Round Robin tests for converter losses (RR'C): Results from phase 1

The RR'C TEAM (phase 1)

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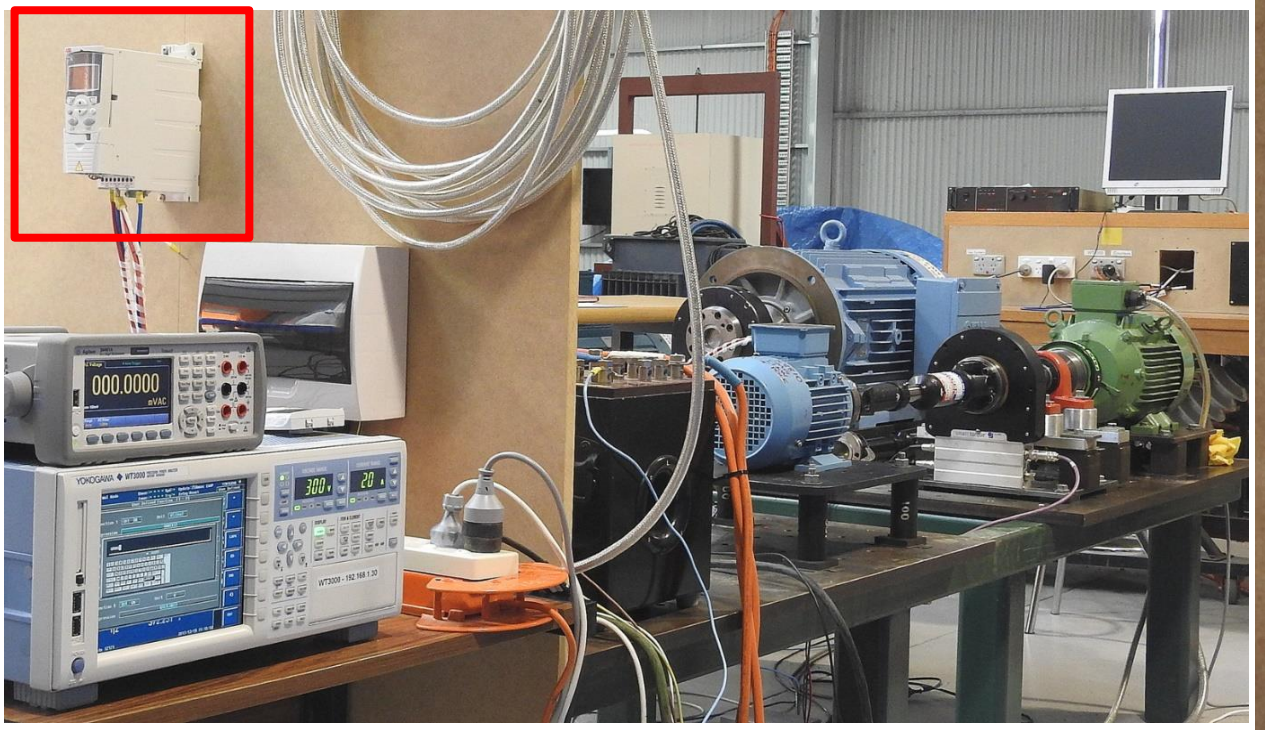
Thanks

- To the 4 testing labs: AE, BFH, CalTest, DTI
- to the 4 governments for funding: AU, CH, DK, US
- to the IEC and 4 E EMSA for good cooperation
- to industry for support and products
- for IEC SC 22G WG18 for patience and consideration of results

The Problem

1. We know a lot about nominal motor performance and efficiency
2. We know a lot about nominal pump, fan. compressor performance and efficiency
3. We do not know enough about part load performance and efficiency
4. We do not know well how to test a Variable Frequency Converter and its performance and efficiency

Measuring of losses of VFC



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

Background

- IEC 61800-9-2, edition 1: 3 March 2017
  - Unsatisfactory testing description
  - Discussion on level of reference losses
  - No statistical evidence to set IE levels
  - No agreement on 0 % and 100 % speed operating points
- EEMODS 2017 in Rome IT: 6 September 2017
  - Launch of RR'C Task Force EMSA & WG18
  - Cooperation agreement EMSA & IEC WG18
- WG18 meeting in Tampa, FL USA: 26 - 28 February 2018
  - Intermediary report: UTP
  - First test results
- Workshop at Motor Summit'18: 13 November 2018
  - Present and discuss intermediary results: Uniform Testing Protocol
  - What to consider in phase 2
- WG18 meeting: 19 - 21 February 2019 in Melbourne, Australia
  - Present RR'C final report phase 1: findings & recommendations on testing method (UTP)
  - Launch of RR'C phase 2

Report RR'C phase 1
(12 February 2019)

Electric Motor Systems EMSA

ROUND ROBIN OF CONVERTER LOSSES

Report of Results of Phase 1

final1 20190212

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

Electric Motor Systems EMSA

RR'C PHASE 2 – UTP version 2.0

Converter loss measurement Uniform Testing Protocol (UTP), including step-by-step measurement procedure

12 February 2019

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1. BACKGROUND

This 2019 Uniform Testing Protocol (UTP 2.0) is based on experience gained in the RR'C phase 1 feasibility study in 2018 and provides guidance for participating laboratories.

This UTP is based on a paper presented at EEMODS '15 in Helsinki [4], in which the following precepts were put forward:

- Converters are power supplies, providing voltage and current at a given frequency
- They do not (directly) produce either speed or torque
- Induction motors operating under variable mechanical load conditions are ideal electrical loads for the measurement of converter losses and efficiency

Electric Motor Systems EMSA

Round Robin test for converter losses
RR'C Phase 2: main study

UNIFORM TESTING PROTOCOL (UTP)

Standard Reporting Format (SRF)

Test object:	ABB		**Load motor:**	LENZE IE3 4p - Delta	
	ACS355-01E-06A7-2			M55AP090M045E00CT	
	1.1	kW		1.1	kW
	230	Supply voltage [V]		230	Volt
	6.7	Max output current [A]		50	Hz
	68.0	Stated manufactorer losses [W]		4.1	Ampere
	4.3	Suggested nominal output current [A]		0.80	Cosφ

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

Mechanical setup:

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

Measurement setup:

All electrical quantities were measured by a Yokogawa WT3000E power analyzer configured in 1 x 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:

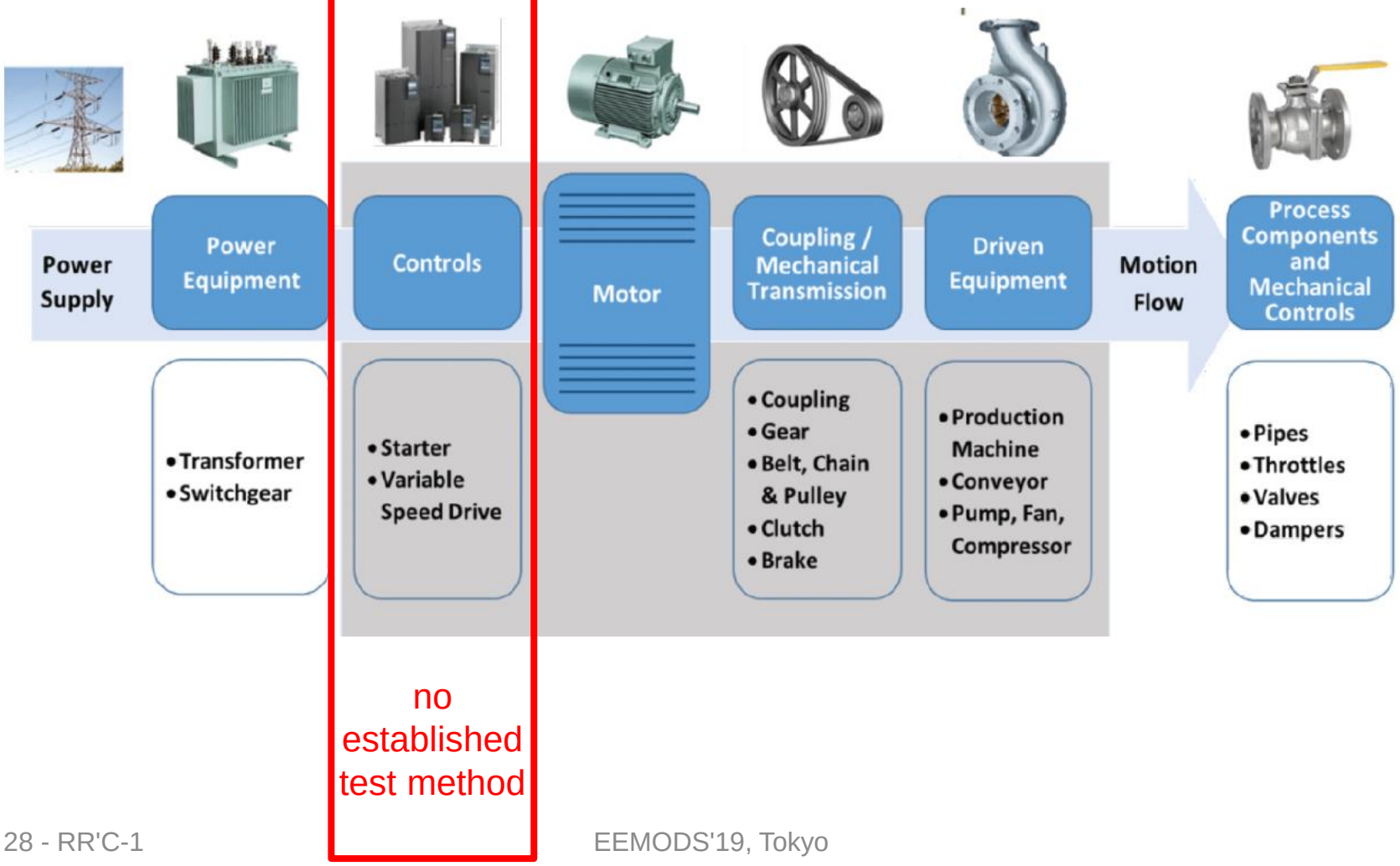
There is no "factory default setting" but changing application macro to "any macro" and back to ABB standard results in something similar.
The converter has a mechanical fan that runs constantly during operation.

The Report RR'C, phase 1 | The UTP V2 | The SRF V2

Collaboration on RR'C between IEC SC 22G WG18 & 4E EMSA

- EMSA provides the management of the RR'C and secures the funding for new scientific evidence.
- Involved governments:
  AU, CH, DK, USA (funders in phase 1),
  plus GE, CA, JP and CN (phase 2)
- All documents and testing results are shared with IEC WG18, and published by 4E EMSA.
- Once the results are on the table regular IEC procedures will take over (CD/CDV/FDIS).
- 11 members of WG18 are members of RR'C Task Force in phase 1,
  all WG18 members are invited to contribute in phase 2.

Electric Motor Driven System



Goal of RR'C

- The test method described in IEC 61800-9-2:2017 (edition 1) for converters (and in IEC TS 60034-2-3:2013 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/IE3 levels.
  ► Clarify spread of product performance by different manufacturers.

Scientific goal of RR'C

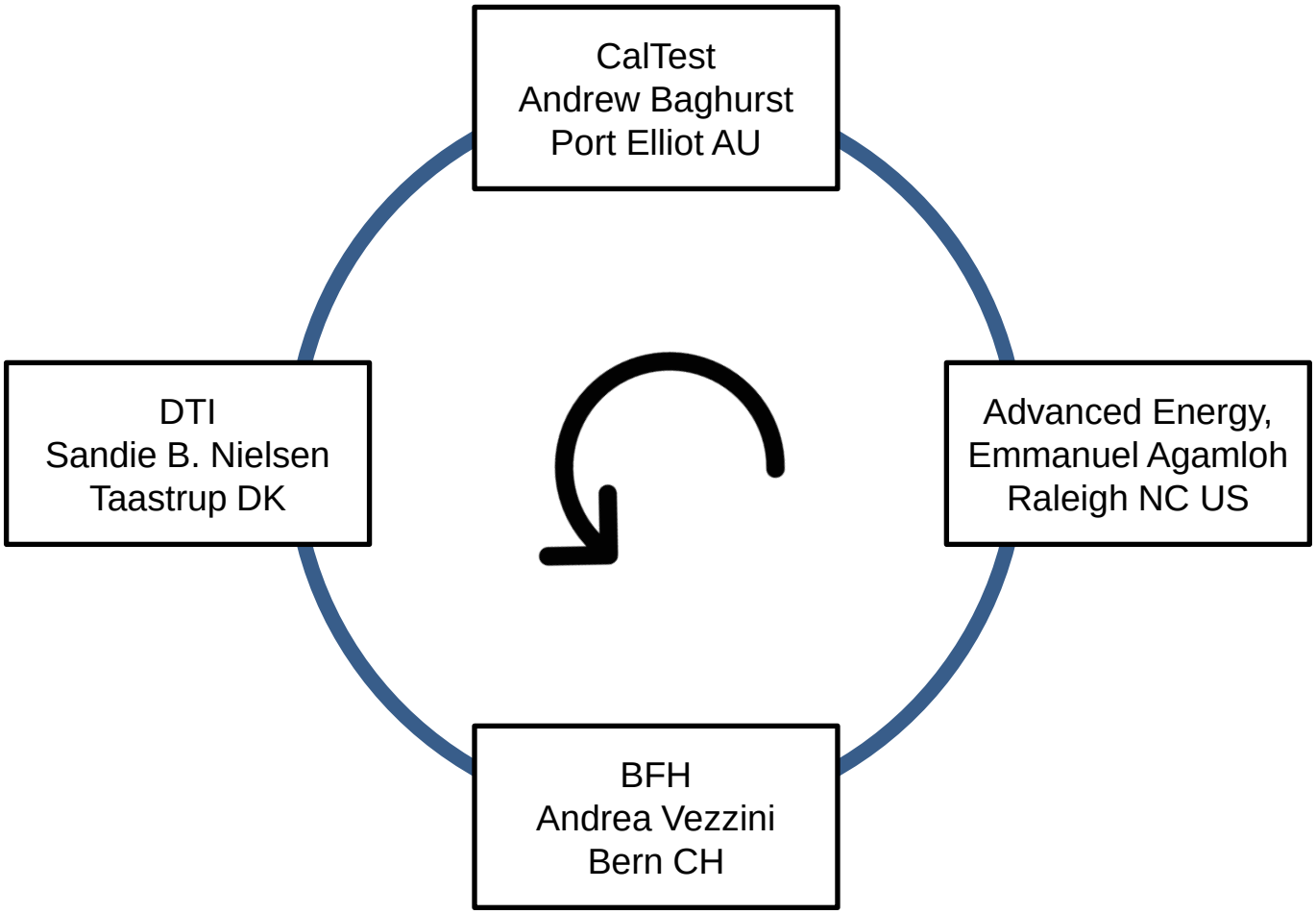
- Accurate test results for losses of converters
- Repeatable test method for converters
- Uniform Testing Protocol (UTP)
- Confidential intermediary RR'C test results until all results are available
- Fully documented tests
- Transparent procedures and results

- Keep in mind:
  Combined efficiency of motor and converter

RR'C in two phases

- **Phase 1: preliminary and preparatory** (9 VFD) - EUR 100 k
  Define and check converter testing methodology with high repeatability (Uniform Testing Protocol)
- **Phase 2: full Round Robin program** (circa 60 VFD) - EUR 300 k
  Test samples from 0.12 kW - 100 kW in RR,
  Test samples from 100 kW to 1000 kW stationary,
  Statistically relevant sample of tests
- Introduce findings into IEC 61800-9-2, edition 2
  - Test method UTP
  - Operating points
  - Reference values
  - Efficiency classes

RR'C labs in phase 1



Tests in phase 1

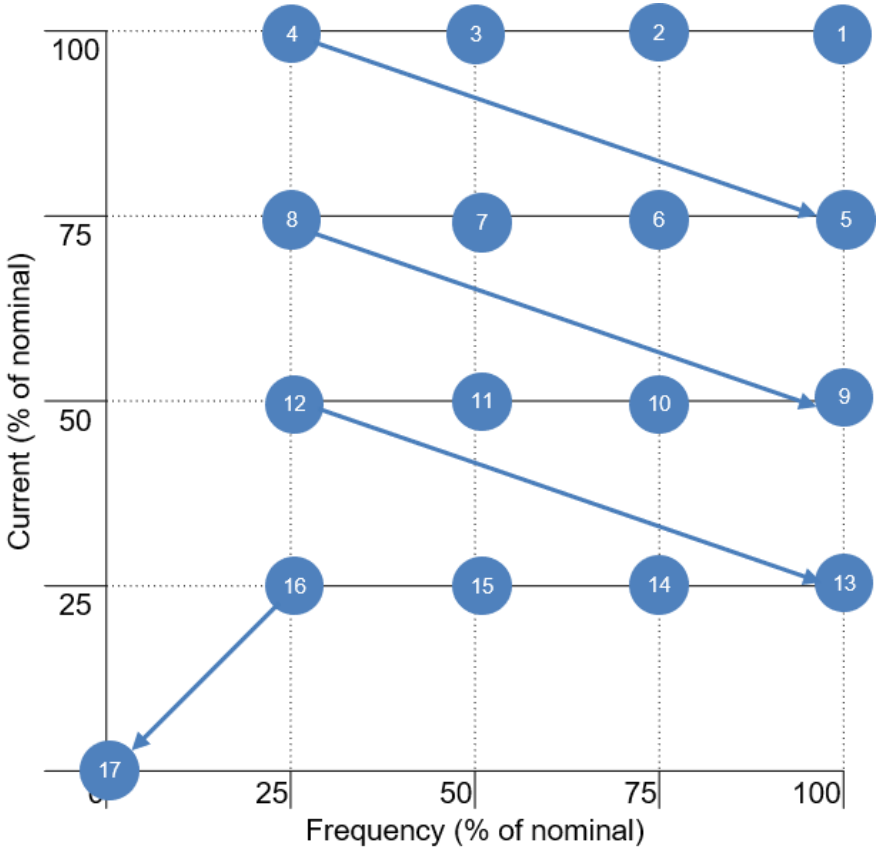
December 2017 - November 2018

- 58 tests
- 9 different converters from 4 manufacturers: 0.75 kW - 11 kW
- 24 different motors
  - 1- / 3-phase,
  - IE1 / IE2 / IE3,
  - 2-pole / 4-pole,
  - 50 Hz / 60Hz
  - same size / larger size VFC

Overview Tests

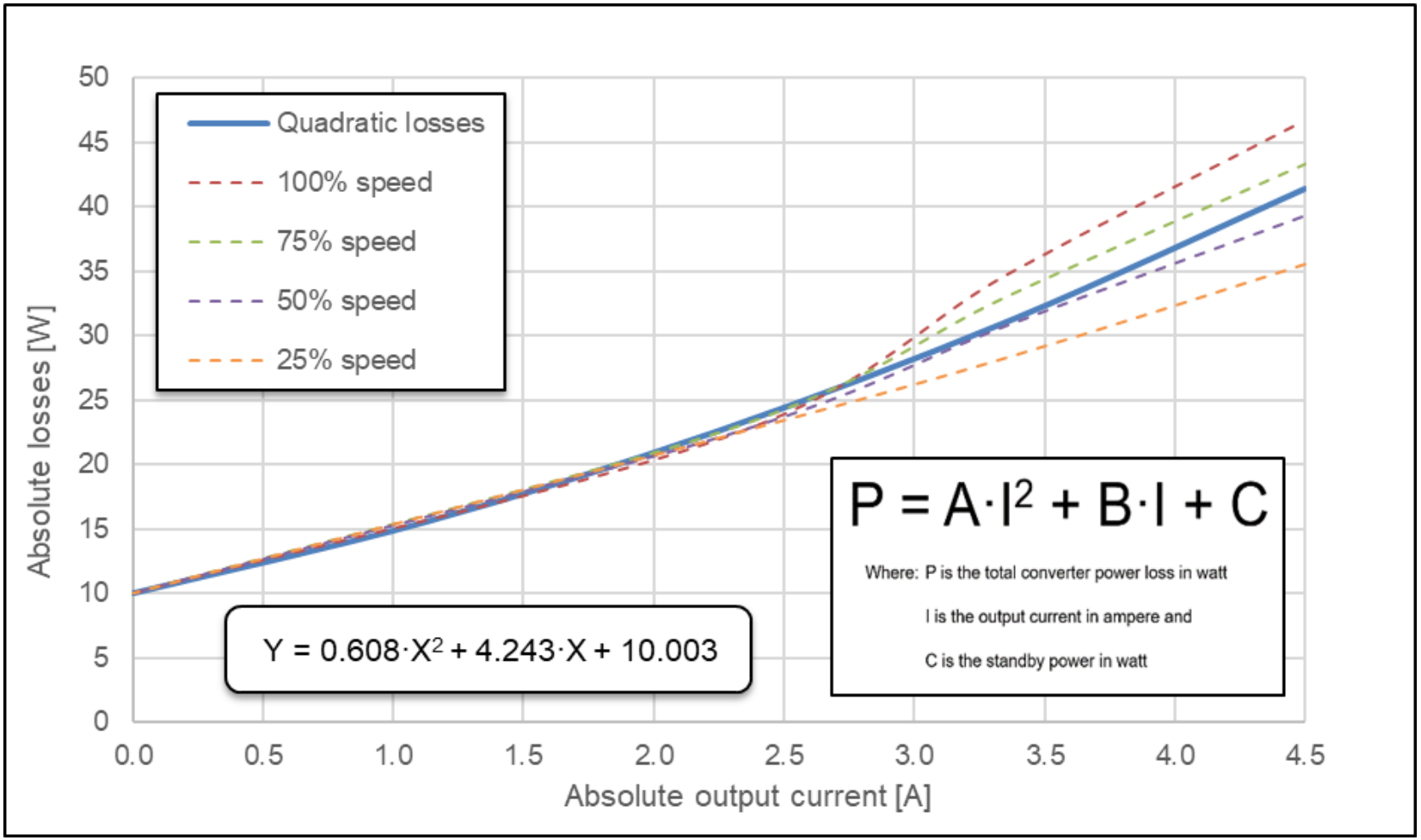
Owner	Brand	Size [kW]	RR'C No.	CalTest	DTI	BFH	AE
Australia	ABB	1.1	01A	X	X	X	X
	ABB	11.0	01B	X			
Denmark	Schneider	2.2	02A		X	X	X
	Parker	0.75	02B		X	X	X
Switzerland	Lenze	5.5	03A	X		X	X
	ABB	5.5	03B	X		X	X
	ABB	2.2	03C			X	
USA	Schneider	2.2	04A	X	X		X
	Schneider	3.0	04B	X	X		X

UTP: 17 Operating Points



- defined number of points
- defined sequence
- defined timing (thermal equilibrium)

Standard Reporting Format:
Quadratic Curve



Standard Reporting Format:
Data Table

Converter tested: **650-21140010-0F0PR0-A1** **Nominal current:** **3,40**

Load Point		Supply			Output				Calculation	
Frequency	Current	V	I	Power	Flux V	$V_{(rms)}$	I	Power	Eta	Losses
% / 50 Hz	% rated	(V)	(A)	(W)	(V)	(V)	(A)	(W)	(%)	(W)
100%	100%	230	7,51	1071		232	3,80	1034	96,6	36,5
	75%	229	5,20	695		239	2,66	670	96,4	24,8
	Min.	231	1,18	139		255	1,66	125	89,7	14,3
75%	100%	231	6,01	825		212	3,40	793	96,1	32,2
	75%	230	4,28	564		214	2,56	541	95,8	23,6
	Min.	230	1,03	114		224	1,72	99	86,8	15,0
50%	100%	231	4,44	591		174	3,49	561	95,0	29,6
	75%	232	3,15	405		177	2,59	383	94,6	21,9
	Min.	230	0,82	88		183	1,69	73	83,3	14,7
25%	100%	231	2,40	309		122	3,48	283	91,4	26,5
	75%	231	1,81	220		123	2,57	200	90,9	20,2
	Min.	230	0,73	76		127	1,62	62	81,3	14,2
0,0%		230	0,13	9		1	0,10	0	-0,5	9,0
Stopped		230	0,10	4,6		0	0,00	0	0,0	4,6

Resulting quadratic equation:

x^2	x^1	x^0	R^2
0,76	4,87	4,59	0,999

Example:

Amps
3,40

A^2 losses: 29,9 W

Converter No.04A : Schneider 2.2 kW

	AE1 IE3	AE2 IE3	CalTest1 IE2	DTI1 IE2	DTI2 IE1	AE1 IE3	AE2 IE3	DTI1 IE1	DTI2 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

Aggregated Results of all Tests

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%

Key Results

- The UTP is a valuable test method that returns highly repeatable results from converter tests in different laboratories.
- The selection of the load motor has some sensitivity with respect to power rating and number of poles whereas manufacturer and efficiency class are less important.
- It is suggested that 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 conducted at 50 Hz and 60 Hz fundamental frequency without any impact on the losses.
- 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.

Recommendations & Conclusions

- The nominal and rated output current in ampere of any converter must be clearly defined. A solution has been introduced to use the reference output current in the standard.
- The converters can be tested with any asynchronous motor to return reasonable results. It is recommended to use IE2 or IE3 and only 4-pole motors of the same nominal rating as the converter.
- The no load/off point must be precisely defined to return repeatable results. Auxiliaries like fans, etc. can distort the measured 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.
- For phase 2 of the RR'C it is recommended to include converters with many typical accessories, filters, 4Q, etc. to evaluate the influence of these factors on the losses. Matrix converters will also be included.
- The comparison of losses and performance in basic drive modules and in complete drive modules (including auxiliaries) shall be more clearly distinguished in phase 2.

Contact

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- RR'C phase 1 report available under
  https://www.motorsystems.org/files/otherfiles/0000/0206/RR_C_report_phase_1_final_1_d_20190322.pdf

- www.motorsystems.org
- www.topmotors.ch
- www.motorsummit.ch