

RR'C PHASE 2 – UTP version 2.0

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

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INDEX

1.	BACKGROUND	1
2.	THE CONVERTERS	3
2.1	Output current	3
3.	INSTRUMENTATION.....	5
4.	ELECTRICAL SUPPLIES AND WIRING	5
5.	THERMAL CONSIDERATIONS.....	5
5.1	Laboratory ambient temperature	5
5.2	Converter mounting, and measurement of ambient air temperature.....	6
5.3	Converters with different (air-) cooling arrangements	6
5.4	Thermal stability	6
6.	CONVERTER SETTINGS.....	7
7.	STEP-BY-STEP MEASUREMENT PROCEDURE FOR UTP 2.0	8
8.	REFERENCES	10

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

- Converter losses are best measured as a function of the current which they deliver to a motor load, as above
- Converter losses tend to be relatively independent of converter output (fundamental) frequency
- Converter losses tend to be a quadratic function of output current, and may therefore be represented by an equation of the form:

$$P = A \cdot I^2 + B \cdot I + C$$

where P is converter power loss in W, I is the output current in A and C is the converter standby power in W

In this protocol, converter total losses shall be measured when a converter provides voltage and current at designated (fundamental) frequencies to a 3-phase cage-rotor induction motor which is capable of drawing current in the range from 50% of converter rated load (or whichever current is the greater of motor no-load converter 50% of converter rated current) to 100% of the converter's rated current.

The most suitable motors for this study are those which have 4-poles and an efficiency rating of IE2 or IE3.

A converter's losses are characterized as a function of load current, by making measurements as described in this protocol, which will allow the above quadratic equation to be fitted to the average of the curves of loss versus load current for various motor fundamental supply frequencies. The value of C in the above equation represents the converter's standby power requirement.

For the purpose of this study, 'rated current' for a given converter will be an agreed typical rated current for 4-pole IE2 induction motors having the same output power rating as the converter under consideration. A calculation method inspired by the tables in the current IEC standard [1] is suggested in the following chapter.

The loading motor for a given converter will thus have a nameplate output power rating which has the same value as the motor output power rating as stated on the converter's nameplate.

NOTE: Small motors tend to have higher per unit no-load currents, and such currents may exceed 50% of the matching converter's rated current, as defined above.

Converter losses and efficiency will be measured by the 'input-output' method.

2. THE CONVERTERS

The RR'C phase 2 will involve low voltage converters only and be carried out on converters (and associated loading motors) with as wide a range of rated output powers as possible. A range from 0.12 to 1000 kW is suggested, covering the range of motors to which IEC 60034-30-1:2014 currently applies.

Whereas the RR'C phase 1 was carried out only on converters of the non-regenerative, d.c.-link type, the RR'C phase 2 will include regenerative units, including both d.c.-link and matrix types, the latter having intrinsic bilateral power flow capability.

In the case of converters with bilateral power flow capability, the detailed loss measurement procedure described below shall be performed firstly with the machine driven by the converter acting as a motor, followed by a second set of measurements in which that machine behaves as a generator. In the latter case, the converter 'loading motor' is driven as a generator by the dynamometer.

To accommodate both the 50 Hz and 60 Hz regions, it is proposed that North American laboratories perform measurements on converters and motors rated for 460 V, 60 Hz supplies, while laboratories deal with 400 V, 50 Hz equipment.

Whilst the RR'C phase 1 dealt exclusively with wall-mounted, air-cooled converters, it is envisaged that in phase 2 converters with other physical architectures and cooling methods will be studied.

NOTE:

Some converters are assigned two power ratings: one for continuous loading at constant power output, without overloads ('light duty'), and another, lower value, but which accommodates overloads of specified magnitude and duration ('heavy duty').

For UTP version 2.0 loss and efficiency measurements shall be made at the rating corresponding to continuous load, without overload, namely 'light duty'.

2.1 Output current

A question arises as to what constitutes the rated current of a converter: Especially in the case of converters with low power ratings, nameplate rated current may be significantly greater than typical rated currents for the motors they will be most likely to supply. Thus, for the purposes of this exercise, it is suggested that 'rated current' for a given converter can be calculated using the tables in the current IEC standard 61800-9-2, edition 1, 2017 [1]:

Relations between informative kW vs. kVA

kW	0,12	0,18	0,25	0,37	0,55	0,75	1,1	1,5	2,2	3	4	5,5	7,5	11	15	18,5	22	30	37
kVA	0,278	0,381	0,5	0,697	0,977	1,29	1,71	2,29	3,3	4,44	5,85	7,94	9,95	14,4	19,5	23,9	28,3	38,2	47

kW	45	55	75	90	110	132	160	200	250	315	355	400	500	560	630	710	800	900	1000
kVA	56,9	68,4	92,8	111	135	162	196	245	302	381	429	483	604	677	761	858	967	1088	1209

Source: IEC 61800-9-2:2017, table A1

Examples for CDM output current at typical line voltages

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

Source: IEC 61800-9-2:2017, table 18

Figure 1 Extracts from table 18 & A1 of IEC 61800-9-2, edition 1, 2017

Example:

A small 50 Hz, 230V 1 phase converter may be rated at 1.1 kW yet have a nameplate maximum current of 6.7 A. That latter figure is significantly larger than the current drawn by a 1.1 kW 4 pole induction motor.

From the tables above the UTP $I_{r,out}$ is calculated:

$$I_{r,out} = \frac{S_{r,eq}}{\sqrt{3} \cdot U_{1,r,out}} = \frac{1.71 \text{ kVA} \cdot 1.000}{1.73 \cdot 230 \text{ V}} = 4.29 \text{ A} \approx 4.3 \text{ A}$$

Load currents should be expressed as follows:

- For motors with full-load current ratings < 100 A: to 2 significant figures
- For motors with full-load current ratings ≥ 100 A: to 3 significant figures

Current drawn from the converter will be adjusted by varying the mechanical load on the loading motor, selected as above, with the lowest current being that which is drawn by the motor operating under no-load conditions.

No motor torque or speed measurements are required but may optionally be recorded and reported.

Note that the above is different from the 'reference motor' approach specified in IEC 61800-9-2, edition 1, 2017 ('the standard'- see reference [1]) which is impracticable.

3. INSTRUMENTATION

Participating laboratories should use the best electrical measuring equipment they have available. This will provide the best possible basis for comparison between measured results.

A minimum requirement is that multi-channel wide bandwidth (≥ 100 kHz) 'power analyzers' with a basic power accuracy of less than 0.05 % be used for the measurement of converter input power, output power and associated voltages and currents.

Connections to the above instrumentation shall be of the 3-wire type (as a neutral connection is generally not available either at converter input or output terminals), with power analyzer voltage signals derived directly from the relevant converter terminals.

Extension of power analyzer input unit current ranges shall be accomplished using high accuracy, wide bandwidth shunts or current transducers of the 'zero flux' type.

4. ELECTRICAL SUPPLIES AND WIRING

Electrical supply quality shall be as specified in IEC 60034-1:2017, Clauses 7.2 and 8.3.1.

Converter losses produced by the need to repeatedly charge screened motor cable capacitance are small and may be neglected.

Cables connecting a converter to its associated motor load may therefore be either screened or unscreened, at the discretion of individual laboratories, with screened cable becoming a necessity if electromagnetic interference with measuring instruments is experienced.

5. THERMAL CONSIDERATIONS

5.1 Laboratory ambient temperature

Current carrying ohmic- and semi-conductors within converters experience losses which increase with temperature, and the ambient temperature conditions under which loss measurements are made must therefore be considered. Converter losses will tend to be lower at lower ambient air temperatures, and the best agreement between converter loss and efficiency figures from different laboratories will be obtained if the ambient temperature at which the measurements are made is specified, although such conditions may not be achievable by some laboratories.

It is suggested that a suitable standard ambient air temperature is 25 °C, since the International motor standard IEC 60034-2-1:2014 [2] requires correction of motor winding resistances to that temperature.

5.2 Converter mounting, and measurement of ambient air temperature

A converter of the wall-mounting type shall be mounted on a vertical non-metallic panel, with the bottom of the converter at least 1 m from the floor.

Inlet air temperature shall be measured using a thermometer installed in a radiation screen and mounted 0.3 m below the air-inlet at the bottom of the converter.

5.3 Converters with different (air-) cooling arrangements

The nature of a converter's cooling system will influence the way its losses are measured:

Air-cooling systems may be categorized as follows:

- Natural convection, i.e. without fans
- Forced convection, with a fan or fans which run continuously at constant speed
- Forced convection, with a fan or fans thermostatically controlled in an 'on-off' fashion
- Forced convection, with a fan or fans which run continuously, but at a speed which is related to the cooling effort required at a given load and ambient air temperature

The third type, as above, requires special consideration, since total converter losses measured at a given time will depend on whether the forced ventilation system is running. In such cases, loss measurements shall be made over a period which is sufficiently long to provide an accurate average total power loss figure.

For water-cooled converters, see below

5.4 Thermal stability

For air-cooled converters, the RR'C phase 1 found that thermal stability under given loading conditions was achieved in a period not exceeding 0.5 h.

If a converter's main heatsinks are accessible, then heatsink temperature measurements may optionally be made to confirm the attainment of thermal stability, which is defined, for the purpose of this study, as a rate of temperature rise which does not exceed 1 K per 0.5 h.

For water-cooled converters, the manufacturer's minimum water flow and maximum inlet water temperatures should be used, if possible. In any case, those coolant parameters shall be measured and recorded.

6. CONVERTER SETTINGS

Converter loss measurements shall be made under 'factory default' set-up conditions.

Many converters require that motor nameplate information be provided before they will run, in which case it will be necessary to enter a converter's nominal full load current (as defined above), in lieu of the motor manufacturer's nameplate current rating, together with the other nameplate parameters, including (motor) output power, voltage, speed and power factor.

A converter set-up check-list is as follows:

- Converter setting shall be 'factory default', and without field enhancement or weakening at low frequencies.
- Converter PWM switching frequency shall be as specified in the current edition of IEC 60034-2-3 (2013), namely 4 kHz for rated powers up to and including 90 kW, and 2 kHz for output power ratings above 90 kW, or the available converter switching frequency which is closest to those values, except for converters in which a single PWM frequency cannot be identified
- All converter settings shall be clearly documented, and the report shall contain a table detailing the converter settings.

NOTE: 'Field enhancement', as above, refers to deviations, at low converter output fundamental frequency, from a strictly constant value of V/f , in which motor voltage is raised at low speeds.

7. STEP-BY-STEP MEASUREMENT PROCEDURE FOR UTP 2.0

The measurement sequence is shown in Figure 2, below, proceeding as follows:

- 1 Run the converter at point (1) (100% frequency, 100% load current) for 0.5 h, after which time, make and record all relevant measurements at that point
- 2 Follow immediately with measurements at (2), (3) and (4)
- 3 Reduce the load current to 75%, and run at (5) for 0.25 h, after which measurements are made and recorded at that operating point
- 4 Follow immediately with measurements at (6), (7) and (8)
- 5 Reduce the load current to 50% (or the load motor no-load current, if that exceeds 50%) and run at (9) for 0.25 h, after which measurements are made and recorded at that operating point.
- 6 Follow immediately with measurements at (10), (11) and (12)
- 7 Reduce the converter output frequency to zero, and with the loading motor stationary, but still connected to the converter, measure and record the power input (the standby power) to the converter (point 13).

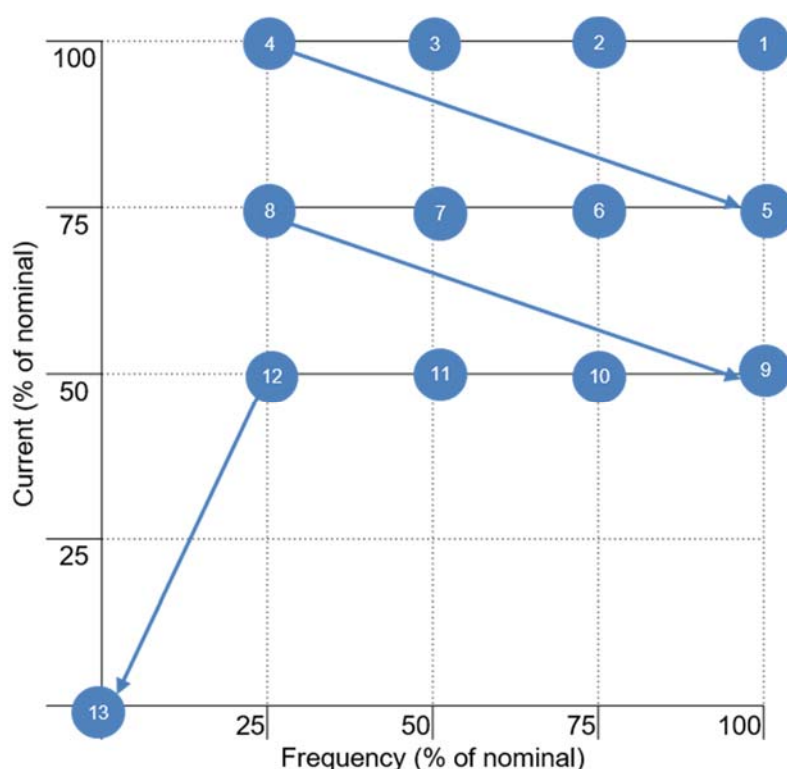


Figure 2 Graphical depiction of the converter measurement sequence

If the loading motor's no-load current exceeds the converter 50 % load current, then measurements 9 to 12 shall be made at that (no-load) current.

Measured values shall be recorded in a table shown below in Figure 3.

Load Point		Supply			Output				Calculation	
Frequency % / 50 Hz	Current % rated	V (V)	I (A)	Power (W)	V _(Fund) (V)	V _(rms) (V)	I (A)	Power (W)	Eta (%)	Losses (W)
100%	100%									
	75%									
	50%									
	Min.									
75%	100%									
	75%									
	50%									
	Min.									
50%	100%									
	75%									
	50%									
	Min.									
25%	100%									
	75%									
	50%									
	Min.									
0%										
Stopped										

Figure 3 Table for recording measured data

The A, B and C coefficients in the loss equation $P = AI^2 + BI + C$, shall be evaluated and reported. This requires the fitting of a quadratic curve to the average of the power loss values (W) measured at each fundamental converter output frequency versus output current (A).

IMPORTANT NOTE:

The loss equation curve, fitted as above, must be forced to pass through measurement point (13), representing the converter standby power (this facility is available in Microsoft Excel).

A fully automated Excel spreadsheet has been prepared to assist UTP version 2.0 testing and can be supplied at request: **UTP 2.0 Standard Reporting Format ver. 2.0.xlsm**

8. REFERENCES

- [1] IEC 61800-9-2, edition 1, 2017
Adjustable speed electrical power drive systems - Part 9-2: Ecodesign for power drive systems, motor starters, power electronics and their driven applications - Energy efficiency indicators for power drive systems and motor starters
- [2] IEC 60034-2-1:2014
Rotating electrical machines – Part 2-1: Standard methods for determining losses and efficiency from tests (excluding machines for traction vehicles)
- [3] Pierre Angers: NEMA Motor Round Robin, in: proceedings of the Motor Summit 2018 International, Zurich, Switzerland
- [4] Andrew Baghurst, Martin Doppelbauer, Roland Wetter: Loading means for the characterization and measurement of converter loss and efficiency, in EEMODS'15, proceedings, Helsinki Finland, 2015