be tested normally by three labs. A total of circa 160 tests are anticipated (circa 15 - 25 tests per lab).

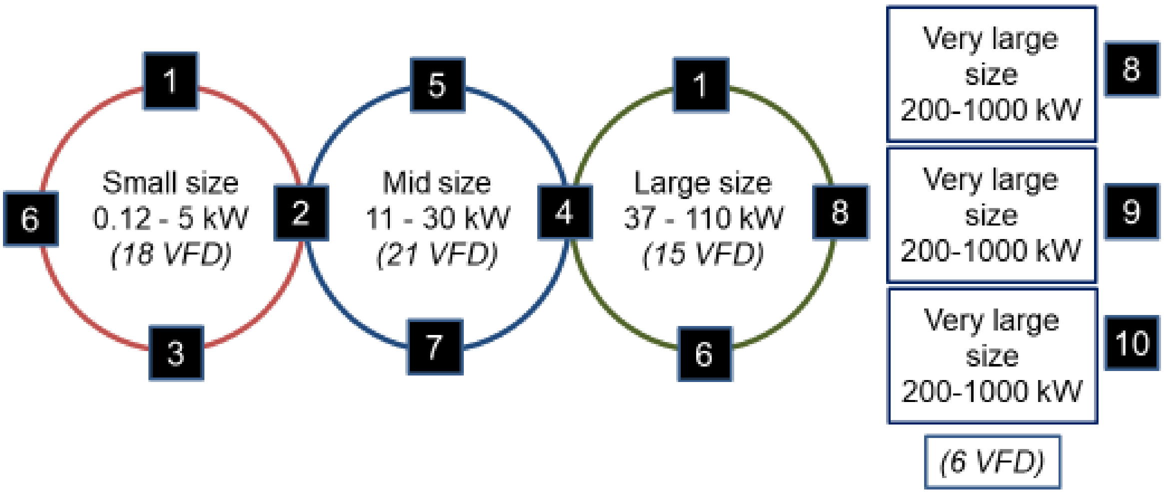


Figure 32 Four subgroups of laboratories for the Round Robin

In order to have the necessary testing capacity which only few manufacturers have (and to also save time and money) the test of these bigger machines is not following the formal Round Robin rules, but they will be tested only stationary at the manufacturer's testing lab.

Currently, for the testing of larger machines between 200 - 1000 kW (maybe a total of 6 to 8), the involvement of Danfoss and Rockwell is confirmed, the discussion is ongoing with ABB. The RR'C project management will send one of the independent laboratory testing engineers as auditor to monitor these tests and to make sure that they are executed according to the Uniform Testing Protocol of the RR'C.

Separately, a batch of promised additional industry test results following the UTP will be used to gain statistical evidence.

## 5.3 Organization

### 5.3.1 Experience from RR'C phase 1

The organization of RR'C in Phase 2-profits from the near completion of Phase 1 where a vast body of evidence was gathered by 4 international testing laboratories (Advanced Energy/USA, CalTest/Australia, DTI/Denmark and BFH/Switzerland). We thank the four involved laboratories for their work and the governments of USA, Australia, Denmark and Switzerland for providing the necessary funding.

### 5.3.2 RR'C leading team

The RR'C Task Force and its leadership from 4E EMSA, IEC SC 22G WG18 and industry has been selected and mandated at the EEMODS'17 meeting in Rome on 6 September 2017. The cooperation between IEC WG18 and 4E EMSA has been clarified at the IEC WG18 meeting on 26-28 February 2018 in Tampa FL USA.

**Project manager RR'C phase 2 (PM):**

- Sandie B. Nielsen/DK (Task Force leader)
- Andrea Vezzini/CH (Task Force leader)

**Advisory group (technical support for the PM):**

- Emmanuel Agamloh/Advanced Energy, USA
- Pierre Angers/Hydro Quebec, CA
- Andrew Baghurst/CalTest, AU
- Martin Doppelbauer/KIT, Karlsruhe/GE
- Chai Qing/China National Center for Quality Supervision and Test of Electrical Control and Distribution Equipment/Tianjin, CN
- Kurt Stockman/University of Gent, BE

**Steering committee (strategic support and financial resources):**

- Maarten van Werkhoven/NL (4E EMSA)
- Roland Brüniger/Swiss government CH
- Jesper Ditlefsen, Danish Energy Agency DK

**Industry contact group:**

- ABB (Freddy Gyllensten, Henri Kinnunen, Sweden & Finland)
- Danfoss (Norbert Hanigovszki, Denmark)
- Fuji Electric (Ikuya Sato, Japan)
- Rockwell (Jiangang Hu, USA)
- SEW Eurodrive (Tim Schumann, US)
- Siemens (Bill Finley, USA)

### 5.3.3 Test laboratories in phase 2

A group of independent test laboratories, qualified for converter tests, has been selected to be invited to participate in Phase 2. As a result of a questionnaire, sent to all labs in August 2018, we have positive responses by 18 September 2018 for the participation in the Round Robin Phase 2 from the following 7 laboratories (details see Annex 1):

| | | |
|---|---|---|
| • | Canada | Hydro Quebec, Laboratoire des Technologies de l'Énergie, Shawinigan, Québec |
| • | China | China National Center for Quality Supervision and Test of Electrical Control and Distribution Equipment, Tianjin City |
| • | Denmark | Danish Technological Institute (DTI), Aarhus |
| • | Germany | Karlsruhe Institute for Technology (KIT), Elektrotechnisches Institut, Karlsruhe |
| • | Japan | Fuji Electric Co., Ltd., Suzuka-shi, Mie |
| • | Switzerland | Bern University of Applied Sciences (BFH), Biel |
| • | USA | Advanced Energy, Raleigh NC. |

Pending decision to participate before financing is clarified:

| | | |
|---|---|---|
| • | Australia | CalTest, Port Elliot SA 5212 |

We have also invited three industry laboratories that are capable to test their own large size converters on the factory site (200 - 1000 kW) according to the UTP. So far, we have positive responses to participate in stationary tests with an expert of the Task Force attending from:

| | | |
|---|---|---|
| • | Denmark: | Danfoss Drives, Graasten |
| • | USA | Rockwell, Mequon, Wisconsin, USA |

Currently pending are the responses and the details of the cooperation from ABB to participate in the stationary tests for large converters.

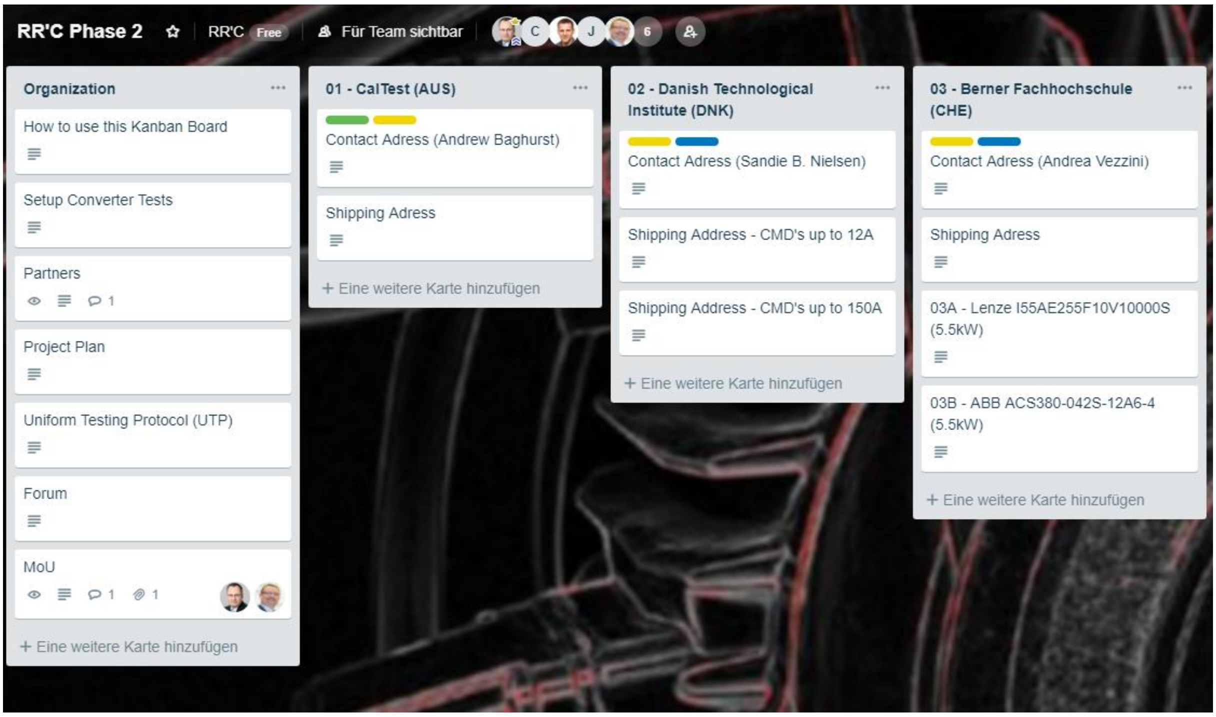
### 5.3.4 Management and collaboration tool

Phase 2 will be coordinated with the help of Trello.

Trello is an online collaboration tool that organizes your projects into boards. In one glance, Trello tells you what's being worked on, who's working on what, and where something is in a process.

Trello can be compared with a white board, filled with lists of sticky notes, with each note representing one of the devices under test. Each of those sticky notes (DUTs) has photos, attachments from other data sources, documents, and a place to comment and collaborate with other team members.

The lists are representing the current position of the DUTs. This can be either in a laboratory or in transit.



Organization
- How to use this Kanban Board
- Setup Converter Tests
- Partners
- Project Plan
- Uniform Testing Protocol (UTP)
- Forum
- MoU
- + Eine weitere Karte hinzufügen

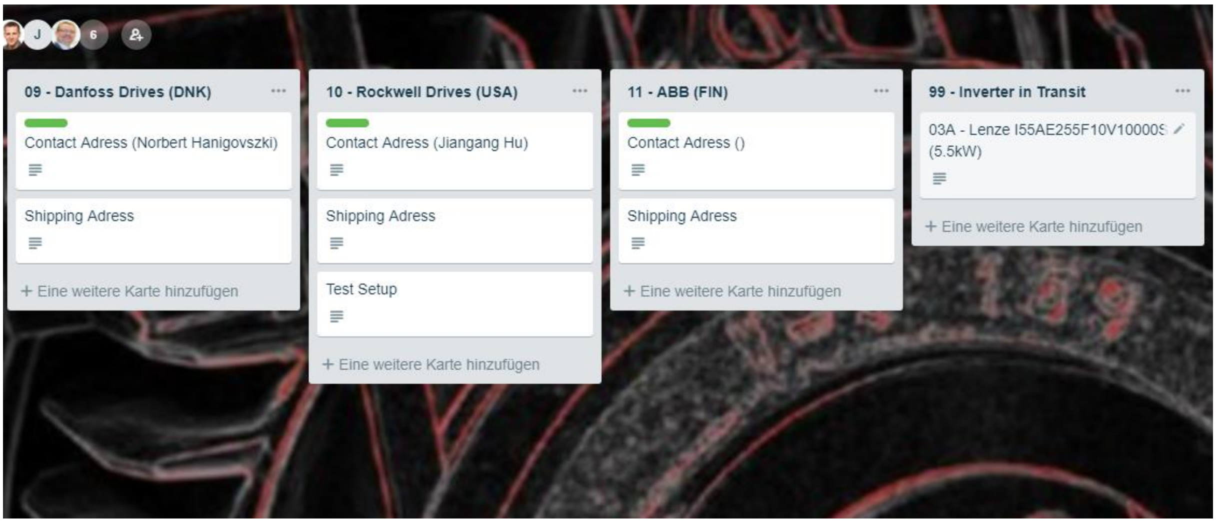
01 - CalTest (AUS)
- Contact Adress (Andrew Baghurst)
- Shipping Adress
- + Eine weitere Karte hinzufügen

02 - Danish Technological Institute (DNK)
- Contact Adress (Sandie B. Nielsen)
- Shipping Address - CMD's up to 12A
- Shipping Address - CMD's up to 150A
- + Eine weitere Karte hinzufügen

03 - Berner Fachhochschule (CHE)
- Contact Adress (Andrea Vezzini)
- Shipping Adress
- 03A - Lenze I55AE255F10V10000S (5.5kW)
- 03B - ABB ACS380-042S-12A6-4 (5.5kW)
- + Eine weitere Karte hinzufügen

**Figure 33** **Part of the Trello whiteboard, showing, that the inverters Nr. 03A and 03B are currently at Berner Fachhochschule.**

Details about the contact Person and the shipping address are also attached to the same list. Once the tests at Bern University of Applied Sciences have been finished, the inverters are shipped to the next lab and the sticky note is moved to the new list called “99 – Inverter in transit”.



09 - Danfoss Drives (DNK)
- Contact Adress (Norbert Hanigovszki)
- Shipping Adress
- + Eine weitere Karte hinzufügen

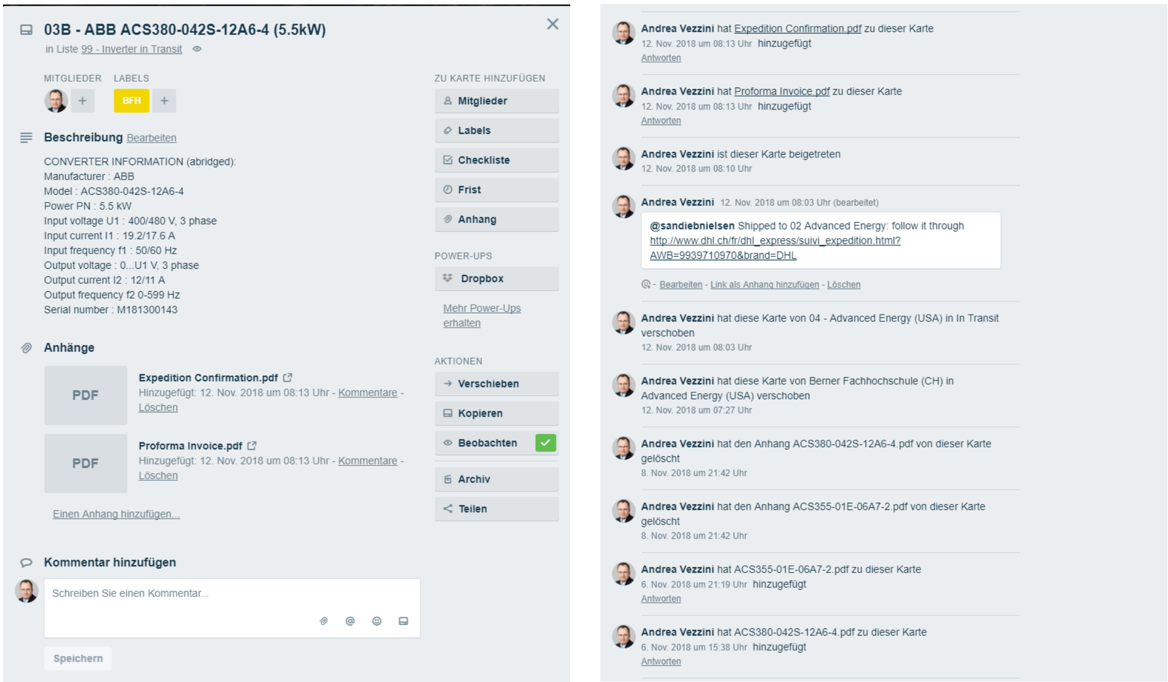
10 - Rockwell Drives (USA)
- Contact Adress (Jiangang Hu)
- Shipping Adress
- Test Setup
- + Eine weitere Karte hinzufügen

11 - ABB (FIN)
- Contact Adress ()
- Shipping Adress
- + Eine weitere Karte hinzufügen

99 - Inverter in Transit
- 03A - Lenze I55AE255F10V10000S (5.5kW)
- + Eine weitere Karte hinzufügen

**Figure 34** **Special list where all the DUTs currently shipping (in transit) are placed). This allows to track the status of the shipping**

Additionally, the shipping documents as well as the expedition confirmation are attached to the note as seen on the next picture. This allows the receiving laboratory to check how long the shipment will take and prepare the reception of the DUTs



**03B - ABB ACS380-042S-12A6-4 (5.5kW)**
in Liste 99 - Inverter in Transit

**Beschreibung** Bearbeiten

CONVERTER INFORMATION (abridged):
Manufacturer : ABB
Model : ACS380-042S-12A6-4
Power PN : 5.5 kW
Input voltage U1 : 400/480 V, 3 phase
Input current I1 : 19.2/17.6 A
Input frequency f1 : 50/60 Hz
Output voltage : 0...U1 V, 3 phase
Output current I2 : 12/11 A
Output frequency f2 0-599 Hz
Serial number : M181300143

**Anhänge**

PDF **Expedition Confirmation.pdf**
Hinzugefügt: 12. Nov. 2018 um 08:13 Uhr - Kommentare - Löschen

PDF **Proforma Invoice.pdf**
Hinzugefügt: 12. Nov. 2018 um 08:13 Uhr - Kommentare - Löschen

Einen Anhang hinzufügen...

**Andrea Vezzini** hat Expedition Confirmation.pdf zu dieser Karte
12. Nov. 2018 um 08:13 Uhr hinzugefügt
Antworten

**Andrea Vezzini** hat Proforma Invoice.pdf zu dieser Karte
12. Nov. 2018 um 08:13 Uhr hinzugefügt
Antworten

**Andrea Vezzini** ist dieser Karte beigetreten
12. Nov. 2018 um 08:10 Uhr

**Andrea Vezzini** 12. Nov. 2018 um 08:03 Uhr (bearbeitet)
**@sandiebnielsen** Shipped to 02 Advanced Energy: follow it through http://www.dhl.ch/fr/dhl_express/suivi_expedition.html?AWB=9939710970&brand=DHL
- Bearbeiten - Link als Anhang hinzufügen - Löschen

**Andrea Vezzini** hat diese Karte von 04 - Advanced Energy (USA) in In Transit verschoben
12. Nov. 2018 um 08:03 Uhr

**Andrea Vezzini** hat diese Karte von Berner Fachhochschule (CH) in Advanced Energy (USA) verschoben
12. Nov. 2018 um 07:27 Uhr

**Andrea Vezzini** hat den Anhang ACS380-042S-12A6-4.pdf von dieser Karte gelöscht
8. Nov. 2018 um 21:42 Uhr

**Andrea Vezzini** hat den Anhang ACS355-01E-06A7-2.pdf von dieser Karte gelöscht
8. Nov. 2018 um 21:42 Uhr

**Andrea Vezzini** hat ACS355-01E-06A7-2.pdf zu dieser Karte
6. Nov. 2018 um 21:19 Uhr hinzugefügt
Antworten

**Andrea Vezzini** hat ACS380-042S-12A6-4.pdf zu dieser Karte
6. Nov. 2018 um 15:38 Uhr hinzugefügt
Antworten

**Figure 35 In this example BFH has directly adressed DTI (by using the identifier @sandiebnielsen) to give a link where the shipment can be tracked.**

An introduction to Trello will be given during the workshop at the next WG18 meeting in February 2019 in Australia).

# 6. Testing laboratories and converters tested

## 6.1 Testing Laboratories

### 6.1.1 Bern University of Applied Sciences, Switzerland

The laboratory for power electronics and electric machines at Bern University of Applied Sciences in Biel/Bienne, Switzerland offers a wide range of testing facilities. The test benches are located in a large open basement on campus. Temperatures range from a minimum of 21 °C during winter to a maximum temperature of approximately 25 °C during summer. Currently, there is no possibility for climate control.

Ranging from 0-6 Nm and 2500 rpm for the smallest bench, up to 0-50 Nm and 9000 rpm for the largest bench, motors and electric drive systems with a maximal mechanical power output of 11 kW and 50 Nm can currently be tested. During the course of 2019, an additional 50 kW test bench will be completed, allowing an even wider range of testing capabilities. This latest upgrade also includes a 60 kVA Chroma grid simulator and a 60 kW Chroma battery simulator, allowing better control of testing environment variables.

**Figure 36 Available Test Benches at Bern University of Applied Sciences in Biel (smallest to largest)**

For testing VFDs, several IE3, four pole induction machines are readily available in the lab. The available machines offer mechanical power output of 0.75 kW, 1.1 kW, 1.75 kW, 2.2 kW, 5.5 kW (2 different machines available for this size – IE1 and IE3) as well as 11 kW. Apart from the 1.75 kW and one of the 5.5 kW machines, all motors are from the same supplier and the same product line.

Measurements are performed using two Hioki PW6001 in master-slave mode, offering a total of 8 high resolution measurement channels. This allows full three-phase input-output measurement of grid connected VFDs or similar applications. Current measurements up to 50 A are performed using high bandwidth current shunt boxes (Hioki PW9001, 8 channels in total) whereas higher currents up to 200 A are measured using hall-type sensors (Hioki CT6863). Example: The following table shows the theoretical accuracy testing of an 11 kW VFD using the PW9001 50 A current shunt boxes:

| **Frequency** | **DC** | **10 Hz** | **50/60 Hz** | **100 Hz** | **1 kHz** | **10 kHz** | **100 kHz** | **1 MHz** |
|---|---|---|---|---|---|---|---|---|
| **Error** | 0.16 % | 0.6 % | 0.12 % | 0.15 % | 0.21 % | 0.43 % | 1.70 % | 32.43 % |

**Figure 37 Table illustrating measurement accuracy of three phase measurement (11 kW VFD test)**

More detailed information regarding power analyzer accuracy and specifications is given in the Figure 38.

.

| ***Unit*** | **PW6001** | **PW9001** | **CT6863** |
|---|---|---|---|
| ***S.N.*** | Unit 1: 151026458<br>Unit 2: 151028246 | Unit 1:180430518<br>Unit 2: 180430517 | Unit 1: 150613622<br>Unit 2: 150900323<br>Unit 3: 150900324<br>Unit 4: 150900325 |
| ***Specs*** | Master-Slave (23$\mu s$ sync)<br>Quad Channel<br>18 Bit ADCs<br>U: ±2 % rdg. ± 0.02 % fs.<br>I: ±2 % rdg. ± 0.02 % fs. | ± 50 A<br>3.5 MHz<br>± 0.04 % (@ 2 MHZ) | ± 200 A<br>500 kHz<br>± 0.05 % rdg. ±0.01 % fs. |

**Figure 38 Power analyzer accuracy and specifications**

### 6.1.2 Advanced Energy, USA

Advanced Energy motors testing is carried out in its motor test laboratory in Raleigh, North Carolina, USA. The laboratory has maintained an ISO/IEC 17025 accreditation since 1997 through NIST/NVLAP. The lab has also maintained a NOM designation through ANCE, the first laboratory outside Mexico to gain such designation. From 2010 to 2014 the laboratory participated in UL's data acceptance program and has worked closely with UL to test motors intended for certification for UL clients. The laboratory has also in the past assisted CSA to certify motors for its clients, following a witness by CSA staff. The lab is currently the sole source in the US for testing converters to the AHRI standard 1210.

Advanced Energy has a number of dynamometers ranging from below 0.75 kW up to 225 kW. The 225 kW Eddy current dynamometer is shown on the left and the mid-range dynamometer where the round robin tests were conducted is shown on the right.

The laboratory is equipped with high precision instrumentation including a Yokogawa WT 3000 and Lebow torque instruments and torque transducers of various sizes, matched to the motor size under test. More information on the test lab and instrumentation can be found at: [www.advancedenergy.org/markets/motorsanddrives/.](www.advancedenergy.org/markets/motorsanddrives/)

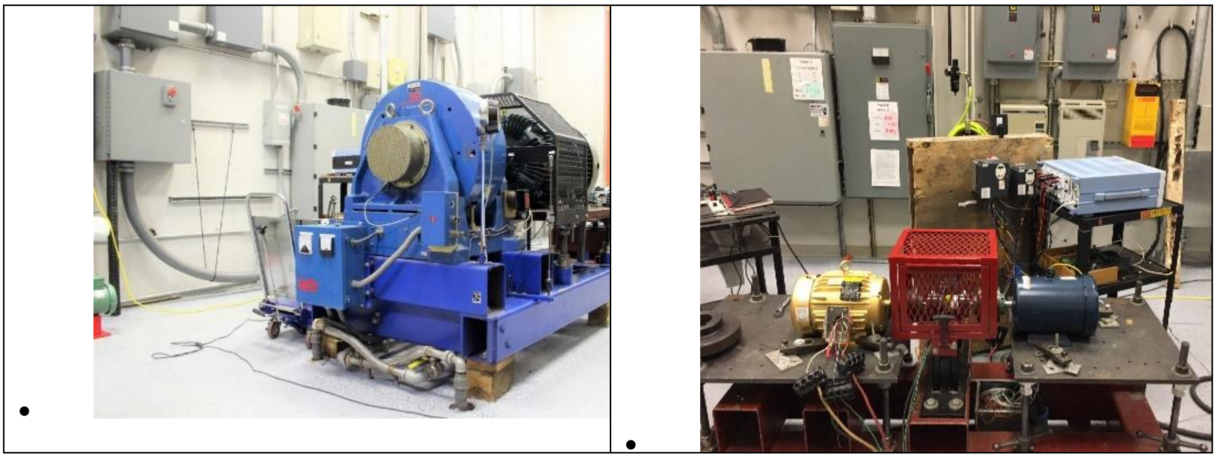


**Figure 39 Advanced Energy Test benches, left: 225 kW Eddy current dynamometer, right: mid-range dynamometer where the round robin tests were conducted**

### 6.1.3 CalTest Laboratory, Australia

Main testing fields of the CalTest lab in St, Port Elliot, South Australia 5212 (www.caltestlab.com.au) are rotating electrical machines, with dynamometers providing loading facilities for machines rated up to 185 kW, and no-load tests and measurements on motors with output power ratings up to 1'500 kW, and voltage ratings up to 11 kV.

CalTest is accredited by Australia’s laboratory accreditation organization, NATA, to the requirements of ISO 17025: 2017; accreditation no. 15303

The equipment used for the RR'C phase 1:

- Power supply: Mecc Alte 220 kVA motor-driven 3-phase alternator, providing either 50 or 60 Hz, depending on prime-mover speed and with voltage control by means of adjustment of alternator excitation
- Power analyzer: Yokogawa WT3000 – Motor version - with 4 input modules: 2 modules for input, and 2 for output, each connected ‘3P3W’
- Dynamometer: Purpose built for the project, consisting of two in-line connected induction machines, one of which loaded the converter. The system included an HBM model T12 ‘torque flange’ torque meter, but that equipment was used for monitoring purposes only: no torque or shaft speed readings were recorded.
- Motor loading: Mechanical loading of the converter-driven motor was by means of appropriately rated ABB model ACS800 variable frequency drive units operating in torque control (‘DTC’) mode, returning electrical power to the d.c. link of a similar type of VFD which supplied the (55 kW 4-poleole) motor driving the main power supply alternator, as above.
- Temperature measurement: T-type thermocouples connected to a Fluke model 54 II digital thermometer, uncontrolled laboratory ambient air temperature

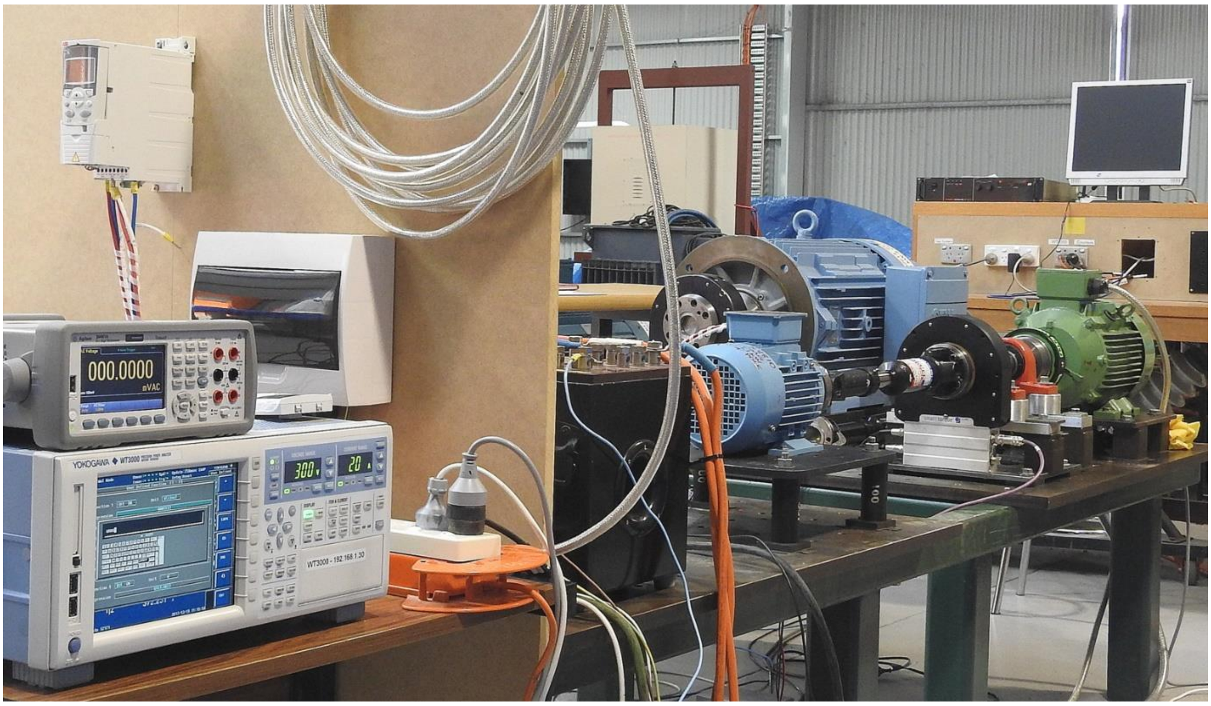


**Figure 40 General view of the measurement system at CalTest**

Top left: the converter under test, with coiled shielded output cable to the right Bottom left: Instrumentation – Yokogawa WT3000 power analyzer with flux voltmeter above Centre: (Blue) 1.1 kW 4-poleole IE2 motor for loading the converter Right: (Green) dynamometer machine for loading the above motor (Torque transducer not used).

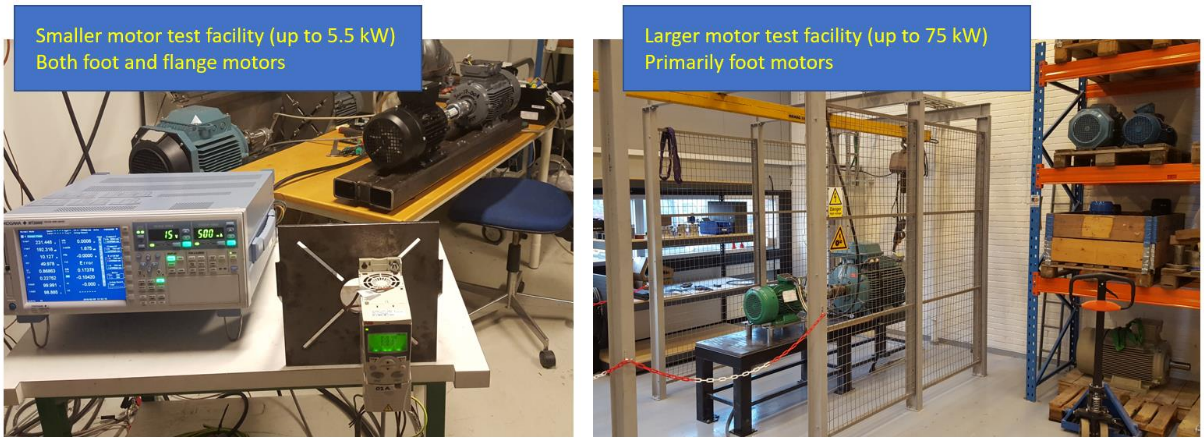
### 6.1.4 Danish Technological Institute – DTI Drives-Lab, Denmark

Danish Technological Institute is a leading research and technology Institute located in Denmark. DTI employ 1041 specialists and help in excess of 10.000 customers a year – representing 65 different countries. DTI are organizational divided into 8 divisions (Production, Materials, Life Science, Business and Society, Energy and Climate, Agro technology, Building and Construction and Meat research) – The motor test facilities are a part of Energy and Climate division.

DTI Electric motor test facilities, Drives-Lab, are as most of DTI labs, a part of the ISO/IEC 17025 accreditation and have been so since 2011 annually assessed by Danish accreditation body: DANAK which is a member of ILAC.

DTI Drives-Lab offers testing of both power electronics, electric machines, gear boxes etc. and are equipped with a wide range of testing facilities. It is physically divided into two locations in eastern and western part of Denmark which both offers climate control.

DTI Drives-Lab have been an important part of the European MEPS program on electric motors since the launch in 2011 and have today more than 150 accredited compliancy tests on motors on record performed on behalf of several European countries.



Smaller motor test facility (up to 5.5 kW)
Both foot and flange motors

Larger motor test facility (up to 75 kW)
Primarily foot motors

**Figure 41** **DTI Drives-Labs**

DTI Drives-Lab is equipped with high precision instrumentation including Yokogawa WT3000E, ZES Zimmer power analyzers, DANISENSE current transducers and a selection of Lorentz torque transducers of various sizes. All testing is fully automated and DAQ collected through self-developed Lab-VIEW software.

For more information on DTI Drives-Lab please see:
[https://www.dti.dk/testing/electric-motors-and-drives/38003](https://www.dti.dk/testing/electric-motors-and-drives/38003)

## 6.2 Data of 9 Converters tested

### 6.2.1 No. 01A: ABB 1.1 kW

| | |
|---|---|
| **Manufacturer** | ABB |
| **Model** | ACS355 |
| **Input Section** | Diode bridge rectifier without filter |
| **Power PN** | 1.1 kW |
| **Input voltage U1** | 200-240 V, 1 phase |
| **Input current I1** | 16 A |
| **Input frequency f1** | 48-63 Hz |
| **Output voltage** | 0-U1 V, 3 phases |
| **Output current I2** | 6.7 A |
| **Output frequency f2** | 0-599 Hz |
| **Serial number** | 41711F3363 |

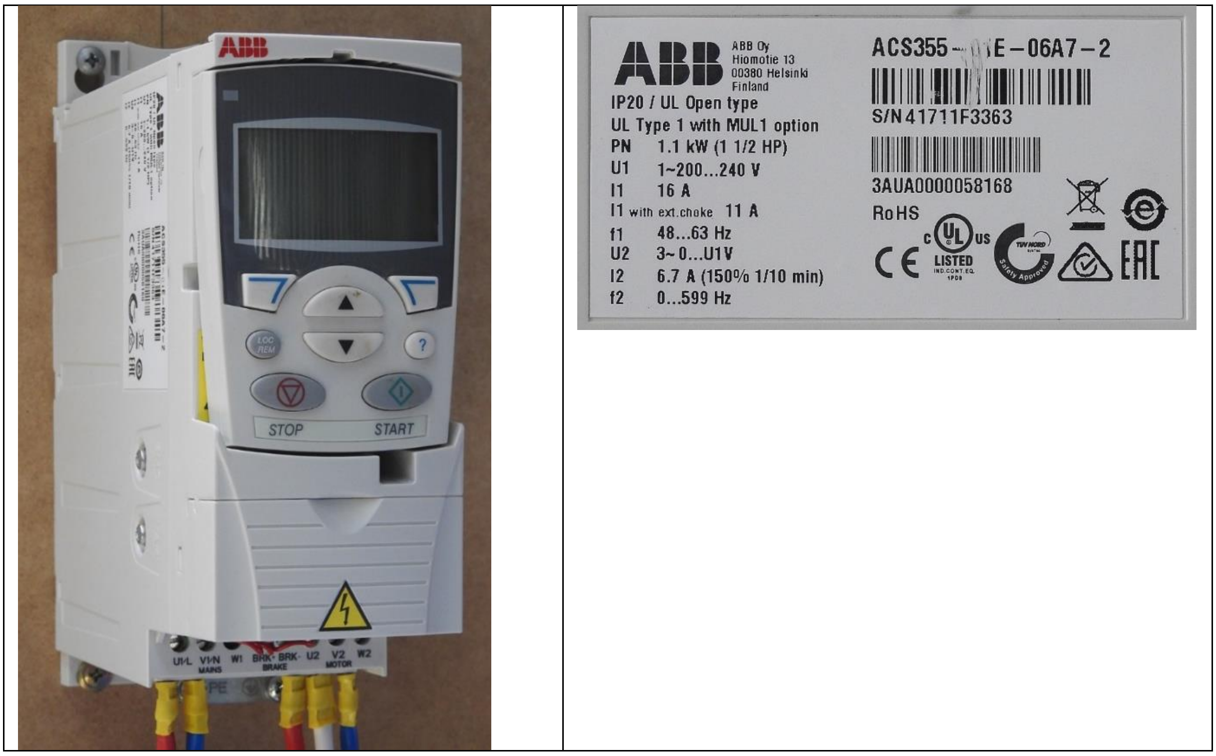


ABB Oy
Hiomotie 13
00380 Helsinki
Finland

ACS355-[illegible]E-06A7-2
S/N 41711F3363
3AUA0000058168
RoHS

IP20 / UL Open type
UL Type 1 with MUL1 option
PN 1.1 kW (1 1/2 HP)
U1 1~200...240 V
I1 16 A
I1 with ext.choke 11 A
f1 48...63 Hz
U2 3~ 0...U1V
I2 6.7 A (150% 1/10 min)
f2 0...599 Hz

**Figure 42** No. 1A: external view and rating plate

### 6.2.2 No. 01B: ABB 11 kW

| | |
|---|---|
| **Manufacturer** | ABB |
| **Model** | ACS355 |
| **Input Section:** | Diode bridge rectifier without filter |
| **Power PN** | 11 kW |
| **Input voltage U1** | 380-480 V, 3 phases |
| **Input current I1** | 30.9 A |
| **Input frequency f1** | 48-63 Hz |
| **Output voltage** | 0-U1 V, 3 phases |
| **Output current I2** | 23.1 A |
| **Output frequency f2** | 0-600 Hz |
| **Serial number** | 41051D5043 |

ABB

IP20/UL Open type
UL Type 1 with MUL1 option
11 kW (15 HP)
U1 3 ~380...480 V
I1 30.9 A
f1 48...63 Hz
U2 3 ~0...U1 V
I2 23.1 A (150% 1/10 min)
f2 0...600 Hz

ACS355 – 03E – 23A1 – 4
S/N 41051D5043
3AUA0000058192
RoHS
LISTED
IND.CONT.EQ.
1PD8

Figure 43 No. 1B: external view and rating plate

### 6.2.3 No. 02A: Schneider 2.2 kW, nominal output 5.8 Amps – 3 phases supply

The Schneider Altivar 61, 2.2 kW CDM with device No. 02A and serial number 8B 1151 112 029 was submitted “off the shelf” to the UTP RR’C Phase 1 by Danish Technological Institute.

- Manufacturer: Schneider Electric
- Model: Altivar 61 – ATV61HU22N4
- Input Section: Diode bridge rectifier without filter
- Nominal Power: 2.2 kW
- Input side: 3 phases, 50 Hz: 400 VAC / 8.2 A, 60 Hz: 460 VAC / 8.2 A
- Output CDM nominal: 400 VAC / 5.8 A
- Output UTP nominal: 400 VAC / 4.75 A

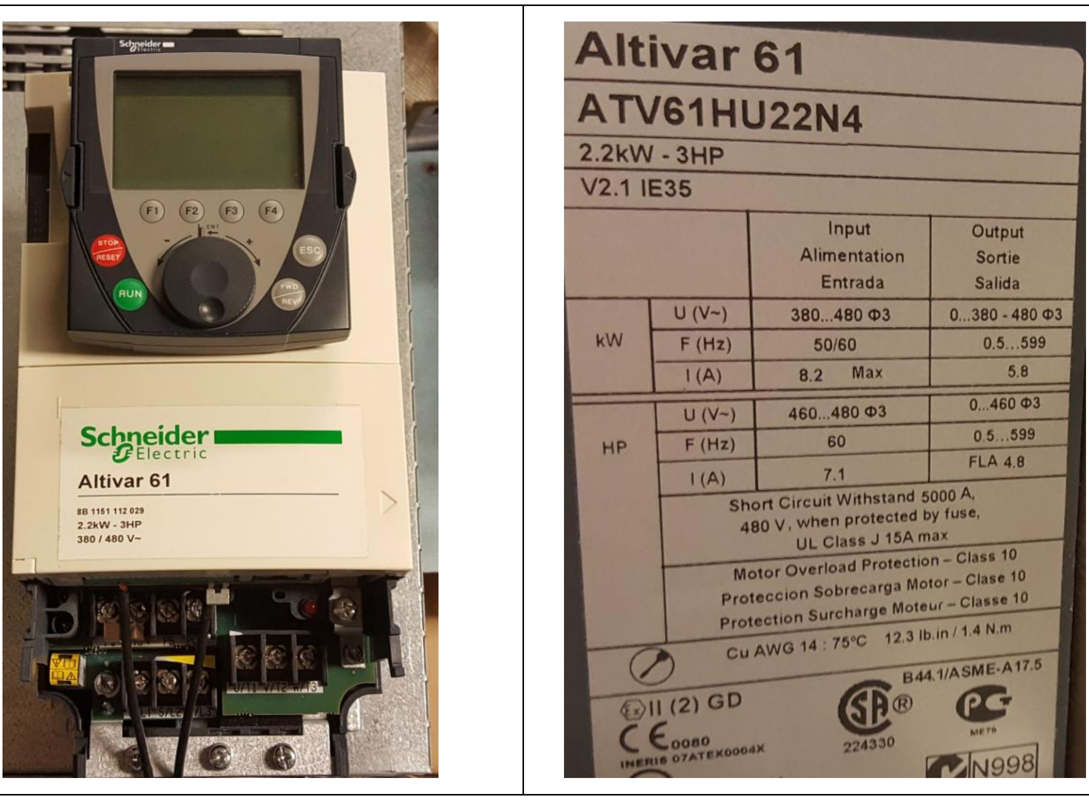
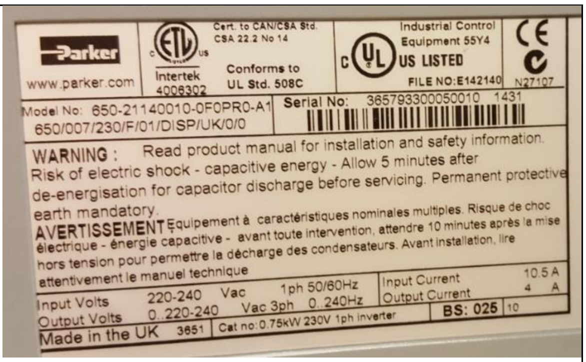


**Figure 44** No. 2A: Schneider Altivar 61 – 2.2 kW

### 6.2.4 No. 02B: Parker 0.75 kW, nominal output 4.0 Amps – 1 phase supply

The Parker 650, 0.75 kW CDM with device No. 02B and serial number 365793300050010 1431 was submitted “off the shelf” to the UTP RR’C Phase 1 by Danish Technological Institute.

| | |
|---|---|
| Manufacturer: | Parker |
| Model: | 650-21140010-0F0PR0-A1 |
| Input Section: | Diode bridge rectifier without filter |
| Nominal Power: | 0.75 kW |
| Input side: | 1 phase, 50/60 Hz: 230 VAC / 10.5 A |
| Output CDM nominal: | 230 VAC / 4.0 A |
| Output UTP nominal: | 400 VAC / 3.4 A |


Parker
www.parker.com
Intertek
4006302
Cert. to CAN/CSA Std.
CSA 22.2 No 14
Conforms to
UL Std. 508C
C UL US LISTED
Industrial Control
Equipment 55Y4
FILE NO:E142140
N27107
Model No: 650-21140010-0F0PR0-A1
650/007/230/F/01/DISP/UK/0/0
Serial No: 365793300050010 1431

WARNING : Read product manual for installation and safety information. Risk of electric shock - capacitive energy - Allow 5 minutes after de-energisation for capacitor discharge before servicing. Permanent protective earth mandatory.

AVERTISSEMENT Equipement à caractéristiques nominales multiples. Risque de choc électrique - énergie capacitive - avant toute intervention, attendre 10 minutes après la mise hors tension pour permettre la décharge des condensateurs. Avant installation, lire attentivement le manuel technique

Input Volts 220-240 Vac 1ph 50/60Hz
Output Volts 0..220-240 Vac 3ph 0..240Hz
Input Current 10.5 A
Output Current 4 A
BS: 025 10
Made in the UK 3651
Cat no:0.75kW 230V 1ph inverter

Figure 45 No. 2B: Parker 650 – 0.75 kW

### 6.2.5 No. 03A: Lenze I550 5.5 kW

The Lenze I550, 5.5 kW VFD with device No. 03A and serial number 1606488208508959000001 was submitted to the UTP RR pilot round by the Bern University of Applied Sciences.

- Manufacturer: Lenze
- Model: I550 (I55AE255F20V10000S)
- Input Section: Diode bridge rectifier without filter
- Power (Heavy Duty): 5.5 kW
- Input (Heavy Duty): 3/PE, 50Hz: 400VAC/17.2A, 60 Hz: 480 VAC/14.3 A
- Output (Heavy Duty): 0-400 VAC/13 A, 0-480 VAC/11 A, 0-599 Hz
- Power (Light Duty): 7.5 kW
- Input (Light Duty): 3/PE, 50 Hz: 400 VAC/18.3 A, 60 Hz: 480 VAC/15.3 A
- Output (Light Duty): 0-400 VAC/15.6 A, 0-480 VAC/13.2 A, 0-599 Hz

Figure 46 No. 3A: Lenze I550

**i500 ist die neue Inverterreihe im Leistungsbereich von 0.25 – 132 kW. Schlankes Design, skalierbare Funktionalität und außerordentlich anwenderfreundlich – das sind die Attribute, die sie auszeichnen.**

Mit i500 steht ein qualitativ hochwertiger Umrichter zur Verfügung, der bereits heute die zukünftig geltende Norm nach der Wirkungsgradklassen (IE) der EN 50598-2 erfüllt. In Summe steht somit ein verlässlicher und zukunftssicherer Antrieb für umfangreiche Maschinenaufgaben zur Verfügung.

## Highlights

- Platzsparendes Design von 60 mm Breite und 130 mm Tiefe spart Raum im Schaltschrank.
- Innovative Interaktionsmöglichkeiten ermöglichen neue Bestzeiten bei der Inbetriebnahme.
- Breit aufgestellt ermöglicht die modulare Bauweise unterschiedliche Produktkonfigurationen, ganz so, wie es die Maschine erfordert.
- i500 empfiehlt sich für Anwendungen im Bereich der Pumpen und Lüfter, der Förder-, Fahr-, Wickel-, Form-, Werkzeug- und Hubantriebe.

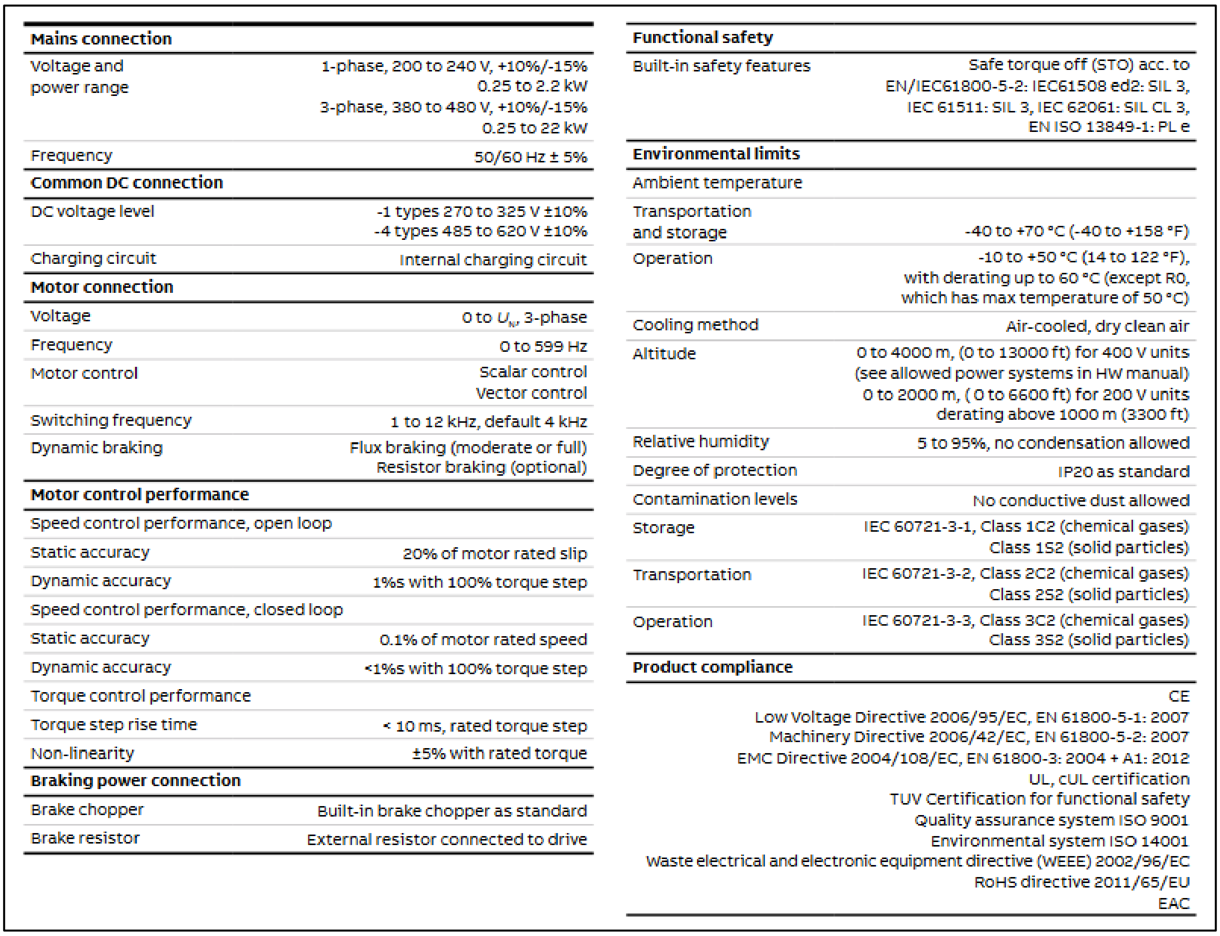
Figure 47 No. 3A: Extract from specifications

### 6.2.6 No. 03B: ABB ACS380 5.5 kW

The ABB ACS380 5.5 kW VFD with device No. 03C and serial number M181300140 was submitted to the UTP RR pilot round by the Bern University of Applied Sciences.

- Manufacturer: ABB
- Model: ACS380 (ACS380-042S-12A6-4)
- Input Section: Diode bridge rectifier without filter
- Power (Heavy Duty): 5.5 kW
- Input (Heavy Duty): 3/PE, 50 Hz: 400VAC/15 A, 60 Hz: 480 VAC/12.2 A
- Output (Heavy Duty): 0-400 VAC/9.4 A, 0-480 VAC/7.6 A, 0-599 Hz
- Power (Light Duty): N.A.
- Input (Light Duty): 3/PE, 50 Hz: 400 VAC/19.2 A, 60 Hz: 480 VAC/17.6 A
- Output (Light Duty): 0-400 VAC/12 A, 0-480 VAC/11 A, 0-599 Hz

Figure 48 No. 3B: ABB ACS380 5.5 kW



| | |
|---|---|
| **Mains connection** | |
| Voltage and power range | 1-phase, 200 to 240 V, +10%/-15%<br>0.25 to 2.2 kW<br>3-phase, 380 to 480 V, +10%/-15%<br>0.25 to 22 kW |
| Frequency | 50/60 Hz ± 5% |
| **Common DC connection** | |
| DC voltage level | -1 types 270 to 325 V ±10%<br>-4 types 485 to 620 V ±10% |
| Charging circuit | Internal charging circuit |
| **Motor connection** | |
| Voltage | 0 to $U_N$, 3-phase |
| Frequency | 0 to 599 Hz |
| Motor control | Scalar control<br>Vector control |
| Switching frequency | 1 to 12 kHz, default 4 kHz |
| Dynamic braking | Flux braking (moderate or full)<br>Resistor braking (optional) |
| **Motor control performance** | |
| Speed control performance, open loop | |
| Static accuracy | 20% of motor rated slip |
| Dynamic accuracy | 1%s with 100% torque step |
| Speed control performance, closed loop | |
| Static accuracy | 0.1% of motor rated speed |
| Dynamic accuracy | <1%s with 100% torque step |
| Torque control performance | |
| Torque step rise time | < 10 ms, rated torque step |
| Non-linearity | ±5% with rated torque |
| **Braking power connection** | |
| Brake chopper | Built-in brake chopper as standard |
| Brake resistor | External resistor connected to drive |

| | |
|---|---|
| **Functional safety** | |
| Built-in safety features | Safe torque off (STO) acc. to EN/IEC61800-5-2: IEC61508 ed2: SIL 3, IEC 61511: SIL 3, IEC 62061: SIL CL 3, EN ISO 13849-1: PL e |
| **Environmental limits** | |
| Ambient temperature | |
| Transportation and storage | -40 to +70 °C (-40 to +158 °F) |
| Operation | -10 to +50 °C (14 to 122 °F), with derating up to 60 °C (except R0, which has max temperature of 50 °C) |
| Cooling method | Air-cooled, dry clean air |
| Altitude | 0 to 4000 m, (0 to 13000 ft) for 400 V units (see allowed power systems in HW manual)<br>0 to 2000 m, ( 0 to 6600 ft) for 200 V units derating above 1000 m (3300 ft) |
| Relative humidity | 5 to 95%, no condensation allowed |
| Degree of protection | IP20 as standard |
| Contamination levels | No conductive dust allowed |
| Storage | IEC 60721-3-1, Class 1C2 (chemical gases)<br>Class 1S2 (solid particles) |
| Transportation | IEC 60721-3-2, Class 2C2 (chemical gases)<br>Class 2S2 (solid particles) |
| Operation | IEC 60721-3-3, Class 3C2 (chemical gases)<br>Class 3S2 (solid particles) |
| **Product compliance** | |
| | CE<br>Low Voltage Directive 2006/95/EC, EN 61800-5-1: 2007<br>Machinery Directive 2006/42/EC, EN 61800-5-2: 2007<br>EMC Directive 2004/108/EC, EN 61800-3: 2004 + A1: 2012<br>UL, cUL certification<br>TUV Certification for functional safety<br>Quality assurance system ISO 9001<br>Environmental system ISO 14001<br>Waste electrical and electronic equipment directive (WEEE) 2002/96/EC<br>RoHS directive 2011/65/EU<br>EAC |

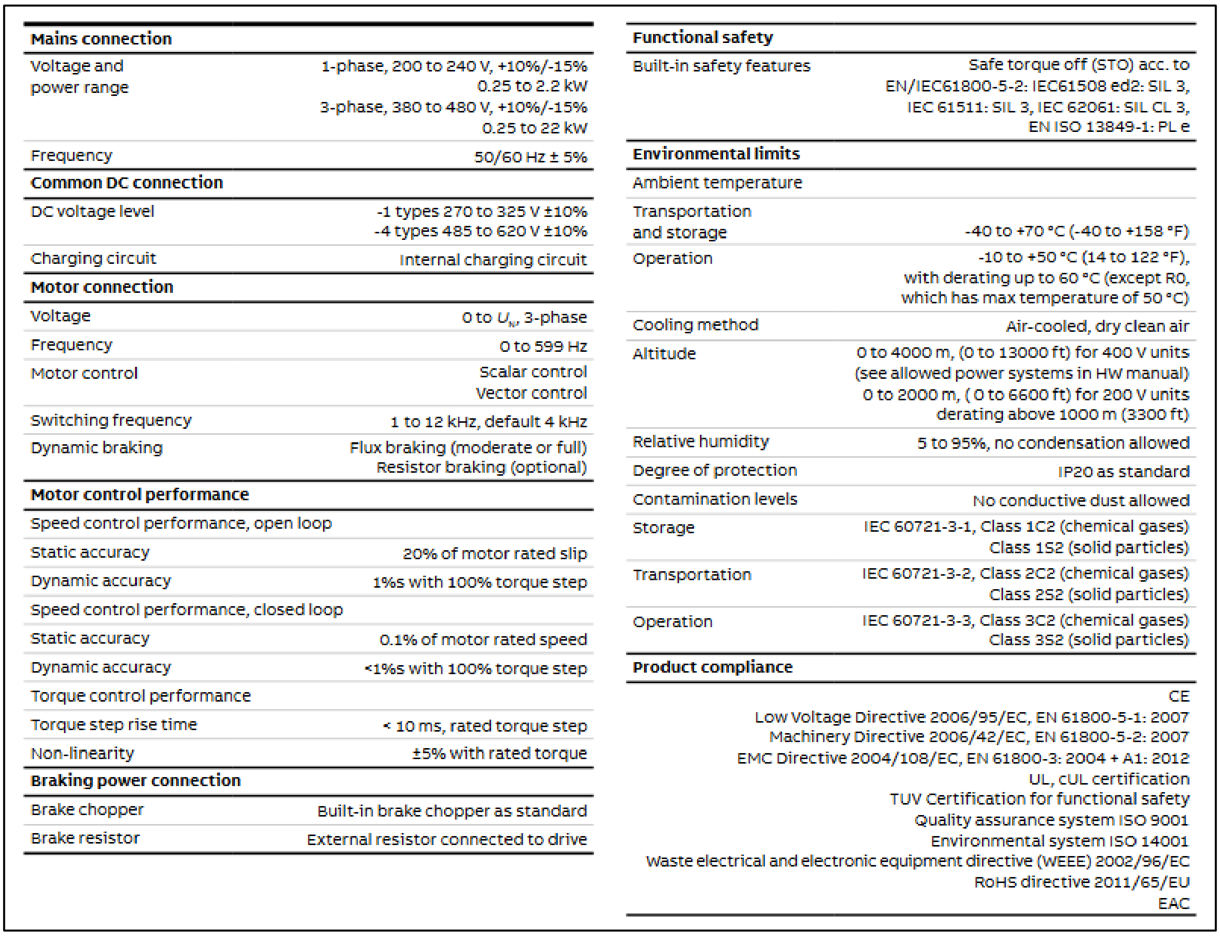
Figure 49 No. 3B: Extract from specifications

### 6.2.7 No. 03C: ABB ACS380 2.2 kW

The ABB ACS380 2.2 kW VFD with device No. 03C and serial number M181300143 was submitted to the UTP RR pilot round by the Bern University of Applied Sciences.

| | |
|---|---|
| Manufacturer: | ABB |
| Model: | ACS380 (ACS380-042S-05A6-4+R701) |
| Input Section: | Diode bridge rectifier without filter |
| Power (Heavy Duty): | 2.2 kW |
| Input (Heavy Duty): | 3/PE, 50 Hz: 400 VAC/6.4 A, 60 Hz: 480 VAC/5.4 A |
| Output (Heavy Duty): | 0-400 VAC/4 A, 0-480 VAC/3.4 A, 0-599 Hz |
| Power (Light Duty): | N.A. |
| Input (Light Duty): | 3/PE, 50 Hz: 400 VAC/8.5 A, 60 Hz: 480 VAC/7.7 A |
| Output (Light Duty): | 0-400 VAC/5.3 A, 0-480 VAC/4.8 A, 0-599 Hz |

**Figure 50** No. 3C: ABB ACS380 2.2 kW



| | |
|---|---|
| **Mains connection** | |
| Voltage and power range | 1-phase, 200 to 240 V, +10%/-15%<br>0.25 to 2.2 kW<br>3-phase, 380 to 480 V, +10%/-15%<br>0.25 to 22 kW |
| Frequency | 50/60 Hz ± 5% |
| **Common DC connection** | |
| DC voltage level | -1 types 270 to 325 V ±10%<br>-4 types 485 to 620 V ±10% |
| Charging circuit | Internal charging circuit |
| **Motor connection** | |
| Voltage | 0 to $U_N$, 3-phase |
| Frequency | 0 to 599 Hz |
| Motor control | Scalar control<br>Vector control |
| Switching frequency | 1 to 12 kHz, default 4 kHz |
| Dynamic braking | Flux braking (moderate or full)<br>Resistor braking (optional) |
| **Motor control performance** | |
| Speed control performance, open loop | |
| Static accuracy | 20% of motor rated slip |
| Dynamic accuracy | 1%s with 100% torque step |
| Speed control performance, closed loop | |
| Static accuracy | 0.1% of motor rated speed |
| Dynamic accuracy | <1%s with 100% torque step |
| Torque control performance | |
| Torque step rise time | < 10 ms, rated torque step |
| Non-linearity | ±5% with rated torque |
| **Braking power connection** | |
| Brake chopper | Built-in brake chopper as standard |
| Brake resistor | External resistor connected to drive |

| | |
|---|---|
| **Functional safety** | |
| Built-in safety features | Safe torque off (STO) acc. to EN/IEC61800-5-2: IEC61508 ed2: SIL 3, IEC 61511: SIL 3, IEC 62061: SIL CL 3, EN ISO 13849-1: PL e |
| **Environmental limits** | |
| Ambient temperature | |
| Transportation and storage | -40 to +70 °C (-40 to +158 °F) |
| Operation | -10 to +50 °C (14 to 122 °F), with derating up to 60 °C (except R0, which has max temperature of 50 °C) |
| Cooling method | Air-cooled, dry clean air |
| Altitude | 0 to 4000 m, (0 to 13000 ft) for 400 V units (see allowed power systems in HW manual)<br>0 to 2000 m, ( 0 to 6600 ft) for 200 V units derating above 1000 m (3300 ft) |
| Relative humidity | 5 to 95%, no condensation allowed |
| Degree of protection | IP20 as standard |
| Contamination levels | No conductive dust allowed |
| Storage | IEC 60721-3-1, Class 1C2 (chemical gases)<br>Class 1S2 (solid particles) |
| Transportation | IEC 60721-3-2, Class 2C2 (chemical gases)<br>Class 2S2 (solid particles) |
| Operation | IEC 60721-3-3, Class 3C2 (chemical gases)<br>Class 3S2 (solid particles) |
| **Product compliance** | |
| | CE<br>Low Voltage Directive 2006/95/EC, EN 61800-5-1: 2007<br>Machinery Directive 2006/42/EC, EN 61800-5-2: 2007<br>EMC Directive 2004/108/EC, EN 61800-3: 2004 + A1: 2012<br>UL, cUL certification<br>TUV Certification for functional safety<br>Quality assurance system ISO 9001<br>Environmental system ISO 14001<br>Waste electrical and electronic equipment directive (WEEE) 2002/96/EC<br>RoHS directive 2011/65/EU<br>EAC |

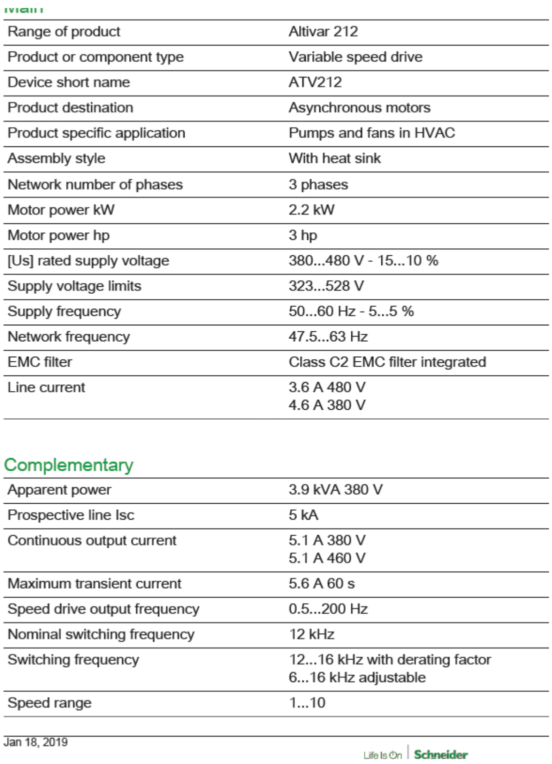
Figure 51 No. 3C: Extract from specifications

### 6.2.8 No. 04A: Schneider Altivar 212 - ATV212HU22N4 2.2 kW

The 2.2 kW VFD with device No. 04A was submitted to the UTP RR pilot round testing by Advanced Energy, having been donated to Advanced Energy by Schneider Electric.

Datasheets and operating manuals for converter 04A are readily available online from the manufacturer's website. Extracts from the datasheets are provided in Figure 50.

Input Section: Diode bridge rectifier without filter



| | |
|---|---|
| Range of product | Altivar 212 |
| Product or component type | Variable speed drive |
| Device short name | ATV212 |
| Product destination | Asynchronous motors |
| Product specific application | Pumps and fans in HVAC |
| Assembly style | With heat sink |
| Network number of phases | 3 phases |
| Motor power kW | 2.2 kW |
| Motor power hp | 3 hp |
| [Us] rated supply voltage | 380...480 V - 15...10 % |
| Supply voltage limits | 323...528 V |
| Supply frequency | 50...60 Hz - 5...5 % |
| Network frequency | 47.5...63 Hz |
| EMC filter | Class C2 EMC filter integrated |
| Line current | 3.6 A 480 V<br>4.6 A 380 V |

Complementary

| | |
|---|---|
| Apparent power | 3.9 kVA 380 V |
| Prospective line Isc | 5 kA |
| Continuous output current | 5.1 A 380 V<br>5.1 A 460 V |
| Maximum transient current | 5.6 A 60 s |
| Speed drive output frequency | 0.5...200 Hz |
| Nominal switching frequency | 12 kHz |
| Switching frequency | 12...16 kHz with derating factor<br>6...16 kHz adjustable |
| Speed range | 1...10 |

Jan 18, 2019

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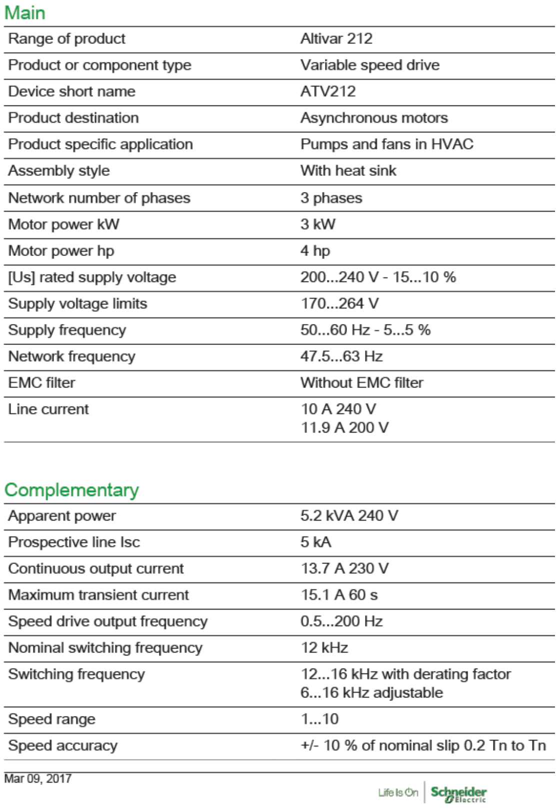
**Figure 52 No. 4A: external feature and data sheet**

### 6.2.9 No. 04B: Schneider Altivar 212 - ATV212HU30M3X 3 kW

The 3 kW VFD with device No. 04B was submitted to the UTP RR pilot round testing by Advanced Energy, having been donated to Advanced Energy by Schneider Electric.

Datasheets and operating manuals for converter 04B are readily available online from the manufacturer’s website. Extracts from the datasheets are provided in Figure 51.

Input Section: Diode bridge rectifier without filter



Main

| | |
|---|---|
| Range of product | Altivar 212 |
| Product or component type | Variable speed drive |
| Device short name | ATV212 |
| Product destination | Asynchronous motors |
| Product specific application | Pumps and fans in HVAC |
| Assembly style | With heat sink |
| Network number of phases | 3 phases |
| Motor power kW | 3 kW |
| Motor power hp | 4 hp |
| [Us] rated supply voltage | 200...240 V - 15...10 % |
| Supply voltage limits | 170...264 V |
| Supply frequency | 50...60 Hz - 5...5 % |
| Network frequency | 47.5...63 Hz |
| EMC filter | Without EMC filter |
| Line current | 10 A 240 V<br>11.9 A 200 V |

Complementary

| | |
|---|---|
| Apparent power | 5.2 kVA 240 V |
| Prospective line Isc | 5 kA |
| Continuous output current | 13.7 A 230 V |
| Maximum transient current | 15.1 A 60 s |
| Speed drive output frequency | 0.5...200 Hz |
| Nominal switching frequency | 12 kHz |
| Switching frequency | 12...16 kHz with derating factor<br>6...16 kHz adjustable |
| Speed range | 1...10 |
| Speed accuracy | +/- 10 % of nominal slip 0.2 Tn to Tn |

Mar 09, 2017

Figure 53 No. 4B: external feature

# 7. References

[1] IEC 61800-9-2, edition 1: 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, published 3 March 2017, Geneva, Switzerland

[2] Pierre Angers: NEMA Motor Round Robin, in Motor Summit 2018 International: conference proceedings, Zurich, Switzerland, 2018

[3] Andrew Baghurst, Martin Doppelbauer, Roland Wetter: Loading means for the characterization and measurement of converter loss and efficiency, in EEMODS'15: conference proceedings, Helsinki Finland, 2015