BS EN 50463-2:2012

BSI Standards Publication

Railway applications — Energy measurement on board trains -

Part 2: Energy measuring

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National foreword

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The UK participation in its preparation was entrusted to Technical Committee GEL/9, Railway Electrotechnical Applications.

A list of organizations represented on this committee can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

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CENELEC

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Foreword

This document (EN 50463-2:2012) has been prepared by CLC/TC9X "Electrical and electronic applications for railways".

The following dates are proposed:

• latest date by which this document has to be implemented at national level by publication of an identical national standard or by endorsement	(dop)	2013-10-15
• latest date by which the national standards conflicting with this document have to be withdrawn	(dow)	2015-10-15

This document (EN 50463-2:2012), together with parts 1, 3, 4 and 5, supersedes EN 50463:2007.

EN 50463-1:2012 includes the following significant technical changes with respect to EN 50463:2007:

— the series is based on and supersedes EN 50463:2007;

— the scope is extended, new requirements are introduced and conformity assessment arrangements are added.

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This document has been prepared under a mandate given to CENELEC by the European Commission and the European Free Trade Association, and supports essential requirements of EU Directive(s).

For relationship with EU Directive 2008/57/EC amended by Commission Directive 2011/18/EU, see informative Annex ZZ, which is an integral part of this document.

This document is Part 2 of the EN 50463 series which consists of the following parts, under the common title *Railway applications - Energy measurement on board trains*:

Part 1, General;

Part 2, Energy measuring;

Part 3, Data handling;

Part 4, Communication;

Part 5, Conformity assessment.

EN 50463-2 follows the functional guidelines description in Annex A “Principles of conformity assessment” of EN ISO/IEC 17000 tailored to the Energy Measurement System (EMS).

The requirements for Energy Measurement Systems in the relevant Technical Specifications for Interoperability are supported by this series of European Standards.

Introduction

The Energy Measurement System provides measurement and data suitable for billing and may also be used for energy management, e.g. energy saving.

This series of European Standards uses the functional approach to describe the Energy Measurement System. These functions are implemented in one or more physical devices. The user of this series of standards is free to choose the physical implementation arrangements.

Structure and main contents of the EN 50463 series

This series of European Standards is divided into five parts. The titles and brief descriptions of each part are given below:

EN 50463-1 – General

The scope of EN 50463-1 is the Energy Measurement System (EMS).

EN 50463-1 provides system level requirements for the complete EMS and common requirements for all devices implementing one or more functions of the EMS.

EN 50463-2 – Energy measuring

The scope of EN 50463-2 is the Energy Measurement Function (EMF).

The EMF provides measurement of the consumed and regenerated active energy of a traction unit. If the traction unit is designed for use on a.c. traction supply systems the EMF also provides measurement of reactive energy. The EMF provides the measured quantities via an interface to the Data Handling System.

The EMF consists of the three functions: Voltage Measurement Function, Current Measurement Function and Energy Calculation Function. For each of these functions, accuracy classes are specified and associated reference conditions are defined. This part also defines all specific requirements for all functions of the EMF.

The Voltage Measurement Function measures the voltage of the Contact Line system and the Current Measurement Function measures the current taken from and returned to the Contact Line system. These functions provide signal inputs to the Energy Calculation Function.

The Energy Calculation Function inputs the signals from the Current and Voltage Measurement Functions and calculates a set of values representing the consumed and regenerated energies. These values are transferred to the Data Handling System and are used in the creation of Compiled Energy Billing Data.

The standard has been developed taking into account that in some applications the EMF may be subjected to legal metrological control. All relevant metrological aspects are covered in this part of EN 50463.

EN 50463-2 also defines the conformity assessment of the EMF.

EN 50463-3 – Data handling

The scope of EN 50463-3 is the Data Handling System (DHS).

The on board DHS receives, produces and stores data, ready for transmission to any authorised receiver of data on board or on ground. The main goal of the DHS is to produce Compiled Energy Billing Data and transfer it to an on ground Data Collection Service (DCS). The DHS can support other functionality on board or on ground with data, as long as this does not conflict with the main goal.

EN 50463-3 also defines the conformity assessment of the DHS.

EN 50463-4 – Communication

The scope of EN 50463-4 is the communication services.

Part 4 of EN 50463 gives requirements and guidance regarding the data communication between the functions implemented within EMS as well as between such functions and other on board units where data are exchanged using a communications protocol stack over a dedicated physical interface or a shared network.

It includes the on board to ground communication service and covers the requirements necessary to support data transfer between DHS and DCS.

EN 50463-4 also defines the conformity assessment of the communications services.

EN 50463-5 – Conformity assessment

The scope of EN 50463-5 is the conformity assessment procedures for the EMS.

EN 50463-5 also covers re-verification procedures and conformity assessment in the event of the replacement of a device of the EMS.

EMS functional structure and dataflow

Figure 1 illustrates the functional structure of the EMS, the main sub-functions and the structure of the dataflow and is informative only. Only the main interfaces required by this standard are displayed by arrows.

Because the communication function is distributed throughout the EMS, it has been omitted for clarity. Not all interfaces are shown.

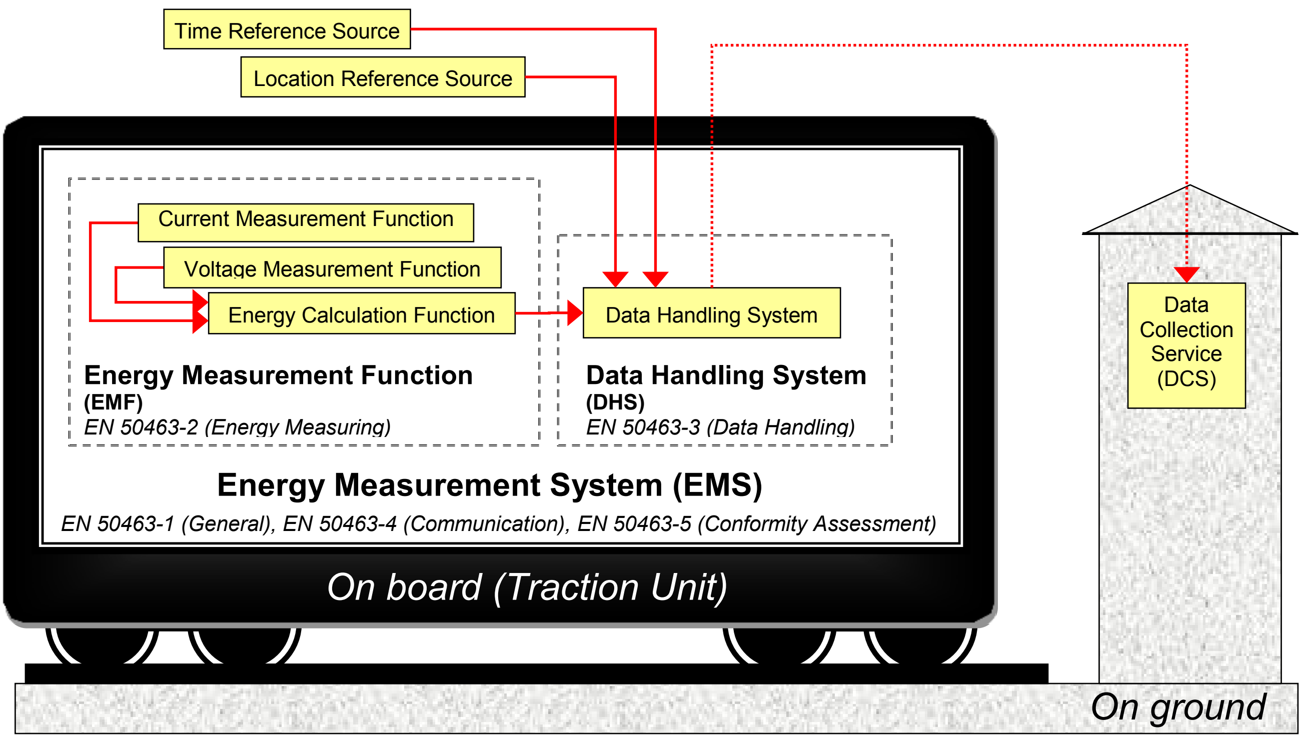


Figure 1 – EMS functional structure and dataflow diagram

1 Scope

This European Standard covers the requirements applicable to the Energy Measurement Function (EMF) of an Energy Measurement System (EMS) for use on board traction units for measurement of energy supplied directly from/to the Contact Line system.

This European Standard also gives requirements for the Current Measurement Function (e.g. current sensor), the Voltage Measurement Function (e.g. voltage sensor) and the Energy Calculation Function (e.g. energy meter).

The Conformity Assessment arrangements for the Voltage Measurement Function, Current Measurement Function, the Energy Calculation Function and a complete Energy Measurement Function are also specified in this document.

The standard has been developed taking into account that in some applications the EMF may be subjected to legal metrological control. All relevant metrological aspects are covered in this part.

Figure 2 shows the flow between the functional blocks of the EMF. Only connections between the functional blocks required by this standard are displayed.

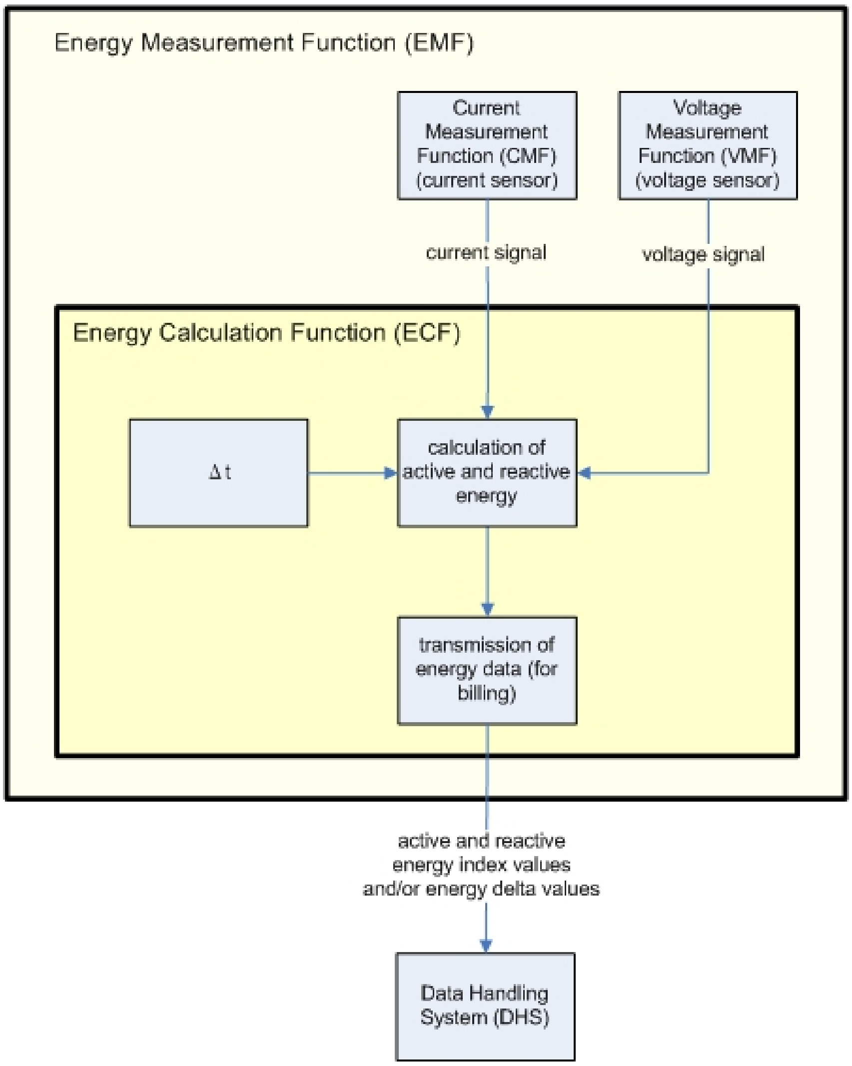


Figure 2 – EMF functional block diagram

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

CEN/TS 45545-2:2009, *Railway applications — Fire protection on railway vehicles — Part 2: Requirements for fire behaviour of materials and components*

CLC/TS 45545-5:2009, *Railway applications — Fire protection on railway vehicles — Part 5: Fire safety requirements for electrical equipment including that of trolley buses, track guided buses and magnetic levitation vehicles*

EN 50121-1:2006, *Railway applications — Electromagnetic compatibility — Part 1: General*

EN 50121-3-2:2006, *Railway applications — Electromagnetic compatibility — Part 3-2: Rolling stock — Apparatus*

EN 50123-1:2003, *Railway applications — Fixed installations — D.C. switchgear — Part 1: General*

EN 50124-1:2001, *Railway applications — Insulation coordination — Part 1: Basic requirements — Clearances and creepage distances for all electrical and electronic equipment*

EN 50125-1, *Railway applications — Environmental conditions for equipment — Part 1: Equipment on board rolling stock*

EN 50155:2007*, Railway applications — Electronic equipment used on rolling stock*

EN 50163:2004, *Railway applications — Supply voltages of traction systems*

EN 50388:2005*, Railway applications — Power supply and rolling stock — Technical criteria for the coordination between power supply (substation) and rolling stock to achieve interoperability*

EN 50463-1:2012, *Railway applications — Energy measurement on board trains — Part 1: General*

EN 50463-3:2012, *Railway applications — Energy measurement on board trains — Part 3: Data handling*

EN 50463-4:2012, *Railway applications — Energy measurement on board trains — Part 4: Communication*

EN 50463-5:2012, *Railway applications — Energy measurement on board trains —Part 5: Conformity assessment*

EN 60044 (all parts), *Instrument transformers (IEC 60044, all parts)*

EN 60068-2-1:2007, *Environmental testing — Part 2-1: Tests — Test A: Cold (IEC 60068-2-1:2007)*

EN 60068-2-2:2008, *Environmental testing — Part 2-2: Tests — Test B: Dry heat (IEC 60068-2-2:2007)*

EN 60068-2-30:2005, *Environmental testing — Part 2-30: Tests — Test Test Db: Damp heat, cyclic (12 h + 12 h cycle) (IEC 60068-2-30:2005)*

EN 60077-4:2003, *Railway applications — Electric equipment for rolling stock — Part 4: Electrotechnical components — Rules for AC circuit-breakers (IEC 60077-4:2003)*

EN 60085:2008, *Electrical insulation — Thermal evaluation and designation (IEC 60085:2007)*

EN 60529:1991+A1:2000, *Degrees of protection provided by enclosures (IP Code) (IEC 60529:1989+A1:1999)*

EN 61000-4-2:2009, *Electromagnetic compatibility (EMC) — Part 4-2: Testing and measurement techniques — Electrostatic discharge immunity test (IEC 61000-4-2:2008)*

EN 61000-4-3:2006+A1:2008, *Electromagnetic compatibility (EMC) — Part 4-3: Testing and measurement techniques — Radiated, radio-frequency, electromagnetic field immunity test (IEC 61000-4-3:2006+A1:2007)*

EN 61000-4-4:2004, *Electromagnetic compatibility (EMC) — Part 4-4: Testing and measurement techniques — Electrical fast transient/burst immunity test (IEC 61000-4-4:2004)*

EN 61000-4-5:2006, *Electromagnetic compatibility (EMC) — Part 4-5: Testing and measurement techniques — Surge immunity test (IEC 61000-4-5:2005)*

EN 61000-4-6:2009, *Electromagnetic compatibility (EMC) — Part 4-6: Testing and measurement techniques — Immunity to conducted disturbances, induced by radio-frequency fields (IEC 61000-4-6:2008)*

EN 61373:2010, *Railway applications — Rolling stock equipment — Shock and vibration tests (IEC 61373:2010)*

IEC 60028:1925, *International standard of resistance for copper*

IEC 60121:1960, *Recommendation for commercial annealed aluminium electrical conductor wire*

3 Terms, definitions, abbreviations and symbols

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in EN 50463-1:2012 and the following apply.

NOTE When possible, the following definitions have been taken from the relevant chapters of the International Electrotechnical Vocabulary (IEV), IEC 60050-311, IEC 60050-312, IEC 60050-313, IEC 60050-314, IEC 60050-321 and IEC 60050-811. In such cases, the appropriate IEV reference is given. Certain new definitions or modifications of IEV definitions have been added in this standard in order to facilitate understanding. Expression of the performance of electrical and electronic measuring equipment has been taken from EN 60359.

3.1.1
accuracy class
designation that identifies a set of error limits for measured quantities under reference conditions and the additional percentage errors due to influence quantities

Note 1 to entry: An individual accuracy class is associated with each metrological function of the EMF

Note 2 to entry: The suffix “R” is used to differentiate classes according to this standard from other technical standards.

3.1.2
consumed active energy
active energy taken from the Contact Line by the traction unit on which the EMF is installed

3.1.3
consumed reactive energy
reactive energy taken from the Contact Line by the traction unit on which the EMF is installed

3.1.4
electronic sensor
device in which electronic circuits are used to process a measured signal

Note 1 to entry: Electronic circuits for processing the measurement signal include items such as analogue to digital converters, signal amplifiers etc.

3.1.5
energy delta value
energy consumed and/or regenerated during a time period

Note 1 to entry: See Figure 3 for example.

3.1.6
energy index value
total accumulated energy consumption and/or energy regeneration at the end of a time period

Note 1 to entry: See Figure 3 for example.

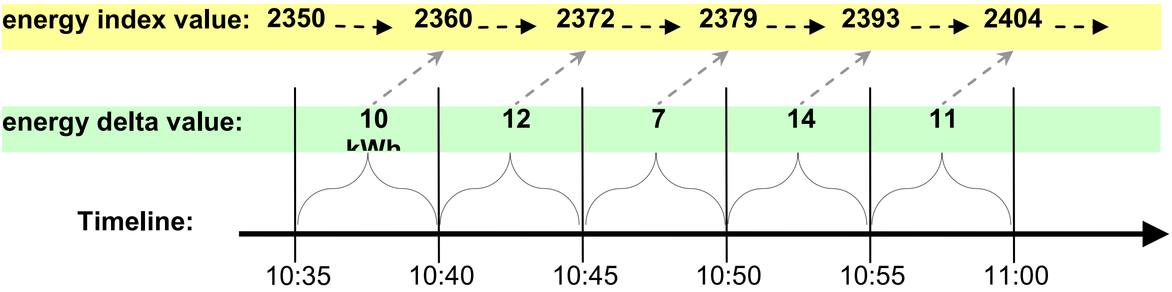


Figure 3 – Example of energy index value

3.1.7
flag
code indicating information relevant to the functioning of the EMS

Note 1 to entry: Examples include data quality, operational status, etc.

3.1.8
index value overrun
return to zero of the index value after reaching the maximum value allowed by the register

3.1.9
influence quantity
external condition which affects metrological performance

3.1.10
k-factor
multiplicand necessary to convert a secondary value into a primary value

Note 1 to entry: Each Voltage Measurement Function and/or Current Measurement Function can have a specific k-factor. If the k-factor is applied to Energy Data, this factor is the product of the k-factors of the Voltage Measurement Function and/or Current Measurement Function used.

3.1.11
percentage error
value given by the following formula:

$$Percentage\ \ error = \left| \frac{measured\ \ quantity - true\ \ quantity}{true\ \ quantity} \right| \times 100$$

Note 1 to entry: Since the true quantity cannot be determined, it is approximated by a quantity with a stated uncertainty that can be traced to standards agreed upon between supplier and purchaser or to national standards.

3.1.12
phase influence function
function of the real or apparent phase angle between a measured voltage and a measured current

Note 1 to entry: Phase influence function expressed as a Power Factor refers to measurements of real and apparent powers and energies, while sin φ refers to reactive powers and energies.

Note 2 to entry: For d.c. measurements the requirements for a phase influence function of 1 need to be used.

3.1.13
Power Factor
PF
ratio of the absolute value of the active power P to the apparent power S

[SOURCE: IEV 131-11-46, modified]

3.1.14
primary value
value referred to the measuring inputs of an EMF

3.1.15
rated continuous thermal current
$I_{CMF,cth}$
value of current which can be permitted to flow continuously into the primary input of a current sensor

3.1.16
rated dynamic current
$I_{CMF,dyn}$
peak value of the primary current which a current sensor will withstand without being damaged

3.1.17
rated primary current of the EMF
$I_{n,EMF}$
value of current which is used to define the relevant performance of the EMF

Note 1 to entry: The term current refers to r.m.s. value for a.c. unless otherwise specified.

3.1.18
rated primary voltage of the EMF
$U_{n,EMF}$
value of voltage which is used to define the relevant performance of the EMF

Note 1 to entry: The term voltage refers to r.m.s. value for a.c. unless otherwise specified.

3.1.19
rated short-time thermal current
$I_{CMF,th}$
value of the primary current which a current sensor will withstand for a specified time period without being damaged

3.1.20
rated traction unit current
maximum current that the traction unit is designed to draw from the Contact Line when operating under normal conditions and with a voltage in the range from U_{min1} to U_{max2} according to EN 50163

3.1.21
reference conditions
set of influence quantities, with reference values and tolerances, with respect to which the error limits are specified for an input quantity range

[SOURCE: IEV 311-06-02, modified]

3.1.22
regenerated active energy
active energy fed back into the Contact Line by the traction unit on which the EMF is installed

3.1.23
regenerated reactive energy
reactive energy fed back into the Contact Line by the traction unit on which the EMF is installed

3.1.24
register
electronic device which stores the information representing the measured energy and associated flags

Note 1 to entry: Registers can also be accessed and displayed locally via a service tool and if available via a local display.

[SOURCE: IEV 314-07-09, modified]

3.1.25
response time
$t_{s,r}$
duration between the instant of a step change in the measured quantity and the instant when the output signal reaches 90 % of the intended value

[SOURCE: IEV 394-39-09, modified]

3.1.26
secondary value
value of current, voltage, power or energy which needs to be multiplied by a k-factor to become a primary value

3.1.27
sensor
device performing the VMF or CMF

Note 1 to entry: Sensor is used as a general term and encompasses a wide variety of technology / devices for measurement purposes e.g. inductive transformers, hall-effect devices, capacitive and resistive dividers, resistive shunts etc.

Note 2 to entry: One sensor may perform multiple functions.

3.1.28
temperature coefficient
ratio between the temperature change and the resulting change in measurement error

3.1.29
time period
period of time for which energy data is produced

3.1.30
Time Reference Period
TRP
period of time for which CEBD is produced

3.2 Abbreviations

For the purposes of this document, the following abbreviations apply.

All the abbreviations are listed in alphabetical order.

CEBD Compiled Energy Billing Data

CMF	Current Measurement Function
DHS	Data Handling System
ECF	Energy Calculation Function
EMF	Energy Measurement Function
EMS	Energy Measurement System
EUT	Equipment under test
PF	Power Factor
RAMS	Reliability, Availability, Maintenance and Safety
TRP	Time Reference Period
VMF	Voltage Measurement Function

3.3 Symbols

For the purposes of this document, the following symbols apply.

f_a	maximum frequency without aliasing
f_n	rated frequency
$I_{CMF,cth}$	rated continuous thermal current
$I_{CMF,dyn}$	rated dynamic current
$I_{CMF,th}$	rated short-time thermal current
$I_{n,CMF}$	rated primary current of the CMF
$I_{n,ECF}$	rated primary current of the ECF
$I_{n,EMF}$	rated primary current of the EMF
$t_{s,r}$	response time
U_{max1}	highest permanent voltage according to EN 50163
U_{max2}	highest non permanent voltage according to EN 50163
U_{max3}	highest long term overvoltage according to EN 50163
U_{min1}	lowest permanent voltage according to EN 50163
U_{min2}	lowest non permanent voltage according to EN 50163
$U_{n,EMF}$	rated primary voltage of the EMF
$U_{n,VMF}$	rated primary voltage of the VMF
ε_{CMF}	maximum percentage (ratio) error allowed in accordance with the selected accuracy class for the CMF
ε_{ECF}	maximum percentage error allowed in accordance with the selected accuracy class for the ECF
ε_{EMF}	calculated maximum percentage error of the EMF
ε_{VMF}	maximum percentage (ratio) error allowed in accordance with the selected accuracy class for the VMF

4 Requirements

4.1 General

The requirements in EN 50463-1:2012, Clause 4, apply to any device containing one or more functions of the Energy Measurement Function (EMF), where applicable. EN 50463-2 defines additional requirements for a complete EMF and to any device comprising one or more functions of the EMF.

4.2 Energy Measurement Function (EMF)

4.2.1 General

The Energy Measurement Function (EMF) is made up of the following functions, which can be contained in one or more devices:

- Voltage Measurement Function (VMF);
- Current Measurement Function (CMF);
- Energy Calculation Function (ECF).

NOTE 1 In this document, the voltage sensor and current sensor are used as terms for the device implementing measurement functions. It is possible that one or more devices may be used to fulfil the role of one function. It is also possible that different functions are combined in one device.

NOTE 2 Multiple CMFs and VMFs can be used with a single ECF (see Annex B).

The purpose of the EMF is to measure the voltage and current, calculate the energy and produce energy data.

The EMF provides energy data through an interface to the Data Handling System (DHS).

4.2.1.1 General requirements

If functions are grouped together in a single device, such grouping shall not degrade the performance (including accuracy) of the system.

4.2.1.2 Marking of the EMF

Devices containing the EMF will have the marking as specified in EN 50463-1:2012, 4.3.1.1. In addition, all devices that include functions which are subject to legal metrological control shall include a metrological mark.

If different functions are included in one device marking need not to be duplicated.

4.2.1.3 Essential information

For all devices containing the EMF the essential information as specified in EN 50463-1:2012, 4.3.1.2 shall be available in a format (e.g. hardcopy or electronic) agreed between supplier and purchaser.

The k-factor of the EMF shall also be stated.

NOTE Further requirement regarding the additional information requirement for sensors and the ECF can be found in 4.3.2.3 and 4.4.2.5 of this standard.

4.2.2 Electrical requirements

4.2.2.1 Rated voltages

The characteristics of the voltage systems to which the EMF can be connected are specified in EN 50163.

The rated primary voltage of the EMF ($U_{n,EMF}$) shall be equal to the nominal voltage of the traction supply system as detailed in EN 50163 and listed in Table 1.

Table 1 – Nominal traction supply system voltages

Nominal voltages U_n V	System
25 000	50 Hz a.c.
15 000	16,7 Hz a.c.
3 000	d.c.
1 500	d.c.
750	d.c.
600	d.c.

If the EMF is designed to be used on more than one traction supply system it shall have a rated primary voltage assigned for each traction supply system.

4.2.2.2 Rated current

The standard values of rated primary current of the EMF ($I_{n,EMF}$) are:

10 A – 12,5 A – 15 A – 20 A – 25 A – 30 A – 40 A – 50 A – 60 A – 75 A , and their decimal multiples.

NOTE For example, decimal multiples of 10 A are 100 A, 1 000 A, 10 000 A.

The rated primary current ($I_{n,EMF}$) of the EMF shall be between 80 % and 120 % of the rated traction unit current.

If an EMF is designed to be used on more than one traction supply system it may have more than one value of rated primary current assigned.

4.2.2.3 Rated frequency (f_n)

The rated frequency of the EMF shall be equal to the frequency of the traction supply system for which it is designed to operate, selected from Table 1.

If an EMF is designed to be used on more than one traction supply system it may have more than one value of rated frequency.

4.2.3 Accuracy requirements

4.2.3.1 General

The accuracy of the EMF is determined by the accuracy of the functions included within the EMF.

For any device which includes one or more functions of the EMF, any interface constraint (e.g. cable type, maximum / minimum burden etc.), which is necessary to ensure accuracy is assured, shall be clearly stated.

The following sub-clauses detail the requirements and procedure for determination of the accuracy of the complete EMF.

4.2.3.2 Limits of error for the EMF

The percentage error for the complete EMF shall be determined in accordance with the following formula:

$$\varepsilon_{EMF} = \sqrt{(\varepsilon_{VMF})^2 + (\varepsilon_{CMF})^2 + (\varepsilon_{ECF})^2}$$

where

ε_{EMF}	is the calculated maximum percentage error of the EMF;
ε_{VMF}	is the maximum percentage (ratio) error allowed in accordance with the selected accuracy class for the VMF under the reference conditions;
ε_{CMF}	is the maximum percentage (ratio) error allowed in accordance with the selected accuracy class for the CMF under the reference conditions;
ε_{ECF}	is the maximum percentage error allowed in accordance with the selected accuracy class for the ECF under the reference conditions.

NOTE Informative Annex C provides further explanation about the method above.

For EMFs with more than one VMF, CMF or ECF, the formula above shall be used, but with errors for the squared terms being determined in accordance with appropriate rules in Annex B.

4.2.3.3 Reference conditions

The following table details the reference conditions to be used for any part of the EMF and the complete EMF.

Table 2 – Reference conditions

Influence quantity	**Reference value**	**Permissible tolerances**
Ambient temperature	23 °C [a]	± 2 °C
Frequency	Rated frequency	± 0,3 %
Wave-form a.c.	Sinusoidal voltages and currents	Distortion factor less than: 2 %
Wave-form d.c.	Pure d.c. voltages and currents	Ripple less than 1 %
Auxiliary supply voltage	Rated auxiliary supply voltage	± 5 %
Continuous magnetic induction of external origin	Equal to Zero	Induction value shall be less than 0,05 mT
Electromagnetic RF fields, 30 kHz to 2 GHz	Equal to Zero	< 1 V/m
Conducted disturbances, induced by radio frequency fields, 150 kHz to 80 MHz	Equal to zero	-
Magnetic induction of external origin at the reference frequency	Magnetic induction equal to zero	Induction value shall be less than 0,05 mT
[a] If the tests have to be made at a temperature other than the reference temperature, including permissible tolerances, the results shall be corrected by applying the appropriate temperature coefficient of the equipment under test.		

4.2.3.4 Limits of error due to variations in input quantities

When all functions of the EMF pass the accuracy tests as detailed in Clause 5, and the input quantities and Power Factor are within the range given in Table 3, the percentage error when calculated in accordance with 4.2.3.2 shall not exceed the limits given in Table 3. These limits shall apply to the measurement of energy in each direction.

Table 3 – EMF percentage error limits

	Input quantity range				
System type	**Value of current** [a]	**Value of voltage** [b]	**PF = Power Factor or *sin φ*** [c]	**Percentage error limit, active energy**	**Percentage error limit, reactive energy**
a.c.	10 % $I_n \leq I \leq$ 120 % I_n	$U_{min1} \leq U \leq U_{max2}$	0,85 ≤ PF or *sin φ* = 1 Inductive	1,5	3,0
d.c.	10 % $I_n \leq I \leq$ 120 % I_n	$U_{min1} \leq U \leq U_{max2}$	N/A	2,0	N/A

[a] I_n is the rated primary current of the EMF.

[b] The values of U_{min1} and U_{max2} are as specified in EN 50163:2004, Table 1.

[c] The Power Factor is taken from EN 50388:2005, Table 1. The reactive energy cannot be measured accurately for Power Factor near 1. Therefore the reactive energy is tested at *sin φ = 1.*

The accuracy classes of the VMF, CMF and ECF (which together form an EMF) shall be selected to ensure that the EMF accuracy requirements detailed above are achieved.

4.2.3.5 Starting conditions

The EMF shall measure energy if the primary current is equal to or greater than 0,4 % I_n, and the voltage is at U_{min2} or above.

If the primary current is zero, no energy shall be added to the energy registers.

4.2.4 Traction supply system change

When there is a changeover between traction supply systems the EMF shall ensure that all consumption is measured.

4.2.5 Re-verification

The supplier shall provide recommendations to the purchaser regarding any re-verification activities (testing and surveillance) that are considered necessary to ensure that the metrological performance of the functions making up the EMF can be expected to remain within the specified accuracies during the intended design life of the device containing these functions.

The recommendations shall be accompanied by supporting evidence based on technical justification to explain why the ongoing metrological performance can be expected to remain within the accuracy limits for the duration of the design life. The supporting evidence shall also indicate which aspects of the devices (making up the EMF) are relevant to ensure the ongoing metrological performance perspective. The supplier shall clearly identify all aspects which require planned intervention (i.e. re-verification testing and surveillance). The supplier shall clearly describe how this planned intervention should be undertaken.

Further information on re-verification is included in the Annex D.

4.3 Sensors

4.3.1 General

Sensors measure the primary voltage and primary current input to the EMF and provide an output (digital or analogue) for use by the Energy Calculation Function (ECF).

NOTE Sensors may be self-powered (i.e. drawing any power they require from the sensor input) or may be separately powered from an auxiliary power supply external to the sensor.

4.3.2 General requirements

Voltage and current sensor requirements may be realised using separate devices or within a combined device.

Where sensor technology is covered by EN 60044, these standards may be applied to sensors as applicable. Where requirements in EN 60044 conflicts with the requirements in EN 50463, the latter shall take precedence.

4.3.2.1 Insulation requirements

4.3.2.1.1 Insulation withstand for passive analogue sensors

For passive analogue sensors having insulation between the input and output, the rated power-frequency withstand voltage of the output signal to ground shall be 3 kV (r.m.s.) according to EN 60044-1 and EN 60044-2.

For passive analogue sensors having two or more outputs separated by insulation, the rated power-frequency withstand voltage between the sections shall be 3 kV (r.m.s.) according to EN 60044-1 and EN 60044-2.

Where passive analogue sensors have no galvanic isolation between the input and output, the rated withstand voltage of the output signal to ground shall be equal to that applied to the input.

4.3.2.1.2 Insulation withstand for electronic analogue sensors

For electronic analogue sensors with multiple low voltage circuits having galvanic isolation between them, the rated power-frequency withstand voltage between these circuits shall be in accordance with EN 50124-1, taking into account the rated insulation voltage and the overvoltage category.

4.3.2.2 Requirements for outputs

Sensors can have three different types of output: analogue dedicated, digital dedicated or digital shared outputs. The output shall be compatible with the device performing the Energy Calculation Function. The requirements on dataflow security are given in EN 50463-1:2012, 4.3.5 and shall be applied according to the output type.

4.3.2.2.1 Requirements for dedicated outputs

A sensor may have multiple outputs as long as these outputs do not influence any outputs used in the Energy Measurement Function.

If agreed between the supplier and purchaser, equipment may be temporarily connected to any outputs of the EMF, e.g. for short-term monitoring, periodic testing and calibration purposes. The design of these outputs shall take account of the effect of such temporary connections to ensure that no additional errors are introduced, e.g. the effect of additional burden.

4.3.2.2.2 Requirements for digital outputs

Requirements for communication protocols stack and communication security can be found in EN 50463-4:2012, 4.2.2, 4.2.3 and 4.2.4.

4.3.2.3 Essential information

In addition to the requirements given in EN 50463-1:2012, 4.3.1.2, the following essential information relevant to control the operation of the sensors shall be available on an accompanying document:

a) the accuracy-class of the sensors;

b) if applicable: the auxiliary voltage and form (e.g. 230 V 50 Hz, 110 V d.c.), together with the tolerance, maximum power consumption and the supply voltage interruption class according to EN 50155:2007, 5.1.1.2;

c) main diagrams (e.g. overall schematics, general arrangements, etc.) and drawings including their drawing number, version identifier and title;

d) terminal marking identification information for:

- the primary and secondary connections;
- if applicable, other accessible terminals e.g. testing and service points;
- if applicable, auxiliary voltage connections;
- if applicable, the relative polarities of connections and connector details.

e) the rated primary input;

f) the rated frequency(s) of the primary input (e.g. d.c., 16,7 Hz and 50 Hz);

g) if applicable, the maximum frequency which can be measured without aliasing (see 4.3.3.1.5 and 4.3.4.1.7);

h) in case of analogue outputs, the rated secondary output signal information;

i) if applicable, k-factor of sensor inclusive of measurement units;

j) in case of digital outputs, the communication protocol and, if applicable, how communication security is achieved;

k) all other sensor rated values and classification information (e.g. electrical, mechanical, EMC and environmental ratings and classifications);

l) if applicable, software version and other information necessary for configuration control;

m) integration and installation constraints.

4.3.3 Voltage sensors

4.3.3.1 Electrical requirements

4.3.3.1.1 Rated primary voltage ($U_{n,VMF}$)

The rated primary voltage of the sensor input shall be equal to the nominal voltage of the highest traction supply system nominal voltage at which the sensor is designed to be used, selected from the values given in Table 1.

4.3.3.1.2 Rated secondary values for analogue sensors

The rated secondary values of the sensor output shall be compatible with the input of the ECF to which it is intended to be connected.

The rated values shall be agreed between supplier and purchaser.

4.3.3.1.2.1 Rated secondary output signal for analogue sensors

The rated output signal, either as a voltage or a current, shall be defined.

The preferred values are:

a) for voltage transformers: 100 V, 110 V or 150 V (a.c.);

b) for electronic sensors with voltage output: 2 V, 4 V or 10 V (a.c. or d.c.);

c) for electronic sensors with current output: 20 mA, 50 mA or 100 mA (a.c. or d.c.).

4.3.3.1.2.2 Rated output burden for analogue sensors

The rated output burden shall be defined.

The preferred values are:

a) for rated secondary voltage > 10 V: 1 VA, 2 VA, 4 VA or 5 VA;

b) for rated secondary voltage ≤ 10 V: 0,001 VA, 0,01 VA, 0,1 VA or 0,5 VA;

c) for current outputs, a burden such that the voltage across the burden at maximum input voltage shall not exceed 45 V (a.c. r.m.s. or d.c.).

4.3.3.1.3 Influence of input overvoltage

The sensors shall not be damaged by overvoltage of U_{max3} in accordance with EN 50163:2004, Table A.1.

The sensors shall perform correctly when returned to initial working conditions.

4.3.3.1.4 Response time ($t_{s,r}$)

Sensors for d.c. measurement shall have a maximum response time of 10 ms.

NOTE If the d.c. sensor is to be used in a system where the energy content associated with harmonics is significant, a shorter resonse time may be appropriate.

4.3.3.1.5 Bandwidth requirements for electronic sensors

The supplier shall provide a curve showing the variation in performance of the sensor for variation in frequency.

NOTE 1 This will give an overall view of the frequency performances of the sensor.

For a sensor with digital output, the supplier shall specify the maximum frequency (f_a) which can be measured without aliasing.

For sensors with a digital output, f_a is usually half the sampling frequency used.

NOTE 2 This will give an overall view of the frequency performances of the sensor.

4.3.3.1.6 Power frequency withstand voltage for earthed terminals

Any terminal of the voltage sensor's measuring circuit which is intended to be connected to (the traction unit) earth and which is also insulated from the metallic case or other accessible conductive parts of the sensor, shall withstand a rated power frequency short duration withstand voltage of 3 kV (r.m.s.) for 1 min.

4.3.3.2 Short circuit withstand and fault protection for analogue sensors

Application of a short circuit to the analogue output or outputs of a sensor shall not damage the sensor. The duration of the short circuit shall be

- 1 s (for passive sensors), or
- 60 s (for electronic sensors).

For electronic sensors, the supplier shall indicate the type of current limiting measures used (if any).

For electronic sensors, the supplier shall specify any time delay between removal of the short circuit and the outputs returning to within specified accuracy limits. The time delay shall not exceed 5 s.

Fault protection for electronic sensors shall be provided in accordance with EN 50155:2007, 7.2.2.

4.3.3.3 Limit of temperature rise

Sensors with electrical insulation shall be assigned a thermal class in accordance with EN 60085. The permitted temperature limits for other components shall be stated by the supplier.

The sensor shall not exceed these limits and shall not be damaged when operating under the following conditions:

- continuous operation at U_{max2} and at the rated frequency;
- maximum applicable ambient temperature of the temperature class selected in accordance with environmental requirements of EN 50463-1:2012, 4.3.6.2;
- output conditions which creates the highest temperatures in the sensor;
- if applicable, the auxiliary power supply which creates the highest temperatures in the sensor.

4.3.3.4 Accuracy requirements

The VMF shall be assigned an accuracy class selected from Table 4.

Table 4 – Percentage error limits - VMH

Accuracy class	± Maximum percentage voltage (ratio) error at voltage defined in EN 50163 ε_{VMF}		± Maximum phase displacement at voltage defined in EN 50163 a.c. VMH (minutes) at rated frequency	
	$U_{min2} \le U < U_{min1}$	$U_{min1} \le U \le U_{max2}$	$U_{min2} \le U < U_{min1}$	$U_{min1} \le U \le U_{max2}$
0,2 R	0,4	0,2	15	10
0,5 R	1,0	0,5	30	20
0,75 R	1,5	0,75	45	30
1,0 R	2,0	1,0	60	40

For traction unit designed for multiple traction supply systems, a single voltage sensor can be used if it achieves the accuracy requirement defined in Table 4 for each rated voltage.

4.3.3.5 Effect of temperature on error limits

4.3.3.5.1 Limits of error including the effects of ambient temperature variation

The maximum percentage error, including the effects of temperature variation, shall not exceed the values given in Table 5.

In order to be able to achieve compliance with the maximum error limits specified in Table 5, a VMF of a given class can have its maximum error at reference temperature constrained to a value lower than the maximum allowed by the accuracy class as specified in Table 4. If this is the case, the supplier shall declare this lower maximum error limit at reference temperature and give evidence to demonstrate this lower limit will ensure the maximum limits given in Table 5 are not exceeded.

Table 5 – Maximum percentage error for a VMF including ambient temperature variation

Value of voltage	System type	± Maximum percentage error limits for a VMF	
		Ambient temperature variation, main range -10 °C to +50 °C (or +60 °C for indoor)	Ambient temperature variation, extended range -40 °C to –10 °C (and +60 °C to +75 °C for indoor)
$U_{min2} \le U \le U_{max2}$	a.c. and d.c.	N[b] + (0,01 × ΔT[a])	N[b] + (0,02 × ΔT[a])

[a] ΔT is the temperature variation in Kelvin between reference temperature 23 °C and the ambient temperature.

[b] The term N is the maximum allowable percentage ratio error allowed for the VMF class as specified in Table 4. For example, for a class 0,5 R VMF and input signal in the range $U_{min1} \le U \le U_{max2}$, the formula for the main temperature range becomes 0,5 + (0,01 x ΔT) and for the input signal in the range $U_{min2} \le U \le U_{min1}$ the formula becomes 1,0 + (0,01 x ΔT).

NOTE As an example, the maximum percentage error limits with an input signal in the range $U_{min1} \leq U \leq U_{max2}$ for a class 0,5 R and a class 1,0 R VMF over the temperature range in accordance with Table 5 are shown in Figure 4.

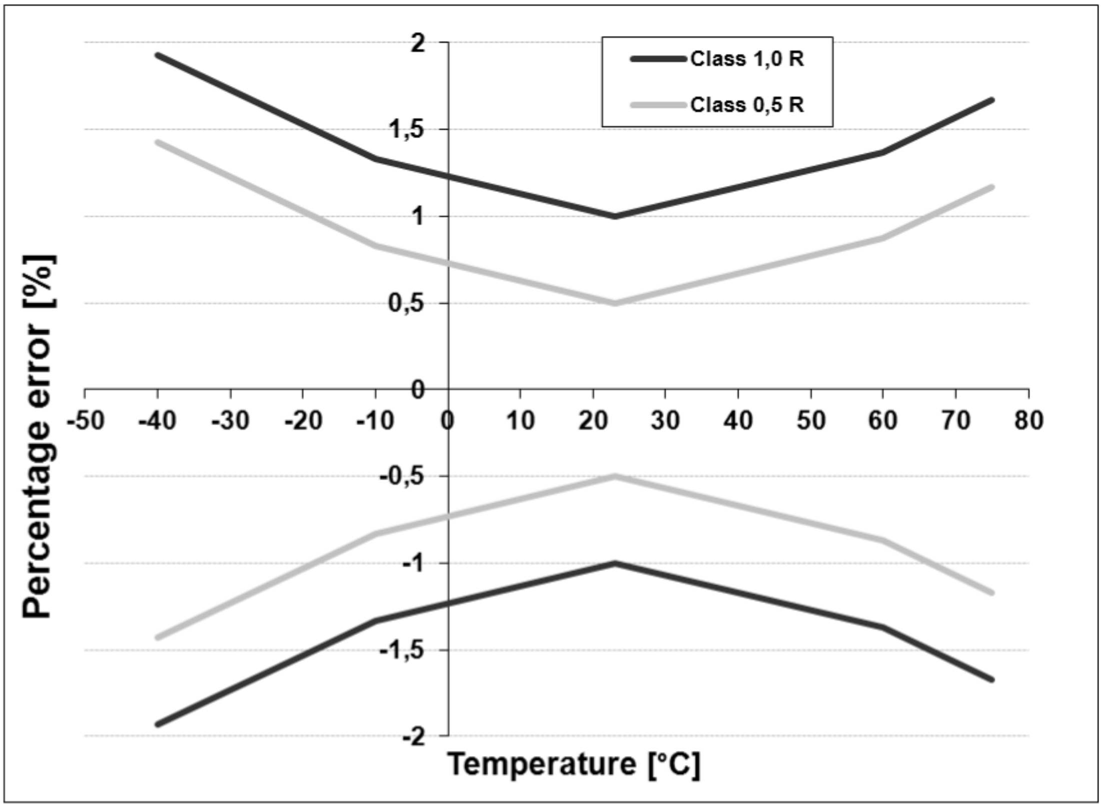


Figure 4 – Example of maximum percentage error for a VMF of class 0,5 R and a VMF of class 1,0 R with input signal in the range $U_{min1} \leq U \leq U_{max2}$

4.3.3.5.2 Mean temperature coefficient of a VMF

In addition to the requirements in 4.3.3.5.1, the mean temperature coefficient of a VMF shall not exceed the limits specified in Table 6.

Table 6 – Temperature coefficient for VMF

Accuracy class	± Mean temperature coefficient %/K
	$U_{min2} \leq U \leq U_{max2}$
0,2 R	0,02
0,5 R	0,025
0,75 R	0,03
1,0 R	0,035

The maximum additional percentage error due to temperature variation specified in Table 5 and the temperature coefficients specified in Table 6 only apply in the range defined by the device's maximum and minimum ambient temperature limits according to the applicable temperature class requirements of EN 50463-1:2012, 4.3.6.2.

4.3.3.6 Limits of additional error due to influence quantities

The limit of variation in errors due to changes in an influence quantity with respect to reference conditions, as given in Table 2, shall not exceed the limits for the relevant accuracy class given in Table 7.

Table 7 – Influence quantities for voltage sensors

Influence quantity	Specified measuring range / measuring points VMF Value of voltage [a]	Additional percentage error limits or output offset = N [g]
Variations of supply voltage according to EN 50155:2007, 5.1[b]	$U_{min1} \le U \le U_{max2}$	± 0,2 × N
Magnetic induction of external origin [c] - maximum magnetic induction, as specified by the supplier	*0 V* U_n	± N/100 x U_{min1} ± 0,5 × N
Fast transient bursts [d]	*0 V* [f] or U_{min1}	± 0,5 × N/100 x U_{min1} ± 0,5 × N
Electromagnetic RF fields [e]	*0 V* [f] or U_{min1}	± 2,0 × N/100 x U_{min1} ± 2,0 × N

[a] U_n is the rated primary voltage of the EMF.

[b] The test conditions are specified in 5.4.3.6, test a) and b).

[c] The test conditions are specified in 5.4.3.8.

[d] The test conditions are specified in 5.4.3.9, test c).

[e] The test conditions are specified in 5.4.3.9, test d) and e).

[f] If the sensor response is linear from 0 to maximum value, the test can be performed without any primary input. If not the test shall be performed with U_{min1}.

[g] N is the numeric part of the accuracy class designation.

4.3.4 Current sensors

4.3.4.1 Electrical requirements

4.3.4.1.1 Rated primary current ($I_{n,CMF}$)

The sensor rated primary current input shall be equal to the rated primary current ($I_{n,EMF}$) of the EMF.

NOTE It is permitted to test the same CMF for different rated primary currents ($I_{n,EMF}$), in order to reduce the number of different types of CMF

4.3.4.1.2 Rated continuous thermal current ($I_{CMF,cth}$)

The rated continuous thermal current shall be at least 1,2 times the rated primary current unless specifically agreed between the purchaser and the supplier.

4.3.4.1.3 Rated short-time thermal current ($I_{CMF,th}$)

The rated short-time current shall be equal to the maximum fault current for the traction supply system on which the sensor is intended to be used as specified in EN 50388:2005, Table 7. The duration of the short-time current shall be 0,3 s for a.c. and 0,1 s for d.c.

NOTE The durations are based on EN 50388:2005, Annex A.

The current sensor shall withstand this current without damage.

4.3.4.1.4 Rated dynamic current ($I_{CMF,dyn}$)

The rated dynamic current shall be at least 2,5 times the rated short-time thermal current for a.c. systems and 1,0 times the rated short-time thermal current for d.c. systems, unless specifically agreed between the purchaser and the supplier.

The current sensor shall withstand this current without damage.

4.3.4.1.5 Rated secondary values

The rated secondary values of the sensor output shall be equal to the rated input of the ECF to which it is connected.

The value for the secondary output signal shall be agreed between purchaser and supplier.

4.3.4.1.5.1 Rated secondary output signal for analogue sensors

The rated output signal, either as a current or a voltage, shall be defined.

The preferred values are:

a) for sensors with current output: 50 mA, 100 mA, 200 mA, 400 mA, 500 mA, 800 mA, 1 A, 2 A or 5 A;

b) for sensors with voltage output: 22,5 mV, 150 mV, 200 mV, 225 mV, 4 V or 10 V.

4.3.4.1.5.2 Rated output power

The rated output power shall be defined.

For sensors with analogue current output, the preferred values of rated output are:

0,5 VA, 1 VA, 2 VA, 4 VA or 5 VA.

4.3.4.1.5.3 Rated burden

The rated burden shall be defined.

For electronic sensors with a analogue voltage output, the preferred values of rated burden are:

20 kΩ, 200 kΩ or 2 MΩ.

4.3.4.1.5.4 Ratings for digital outputs

For sensors with a digital output, the values given in EN 60044-8:2002, 5.3, may be used.

4.3.4.1.6 Response time ($t_{s,r}$)

Sensors for d.c. measurement shall have a maximum response time of 10 ms.

NOTE If the d.c. sensor is to be used in a system where the energy content associated with harmonics is significant, a shorter response time may be appropriate.

4.3.4.1.7 Bandwidth requirements for electronic sensors

The supplier shall provide a curve showing the variation in performance of the sensor for variation in frequency.

NOTE This will give an overall view of the frequency performances of the sensor.

For a sensor with a digital output, the supplier shall specify the maximum frequency (f_a) which can be measured without aliasing.

For sensors with a digital output, f_a is usually half the sampling frequency used.

4.3.4.2 Limit of temperature rise

Sensors with electrical insulation shall be assigned a thermal class in accordance with EN 60085. Permitted temperature limits for other components of the sensor shall be stated by the supplier.

The sensor shall not exceed these limits and shall not be damaged when operating under the following conditions:

- continuous operation at the rated thermal current and at rated frequency;
- maximum applicable ambient temperature of the temperature class selected in accordance with environmental requirements of EN 50463-1:2012, 4.3.6.2;
- output circuit connections which creates the highest temperatures in the sensor;
- if applicable, the auxiliary power supply which creates the highest temperatures in the sensor.

4.3.4.3 Accuracy requirements

The CMF shall be assigned an accuracy class selected from Table 8 or Table 9.

NOTE Where sensor measures a.c. and d.c. current it may have a different accuracy class for a.c. and d.c.

Table 8 shall be used for a.c. current sensors:

Table 8 – Percentage error limits – a.c. CMF

Accuracy class	± Maximum percentage current (ratio) error at percentage of rated current shown below, a.c. CMF ε_{CMF}			± Maximum phase displacement at percentage of rated current shown below, a.c. CMF a.c. CMF, (minutes) at rated frequency		
	1 % $I_n \le I <$ 5 % I_n	5 % $I_n \le I <$ 10 % I_n	10 % $I_n \le I \le$ 120 % I_n	1 % $I_n \le I <$ 5 % I_n	5 % $I_n \le I <$ 10 % I_n	10 % $I_n \le I \le$ 120 % I_n
0,2 R	1,0	0,4	0,2	20	15	10
0,5 R	2,5	1,0	0,5	60	45	30
0,75 R	3,8	1,5	0,75	90	68	45
1,0 R	5,0	2,0	1,0	120	90	60

Table 9 shall be used for d.c. current sensors:

Table 9 – Percentage error limits – d.c. CMF

Accuracy class	± Maximum percentage current (ratio) error at percentage of rated current shown below, d.c. CMF ε_{CMF}		
	1 % $I_n \le I <$ 5 % I_n	5 % $I_n \le I <$ 10 % I_n	10 % $I_n \le I \le$ 120 % I_n
0,2 R	2,0	0,4	0,2
0,5 R	5,0	1,0	0,5
0,75 R	7,5	1,5	0,75
1,0 R	10,0	2,0	1,0

4.3.4.4 Effect of temperature on error limits

4.3.4.4.1 Limits of error including the effects of ambient temperature variation

The maximum percentage error, including the effects of ambient temperature variation, shall not exceed the values given in Table 10.

In order to be able to achieve compliance with the maximum error limits specified in Table 10, a CMF of a given class can have its maximum error at reference temperature constrained to a value lower than the maximum allowed by the accuracy class as specified in Table 8 (for a.c. CMF) or Table 9 (for d.c. CMF). If this is the case, the supplier shall declare this lower maximum error limit at reference temperature and give evidence to demonstrate this lower limit will ensure the maximum limits given in Table 10 are not exceeded.

Table 10 – Maximum percentage error for a CMF including ambient temperature variation

Value of current	System type	± Maximum percentage error limits for a CMF	
		Ambient temperature variation, main range -10 °C to +50 °C (or +60 °C for indoor)	Ambient temperature variation, extended range -40 °C to –10 °C (and +60 °C to +75 °C for indoor)
10 % $I_n \le I \le$ 120 % I_n	a.c. and d.c.	N[b] + (0,01 × ΔT[a])	N[b] + (0,02 × ΔT[a])
5 % $I_n \le I <$ 10 % I_n	a.c. and d.c.	N[b] + (0,02 × ΔT[a])	N[b] + (0,04 × ΔT[a])
1 % $I_n \le I <$ 5 % I_n	a.c. and d.c.	N[b] + (0,1 × ΔT[a])	N[b] + (0,2 × ΔT[a])

[a] ΔT is the temperature variation in Kelvin between reference temperature 23 °C and the ambient temperature.

[b] The term N is the maximum allowable percentage ratio error allowed for the CMF class as specified in Table 8 for a.c. CMF and Table 9 for d.c. CMF. For example, for a class 0,5 R CMF and input signal in the range 10 % $I_n \le I \le$ 120 % I_n, the formula for main temperature range becomes 0,5 + (0,01 x ΔT) and for the input signal in the range 5 % $I_n \le I <$ 10 % I_n the formula becomes 1,0 + (0,02 x ΔT).

NOTE As an example, the maximum percentage error limits with an input signal in the three input current ranges for a class 1,0 R d.c. CMF over the temperature range in accordance with Table 10 are shown in Figure 5.

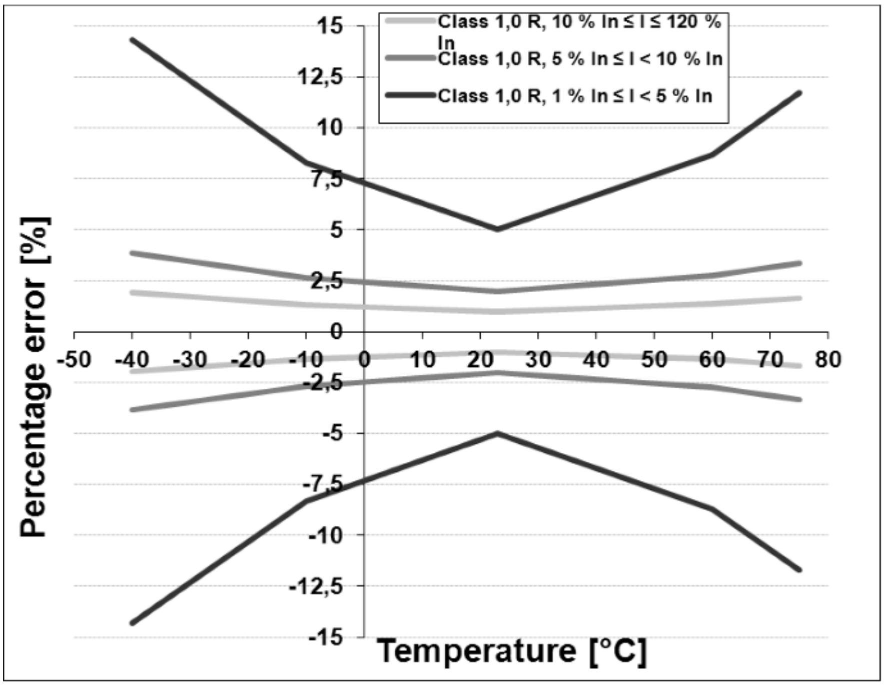


Figure 5 – Example of maximum percentage error for a CMF class 1,0 R a.c. with input signals in the range 10 % $I_n \le I \le$ 120 % I_n , 5 % $I_n \le I <$ 10 % I_n and 1 % $I_n \le I <$ 5 % I_n

4.3.4.4.2 Mean temperature coefficient of a CMF

In addition to 4.3.4.4.1, the maximum temperature coefficient of a CMF is specified in Table 11.

Table 11 – Temperature coefficient for CMF

Accuracy class	± Mean temperature coefficient %/K		
	1 % $I_n \leq I < 5$ % I_n	5 % $I_n \leq I < 10$ % I_n	10 % $I_n \leq I \leq 120$ % I_n
0,2 R	0,175	0,04	0,02
0,5 R	0,2	0,05	0,025
0,75 R	0,225	0,06	0,03
1,0 R	0,25	0,07	0,035

The maximum additional percentage error due to temperature variation specified in Table 10 and the temperature coefficients specified in Table 11 only apply in the range defined by the device's maximum and minimum ambient temperature limits according to the applicable temperature class requirements of EN 50463-1:2012, 4.3.6.2.

4.3.4.5 Limits of error with harmonics

The maximum percentage error of an a.c. current sensor in the presence of harmonics shall not exceed the values given in Table 12.

Table 12 – Percentage error limits with harmonics – a.c. current sensor

Accuracy class	± Maximum percentage current (ratio) error at harmonics shown below				± Maximum phase displacement (Degrees) at harmonics shown below			
	2nd to 4th harmonic	5th and 6th harmonic	7th to 9th harmonic	10th to 13th harmonic	2nd to 4th harmonic	5th and 6th harmonic	7th to 9th harmonic	10th to 13th harmonic
0,2 R	2	4	8	16	1	2	4	8
0,5 R	5	10	20	20	2	4	8	16
0,75 R	7,5	15	20	20	5	10	20	20
1,0 R	10	20	20	20	10	20	20	20

4.3.4.6 Limits of additional error due to influence quantities

The limit of variation of error due to the change in an influence quantity with respect to reference conditions, as given in Table 2, shall not exceed the limits for the relevant accuracy class given in Table 13.

The current sensor shall be tested in accordance with 5.4.3.

Table 13 – Influence quantities for current sensors

Influence quantity	Specified measuring range / measuring points CMF Value of current [a]	Additional percentage error limits or output offset for a sensor of accuracy N [g]
Variations of supply voltage according to EN 50155:2007, 5.1. [b]	10 % $I_n \le I \le 120$ % I_n	± 0,2 × N
Magnetic induction of external origin [c] - maximum magnetic suitable induction, as specified by the supplier	*0 A,* I_n	± 0,004 x I_n ± 0,5 × N
Fast transient bursts [d]	*0 A* [f] or 10 % I_n	± 0,5 × N/100 x (0,1 I_n) ± 0,5 × N
Electromagnetic RF fields [e]	*0 A* [f] or 10 % I_n	± 2,0 × N/100 x (0,1 I_n) ± 2,0 × N

[a] I_n is the rated primary current of the EMF.

[b] The test conditions are specified in 5.4.3.6, test a) and b).

[c] The test conditions are specified in 5.4.3.8.

[d] The test conditions are specified in 5.4.3.9, test c).

[e] The test conditions are specified in 5.4.3.9, test d) and e).

[f] If the sensor response is linear from 0 to maximum value, the test can be performed without any primary input. If not the test shall be performed with 10 % I_n.

[g] N is the numeric part of the accuracy class designation.

4.4 Energy Calculation Function (ECF)

4.4.1 General

The ECF calculates energy values from the output signals of the current and voltage sensors.

The current and voltage values stated in 4.4 are primary input values of the EMF unless otherwise stated. Input signals corresponding to these primary values shall be used as inputs to the ECF.

4.4.2 General requirements

4.4.2.1 Calculation of energy data

The ECF receives outputs from the VMF and CMF and shall calculate the following values which together form the energy data:

- consumed active energy;
- regenerated active energy;
- consumed reactive energy, if the ECF is intended to handle a.c.;
- regenerated reactive energy, if the ECF is intended to handle a.c..

The energy data shall be expressed as primary values or secondary values where a k-factor is necessary to calculate the primary values. This transformation from secondary to primary values can be done either in the EMF or in the DHS.

If an EMF is configured to use multiple VMFs and/or CMFs (see Annex B), only readings based on primary values shall be transferred to DHS.

The ECF shall produce and transfer energy data as delta values and/or index values.

Energy values shall be expressed in watt-hour / var-hour or their decimal-multiples.

4.4.2.2 k-factor

If multiplication with a k-factor is executed within the ECF, then the k-factor shall be stored in a non-volatile ECF register and shall be accessible under access control.

Any change of the k-factor used shall be logged in the ECF and flagged to the DHS.

4.4.2.3 ECF registers

Registers for the storage of energy data and flags shall be provided by the ECF.

The register shall as a minimum retain the last calculated energy data and associated flags.

NOTE Energy data shall be available for testing purposes with sufficient resolution to be able to test the accuracy of the ECF under low load levels.

Other data may be stored as long as this does not interfere with the processing of energy data or mandatory flags.

4.4.2.4 Index value overrun

Where the ECF produces energy data as index values, any register containing energy data of type energy index value shall not have an index value overrun more than once every 60 days of operation.

NOTE The 60 day period above relates to the requirements for storage of CEBD on board as defined in EN 50463-3.

4.4.2.5 Essential information

In addition to the requirements given in EN 50463-1:2012, 4.3.1.2, the following essential information relevant to control the operation of the ECF shall be available on an accompanying document:

a) the accuracy class of the ECF in accordance with 4.4.4;

b) if applicable: the auxiliary voltage and form (e.g. 110 V d.c.), together with the tolerance, maximum power consumption and the supply voltage interruption class according to EN 50155:2007, 5.1.1.2;

c) current measurement input (e.g. 1 A a.c. 50 Hz or communications protocol for digital signals);

d) voltage measurement input (e.g. 110 V a.c. 50 Hz or communications protocol for digital signals);

e) the rated frequency(s) of the ECF (e.g. d.c. and 50 Hz);

f) main diagrams of the ECF (e.g. overall schematics, general arrangements, etc.) and drawings including their drawing number, version identifier and title;

g) if applicable: software version and other information necessary for configuration control;

h) specification of interfaces;

i) all information necessary to identify the output data and associated flags;

j) data exchange arrangements;

k) integration and installation constraints.

4.4.2.6 Flags

The ECF shall be capable of producing and transmitting to the DHS the following type of flags:

- ECF operational status;
- data quality;
- configuration change;

and where applicable

- ECF index value overrun, if required by the DHS;
- ECF identification number (see Annex B.6);
- traction supply system change.

NOTE 1 It is recommended that any data quality flags received from sensors are transmitted to the DHS by the ECF.

NOTE 2 Data quality flags originating in an ECF need to be compatible with the flag requirements in EN 50463-3.

NOTE 3 Configuration change includes alterations to k-factor, software or other parts critical to metrological performance.

4.4.3 Electrical requirements

4.4.3.1 Analogue measuring input to ECF

The ECF input shall be compatible with the output of the sensors to which it is intended to be connected.

4.4.3.1.1 Voltage inputs

For an a.c. ECF, the power consumption of any voltage input shall not exceed 4,0 VA.

For a d.c. ECF, the minimum resistance of each voltage input shall be greater than 20 kΩ.

4.4.3.1.2 Current inputs

For an a.c. ECF, the power consumption of any current input shall not exceed 4,0 VA.

For a d.c. ECF, the maximum resistance of each current input R_{max} shall not be greater than:

$$R_{\max} = \frac{5\,V}{I_{n,ECF}}$$

where

$I_{n,ECF}$ is the rated current of the ECF current input [A].

4.4.3.2 Influence of input voltage

4.4.3.2.1 Voltage range on Contact Line

The variation in the ECF input voltage shall correspond to voltage range from U_{min2} to U_{max2} according to EN 50163:2004.

4.4.3.2.2 Voltage variations and short interruptions

Voltage variations and short interruptions in the voltage circuits and the auxiliary supply circuit shall not produce a change in the register greater than *x*. The value *x* is given by the following formula:

$$x = N \times U_{n,EMF} \times I_{n,EMF} \times 10^{-6}$$

where

N is the numeric part of the accuracy class designation;

$U_{n,EMF}$ is the rated voltage of the EMF [V]. Primary voltage if the energy data is calculated with reference to primary values; secondary voltage if the energy data is calculated with reference to secondary values;

$I_{n,EMF}$ is the rated current of the EMF [A]. Primary current if the energy data is calculated with reference to primary values; secondary current if the energy data is calculated with reference to secondary values.

When the voltage is restored, the ECF shall not have suffered degradation of its metrological characteristics. For testing, see 5.4.4.2.1.2.

NOTE *x* defines a limit of variation of kWh or kvarh.

4.4.3.3 Influence of short-time overcurrents

The ECF analogue current input shall withstand, without damage, input signals from the current sensor under the following conditions:

- sensor input is the rated short-time thermal current according to 4.3.4.1.3;
- sensor input is the rated dynamic current according to 4.3.4.1.4;
- short-time overcurrent at the sensor input.

In the case of short-time overcurrents, the ECF shall be able to sustain for 0,5 s an input signal equivalent to 20 times the rated primary current or the maximum output signal of the sensor if that is limited.

The ECF shall perform correctly when returned to initial working conditions and the variation of error shall not exceed the values shown in Table 14. For testing, see 5.4.4.2.1.3.

Table 14 – Variations due to short-time overcurrents

Value of voltage	Value of current	Power Factor or *sin φ*	Limits of variations in percentage error for an ECF of accuracy N [a]
U_n	I_n	1	0,1 × N
[a] N is the numeric part of the accuracy class designation.			

4.4.3.4 Influence of self-heating

The variation of error due to self-heating shall not exceed the values given in Table 15. For testing, see 5.4.4.2.1.4.

Table 15 – Variations due to self-heating

Value of current	Power Factor or sin φ	Limits of variations in percentage error for a ECF of accuracy N [a]
120 % I_n	PF = 1 or d.c.	0,4 × N
	PF = 0,85 inductive	0,5 × N
	sin φ =1	0,5 × N
[a] N is the numeric part of the accuracy class designation.		

4.4.3.5 Limit of temperature rise

ECF with electrical insulation shall be assigned a thermal class in accordance with EN 60085. Permitted temperature limits for other components of the ECF shall be stated by the supplier.

The ECF shall not exceed these limits and shall not be damaged when operating under the following conditions:

- at input signals corresponding to the highest non-permanent voltage U_{max2} and the rated continuous thermal current $I_{CMF,cth}$ of the current sensor;
- maximum applicable ambient temperature of the temperature class selected in accordance with environmental requirements of EN 50463-1:2012, 4.3.6.2;
- if applicable, the auxiliary power supply which creates the greatest temperature rise in the ECF.

4.4.4 Accuracy requirements

The ECF shall be assigned an accuracy class according to Table 16.

4.4.4.1 Percentage error limits for active energy measurement

Table 16 specifies the percentage error limits for active energy measurement under reference conditions as given in Table 2 in 4.2.3.3.

Table 16 – ECF percentage error limits for active energy

Accuracy class	± Maximum percentage energy (ratio) error ($\mathcal{E}_{ECF}$) at percentage of rated current shown below and at voltage defined in EN 50163				
	Area 1 **10 % $I_n \leq I \leq$ 120 % I_n and $U_{min1} \leq U \leq U_{max2}$**	**Area 2** **(1% $I_n \leq I \leq$ 120% I_n and $U_{min2} \leq U < U_{min1}$)**	**Area 3** **0,4% $I_n \leq I <$ 1% I_n and $U_{min2} \leq U \leq U_{max2}$)**	**Area 4** **0% $I_n < I <$ 0,4% I_n and $U_{min2} \leq U \leq U_{max2}$)**	**I = 0% I_n (I = 0 A)**
	0,85 ≤ PF				
0,2 R	0,2	0,4	Energy measurement required; no accuracy requirements	If energy is measured, no accuracy requirements	No energy measurement required
0,5 R	0,5	1,0			
0,75 R	0,75	1,5			
1,0 R	1,0	2,0			

Areas 1, 2, 3 and 4 for primary current and primary voltage listed in Table 16 are shown in Figure 6.

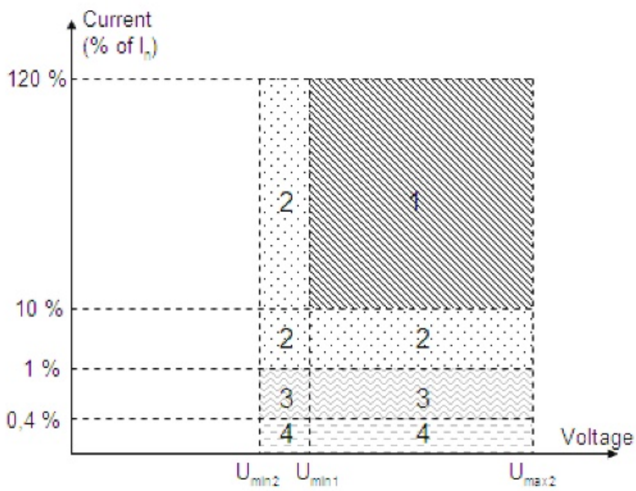


Figure 6 – Primary current and voltage ranges

NOTE 1 I_n is the rated primary current ($I_{n,EMF}$) of the EMF.

NOTE 2 The values of U_{min2}, U_{min1} and U_{max2} are as specified in EN 50163:2004, Table 1.

The accuracy requirements for regenerated active energy are the same as for consumed active energy.

4.4.4.2 Percentage error limits for reactive energy measurement

The percentage error limits for the measurement of reactive energy at *sin φ* = 1 are double those given in Table 16 for active energy.

The accuracy requirements for regenerated reactive energy are the same as for consumed reactive energy.

4.4.5 Effect of temperature on error limits

4.4.5.1 Limits of error including the effects of ambient temperature variation

The maximum percentage error, including the effects of ambient temperature variation, shall not exceed the values given in Table 17.

In order to be able to achieve compliance with the maximum error limits specified in Table 17, an ECF of a given class can have its maximum error at reference temperature constrained to a value lower than the maximum allowed by the accuracy class as specified in Table 16. If this is the case, the supplier shall declare this lower maximum error limit at reference temperature and give evidence to demonstrate this lower limit will ensure the maximum limits given in Table 17 are not exceeded.

Table 17 – Maximum percentage error for an ECF including ambient temperature variation

Value of current Value of voltage	**System type**	**± Maximum percentage error limits for an ECF**	
		Ambient temperature variation, main range -10 °C to +50 °C (or +60 °C for indoor)	**Ambient temperature variation, extended range -40 °C to –10 °C (and +60 °C to +75 °C for indoor)**
Area 1 10 % $I_n \leq I \leq$ 120 % I_n and $U_{min1} \leq U \leq U_{max2}$	a.c. and d.c.	N[b] + (0,01 × ΔT[a])	N[b] + (0,02 × ΔT[a])
Area 2 (1% $I_n \leq I <$ 10% I_n and $U_{min1} \leq U \leq U_{max2}$) and (1% $I_n \leq I \leq$ 120% I_n and $U_{min2} \leq U \leq U_{min1}$)	a.c. and d.c.	N[b] + (0,02 × ΔT[a])	N[b] + (0,04 × ΔT[a])

[a] ΔT is the temperature variation in Kelvin between reference temperature 23 °C and the ambient temperature.

[b] The term N is the maximum allowable percentage ratio error allowed for the ECF class as specified in Table 4. For example, for a class 0,5 R ECF and input signals according to Area 1, the formula for the main temperature range becomes 0,5 + (0,01 x ΔT) and for the input signal according to Area 2 the formula becomes 1,0 + (0,02 x ΔT)

NOTE As an example the maximum percentage error limits of a class 0,5 R and a class 1,0 R ECF over the temperature range and in dependence of the value of voltage and current in accordance with Table 17 are shown in Figure 7.

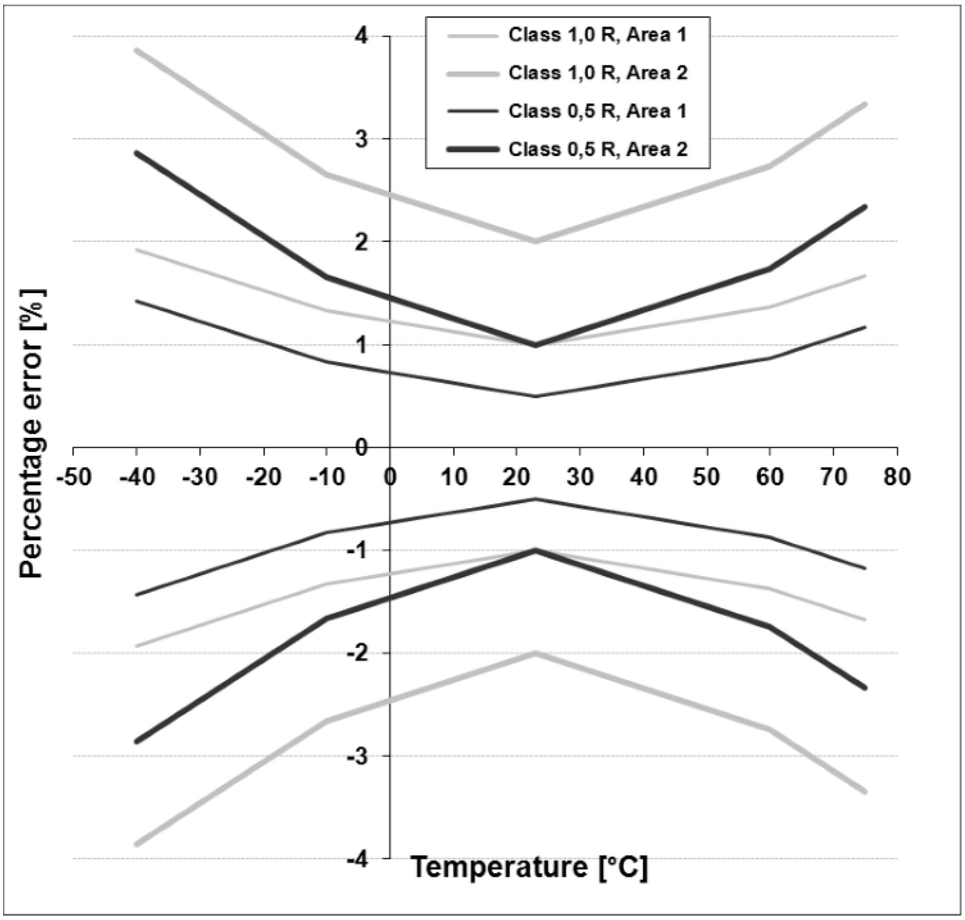


Figure 7 – Example of maximum percentage error for an ECF of class 0,5 R and an ECF of class 1,0 R with input signals in Area 1 and Area 2

4.4.5.2 Mean temperature coefficient of an ECF

In addition to the requirements in 4.4.5.1, the mean temperature coefficient of an ECF shall not exceed the limits specified in Table 18.

Table 18 – Temperature coefficient for the ECF

Accuracy class	**± Mean ECF temperature coefficient** %/K	
	Area 2 **(1% I_n ≤ I < 10% I_n and U_{min1} ≤ U ≤ U_{max2}) and (1% I_n ≤ I ≤ 120% I_n and U_{min2} ≤ U < U_{min1})**	**Area 1** **10 % I_n ≤ I ≤ 120 % I_n and U_{min1} ≤ U ≤ U_{max2}**
0,2 R	0,04	0,02
0,5 R	0,05	0,025
0,75 R	0,06	0,03
1,0 R	0,07	0,035

The maximum additional percentage error due to temperature variation specified in Table 17 and the temperature coefficients specified in Table 18 only apply in the range defined by the device's maximum and minimum ambient temperature limits according to the applicable temperature class requirements of EN 50463-1:2012, 4.3.6.2.

4.4.6 Limits of additional error due to influence quantities

The limit of variation in errors due to changes in an influence quantity with respect to reference conditions, as given in Table 2, shall not exceed the limits for the relevant accuracy class given in Table 19.

The ECF shall be tested in accordance with 5.4.4.4. Tests shall be carried out at rated voltage U_n.

Table 19 – Influence quantities for the ECF *(1 of 2)*

Influence quantity	Specified measuring range	Phase influence function		Additional percentage error limits for a ECF of accuracy N [j]	
	Value of current [a]	Power Factor	*sin φ* inductive or capacitive	For active energy	For reactive energy
Variations of supply voltage according to EN 50155:2007, 5.1.	1 % $I_n \leq I \leq$ 120 % I_n	1	1	± 0,4 × N	± 0,8 × N
Frequency variation 16,7 Hz: +2 %, -3 % [b c] 50 Hz: +2 %, -2 % [b c] according to EN 50163:2004, 4.2	1 % $I_n \leq I \leq$ 120 % I_n	1	1	± 0,4 × N	± 0,8 × N
Harmonic components in the current and voltage circuits [d]	50 % I_n	1	—	± 1,0 × N	± 2,0 × N
Odd harmonics in the current circuit [b e]	50 % I_n	1	1	± 1,5 × N	± 3,0 × N
Sub-harmonics in the current circuit [b e]	50 % I_n	1	1	± 1,5 × N	± 3,0 × N

Table 19 *(2 of 2)*

Continuous magnetic induction of external origin [b f i] - d.c. field with 0,5 mT	I_n	1	1	± 1,0 × N	± 2,0 × N
Magnetic induction of external origin [g i] - 2 mT for an ECF intended to be mounted in close proximity to high magnetic fields (B > 0,5 mT) - 0,5 mT for an ECF intended to be mounted in less harsh magnetic environment (B ≤ 0,5 mT)	I_n	1	1	± 1,0 × N	± 2,0 × N
Electromagnetic RF fields [h]	I_n	1	1	± 1,0 × N	± 2,0 × N

[a] I_n is the rated primary current of the EMF.

[b] This test does not apply to ECFs when measuring d.c.

[c] In practice, the variation of frequency is more closely controlled in Europe than the maximum frequency variations stated in EN 50163:2004, 4.2. Traction units will operate only within the frequency tolerances for 15 kV 16,7 Hz from 16,17 Hz to 17 Hz and for 25 kV/50 Hz range from 49 Hz to 51 Hz. If the frequency is out of this range, the traction unit performance may be reduced or the traction unit drives will be disconnected.

[d] The test conditions are specified in 5.4.4.4.4.

[e] The test conditions are specified in 5.4.4.4.5.

[f] The test conditions are specified in 5.4.4.4.6.

[g] The test conditions are specified in 5.4.4.4.7.

[h] The test conditions are specified in 5.4.4.5.3.

[i] Magnetic induction testing for the sensors and the ECF are different, because there are technological differences.

[j] N is the numeric part of the accuracy class designation.

4.4.6.1 Magnetic induction

When testing for magnetic induction of external origin, the most unfavourable conditions of phase and direction shall not cause a variation in the percentage error of the ECF exceeding the value shown in Table 19. The test conditions shall be as specified in 5.4.4.4.6 and 5.4.4.4.7.

4.4.6.2 Odd harmonics and sub-harmonics in the a.c. current circuit

When testing for the effects of odd harmonics and sub-harmonics in the current circuit, the distortion factor of the voltage shall be less than 1 %. The variation in the percentage error shall not exceed the value shown in Table 19. Test conditions shall be as specified in 5.4.4.4.5.

NOTE Testing for the effects of d.c. and even harmonics in the current circuit is not required.

4.4.7 Electromagnetic compatibility

4.4.7.1 Immunity to electromagnetic disturbance

4.4.7.1.1 General

The ECF shall be designed in such a way that conducted or radiated electromagnetic disturbance as well as electrostatic discharge do not damage the ECF nor substantially influence the result of measurement.

Unless otherwise specified, tests shall be carried out at rated voltage U_n, rated current I_n and phase influence function = 1.

Applicable electromagnetic disturbances are:

a) electrostatic discharges;

b) electromagnetic RF fields;

c) fast transient burst;

d) conducted voltages induced by radio-frequency fields;

e) surges;

f) oscillatory waves;

g) radio interference.

4.4.7.1.2 Immunity to electrostatic discharges

The ECF shall be tested in accordance with 5.4.4.5.2.

Any temporary degradation or loss of function or performance during the test which ceases after the test shall be discounted. After the test, the ECF shall show no damage.

The application of the electrostatic discharge shall not produce a change in the register of more than x and any signal output shall not produce a signal equivalent to more than x where x is as specified in 4.4.3.2.2.

4.4.7.1.3 Immunity to electromagnetic RF fields

The ECF shall be tested in accordance with 5.4.4.5.3.

When tested with a current signal corresponding to zero in the current circuits, the application of the RF field shall not produce a change in the register of more than x and any signal output shall not produce a signal equivalent to more than x where x is as specified in 4.4.3.2.2. Any temporary degradation or loss of function or performance during the test which ceases after the test shall be discounted.

When tested with a current signal corresponding to the rated current $I_{n,EMF}$ of the EMF, and a Power Factor = 1, the variation of error shall be within the limits given in Table 19.

4.4.7.1.4 Immunity to fast transient burst

The ECF shall be tested in accordance with 5.4.4.5.4.

When tested under reference conditions with a current signal corresponding to the rated current $I_{n,EMF}$ of the EMF in the current circuit, and phase influence function = 1, the error of energy measurement during this test shall not vary from a test under the same load conditions but without application of the transients by more than ± 4 × N % for a ECF of N.

When tested with a current signal corresponding to zero in the current circuits, the application of the burst fire test voltage shall not produce a change in the register of more than four times *x* and any signal output shall not produce a signal equivalent to more than four times *x* where *x* is as specified in 4.4.3.2.2. Any temporary degradation or loss of function or performance during the test which ceases after the test shall be discounted (performance criterion B in accordance with EN 50121-1).

4.4.7.1.5 Immunity to conducted disturbances, induced by radio-frequency fields

The ECF shall be tested in accordance with 5.4.4.5.5**.**

During the test, the ECF shall not show any temporary degradation or loss of function or performance. The error of energy measurement during this test shall not vary from a test under the same load conditions but without application of the RF fields by more than ± 2 × N % for an ECF of class N.

4.4.7.1.6 Surge immunity

The ECF shall be tested in accordance with 5.4.4.5.6.

When tested, the application of the surge immunity test shall not produce a change in the register of more than x and any signal output shall not produce a signal equivalent to more than x where x is as specified in 4.4.3.2.2.

4.4.7.2 Radio interference suppression

When tested in accordance with 5.4.4.5.7, the test results shall comply with the requirements given in EN 50121-3-2:2006, Clause 7.

4.4.8 Data transfer from ECF to DHS

At the end of each Time Reference Period (TRP), the energy data and flags shall be transferred to the DHS. By agreement between supplier and purchaser, energy data may be transferred in shorter time periods (e.g. 1 min), provided that the energy data for each corresponding 5 minute TRP can be derived by the DHS.

The specification of the TRP is detailed in EN 50463-3:2012, 4.7.2.

NOTE 1 Time periods shorter than 5 min are to be indicated in the essential data, see 4.4.2.5

NOTE 2 If the energy data is of secondary value, the k-factor will be stated in the essential data of the EMF so that it can be used in the DHS to produce primary values.

Other data such as voltage and current readings may also be transmitted, as long as this does not interfere with transmission of mandatory values.

Requirements on communication protocols stack and communication security are defined in EN 50463-4:2012, 4.2.2, 4.2.3 and 4.2.5.

5 Conformity assessment

5.1 General

Any EMF intended to be used in an EMS, shall be subjected to a conformity assessment as described in Clause 5.

The conformity assessment in Clause 5 relates to the requirements stated in Clause 4 of this document and the applicable requirements stated in EN 50463-1:2012, Clause 4.

The conformity assessment requirements in Clause 5 apply only to parts of the EMS.

In the following clauses, the numbers in square brackets, e.g. [1.2.3.4], indicates the clause number of the clause in this document or in EN 50463-1 containing requirement(s) against which conformity is being established by testing.

5.1.1 Applicability

The conformity assessment described in Clause 5 applies to any device performing any function covered by EN 50463-2.

5.1.2 Methodology

The conformity assessment shall be undertaken using the following methods:

a) device design review;

b) device type test;

c) device routine test.

It is envisaged that a) and b) have been concluded with positive verdict before c) is undertaken.

All conformity activities of a complete EMS are contained in EN 50463-5.

5.1.2.1 Device design review

Assessment of the adequacy of the technical design of the EMF functions shall be undertaken through examination of technical documentation for the device together with any supporting evidence.

This shall also include examination of documentation detailing integration and installation constraints.

If there is any change to a device that has been previously assessed, the review shall focus on the change and its impact on other aspects.

5.1.2.2 Device type test

Type tests shall be carried out to verify that each equipment type including a function of the EMF meets the requirements contained in EN 50463-2.

Type tests shall be performed on at least one sample of a designated equipment type.

If a previously assessed device is altered, the type test shall focus on the alteration and its impact on other aspects.

5.1.2.3 Device routine test

Routine tests shall be carried out on each device including a function of the EMF, to verify that it is in compliance with its stated equipment type.

5.2 Testing framework

5.2.1 General

Any device(s) including one or more functions of the EMF shall be tested according to the test procedures defined in EN 50463-2.

The device shall be tested in its fully assembled state and shall be mounted and connected to simulate the least favourable arrangement for each test.

Where tests of EMF require other parts of the EMS to be present, these parts shall form part of the test assembly. Alternatively, test equipment may be used to simulate these parts of the EMS provided the former authentically replicate the latter so far as it is necessary to ensure the test is valid.

The approval is also valid for assemblies where a device/interface has been replaced with a device/interface having technically equivalent characteristics and is also compliant with the EN 50463 series of standards.

All testing shall be undertaken under reference conditions unless otherwise stated.

5.2.2 Reporting

All tests performed on EMF functions shall be documented. The report shall include all relevant details of the devices of the complete assembly used in the testing procedure.

The report shall, as a minimum, include the following information:

a) test environment:

   1. date and time;
   2. location;
   3. test authority;
   4. parties present;
   5. device and test equipment arrangement;
   6. environmental conditions.

b) device details:

   1. equipment marking details and essential information;
   2. device setting details e.g. k-factor etc.;
   3. functions included in the device;
   4. software and firmware versions, if applicable for the tested function;
   5. specification of physical interfaces included.

c) test details:

   1. type of test and test conditions;
   2. test equipment, tools and software used for the test;
   3. test circuit arrangement and configuration including interfaces used;
   4. test engineer(s);
   5. test results.

5.3 Design review

5.3.1 General

Assessment of the adequacy of the technical design of an EMF shall be performed through examination of technical documentation for the device and supporting evidence provided by the supplier.

The design review shall take account of the location into which the device is intended to be installed (e.g. compliance to safety requirements is in some cases only achieved once the device is installed).

The design review and its outcome shall be documented in a design review report.

5.3.2 Device design review

5.3.2.1 Interfaces

Verify that all mandatory interfaces of each device carrying a function of the EMF are included and fully specified in the accompanying documentation [EN 50463-1:2012, 4.3.2.1].

Verify that the use of any interface will not degrade the performance of other interfaces (e.g. they do not introduce measurement or calculation error, etc.). If this can only be adequately verified by undertaking testing, the design review report shall identify the need for a special test.

Where access to the same signal can be gained via more than one interface (e.g. an operational input interface and a test input interface), verify whether identical performance is assured. If this can only be adequately verified by undertaking testing, the design review report shall identify the need for a special test.

NOTE In order to minimise costs, consideration should be given to include special tests as a supplementary task when type testing according to 5.4.

5.3.2.2 Access security

Verify that all requests for access to data, software or system parameters relevant for the production and storage of energy data pass through an authorisation procedure before access is granted and that all requests and all changes are logged [EN 50463-1:2012, 4.3.2.2].

5.3.2.3 Software

Verify that the requirements in EN 50463-1:2012, 4.3.4 are met.

5.3.2.4 Safety

Verify that the protective provisions at device level conform with the requirements of EN 50463-1:2012, 4.2.5.4.

5.3.2.5 Clearance and creepage distances

Verify that the clearance and creepage distances are in accordance with EN 50124-1 [EN 50463-1:2012, 4.3.8.3].

5.3.2.6 RAMS

Verify that any device performing any of the EMF functions is in compliance with EN 50463-1:2012, 4.2.5.

5.3.3 EMF design review

5.3.3.1 EMF maximum percentage error

Verify that the requirements for the maximum percentage error of the EMF according to 4.2.3.4 are met by using accuracy classes of the functions VMF, CMF and ECF (as ε_{VMF}, ε_{CMF} and ε_{ECF}) in the formula specified in 4.2.3.2 to calculate the maximum percentage error of the EMF (ε_{EMF}).

NOTE The result of the calculation is the total accuracy of the EMF (ε_{EMF}).

5.3.3.2 Device compatibility

Verify that the interfaces of any device including a function of the EMF are compatible with the devices to which they are intended to be connected.

5.3.3.3 Re-verification

Verify that all documents regarding re-verification are provided in compliance with 4.2.5.

5.4 Type testing

5.4.1 General

Any device containing one or more function of the EMF shall be subjected to type testing.

Type testing shall be performed on at least one sample of a designated equipment type.

Where a device has multiple input interfaces and/or multiple output interfaces, then the performance of all interfaces shall be tested. If identical performance of different interfaces has been verified as part of the interface design review (see 5.3.2.1), only a simple functional check is required at the additional interfaces. However, if this is not the case and the design review has identified need for testing, these special tests shall be conducted. The test procedure shall be agreed between the test authority and supplier.

If the design review (see 5.3.2.1) has identified that special tests are necessary to verify that the use of any interface will not degrade the performance of other interfaces, this shall be proven during testing. The test procedure shall be agreed between the test authority and supplier.

5.4.2 Common type testing

5.4.2.1 Visual inspection

Visual inspection shall be undertaken in accordance with EN 50155:2007, 12.2.1.

5.4.2.2 Environmental testing

The requirements in EN 50463-1:2012, 4.3.6 apply based on the devices intended location and environmental classification.

If the device is intended to be installed in an exposed environment, then the requirements of EN 50463-1:2012, 4.3.7.2 related to enclosure also apply.

5.4.2.2.1 Tests of protection against penetration of dust and water

The tests shall be carried out on enclosures according to EN 60529. Any ingress allowed by the standard shall not degrade the operation or safety requirements [EN 50463-1:2012, 4.3.7.2].

5.4.2.2.2 Temperature testing

5.4.2.2.2.1 Cooling test

For electronic devices tests shall be carried out in accordance with EN 50155:2007, 12.2.3, otherwise in accordance with EN 60068-2-1.

The test temperature shall correspond to the minimum value specified for the device's temperature class and shall be maintained for 16 h.

The acceptance requirements in EN 50155 apply. For devices with electronics, checks shall be included to ensure:

a) the device power-up is successfully achieved at the minimum temperature and within the specified time limit;

b) the device power-down is successful at minimum temperature;

c) stored data is unaffected by the test cycle.

5.4.2.2.2.2 Dry heat test

For electronic devices tests shall be carried out in accordance with EN 50155:2007, 12.2.4, otherwise in accordance with EN 60068-2-2.

The test temperature shall correspond to the maximum value specified for the device's temperature class. In addition, if the device is intended to be suitable for mounting in locations exposed to solar radiation then the additional influence shall be taken into account during testing.

The acceptance requirements in EN 50155 apply. For devices with electronics, checks shall be included to ensure:

a) the device power-up is successfully achieved at the maximum temperature and within the specified time limit;

b) the device power-down is successful at maximum temperature;

c) stored data is unaffected by the test cycle.

5.4.2.2.2.3 Damp heat cycle test

For electronic devices tests shall be carried out in accordance with EN 50155:2007, 12.2.5, otherwise in accordance with EN 60068-2-30.

The acceptance requirements in EN 50155 apply and shall also include checks to ensure that stored data is unaffected by the test cycle.

5.4.2.2.3 Test of resistance to heat and fire

The test shall be carried out according to CEN/TS 45545-2 and CLC/TS 45545-5 [EN 50463-1:2012, 4.2.5.4].

5.4.2.2.4 Mechanical testing

The following tests prove compliance with EN 50463-1:2012, 4.3.6.11.

5.4.2.2.4.1 Vibration test

Functional random vibration tests shall be carried out in accordance with EN 61373:2010, Clause 8.

The category and class to be used shall be selected based on the device’s intended mounting location on the traction unit.

The acceptance criteria in EN 61373:2010 shall also include checks to ensure that the following functions are unaffected during the test:

a) any stored data in the device is unaffected;

b) vibration does not inhibit or degrade normal operation and, if powered by an auxiliary supply, power-up and power-down is successful.

5.4.2.2.4.2 Shock test

Shock tests shall be carried out in accordance with EN 61373:2010, Clause 10.

The category and class to be used shall be selected based on the device’s intended mounting location on the traction unit.

The acceptance criteria in EN 61373:2010 shall also include checks to ensure that the following functions are unaffected during the test:

a) any stored data in the device is unaffected;

b) shocks do not inhibit or degrade normal operation and, if powered by an auxiliary supply, power-up and power-down is successful.

5.4.2.3 Electrical testing

5.4.2.3.1 Auxiliary supply

The following tests prove compliance with EN 50463-1:2012, 4.2.2.

5.4.2.3.1.1 Auxiliary supply variations

Tests shall be carried out in accordance with EN 50155:2007, 12.2.2 a).

The acceptance requirements in EN 50155 apply.

NOTE Other tests involving auxiliary supply variation, as an influence quantity, are detailed in 5.4.3.6 (sensors) and 5.4.4.2.1.2 (ECF).

5.4.2.3.1.2 Interruptions of auxiliary supply

Any device of the EMF intended for operation from a class S2 auxiliary supply, shall be subjected to tests in accordance with EN 50155:2007, 12.2.2 b):

The acceptance requirements shall include checks to ensure that the following functions are unaffected by a supply interruption occurring:

a) the device power-up is successfully achieved within the specified time limit;

b) the device power-down is successful;

c) stored data in the device is unaffected (specific requirements for the ECF are defined in 5.4.4.2.1.2);

d) the interruptions do not inhibit or degrade normal operations.

5.4.2.3.1.3 Unintentional power loss

Compliance with the unintentional power loss requirements according to EN 50463-1:2012, 4.2.2.2 shall be demonstrated by the following test:

Each device holding a function of the EMF and powered by an auxiliary power supply shall be in operational state for at least 10 min. Initiate unintentional power loss by cutting the auxiliary power supply, wait a minimum of 5 min and restart feeding of auxiliary power supply.

Check that:

a) the device has successfully powered up;

b) the device is not damaged;

c) for ECF, the register as a minimum retains the last calculated energy data and associated flags in accordance with 4.4.2.3.

5.4.2.3.1.4 Auxiliary supply load test

The maximum loading of the device in VA shall be determined by measurement whilst it is in its normal operating mode. The measurement shall be undertaken with the auxiliary supply voltage at the input terminals to the device at the rated voltage [EN 50463-1:2012, 4.2.2].

5.4.2.3.2 High voltage circuit insulation type tests

5.4.2.3.2.1 Impulse test on primary circuits

Any device with insulation containing circuits carrying traction supply system voltage shall be subjected to a lightning impulse test based on test method and arrangements given in EN 60044.

The impulse test voltage shall be in accordance with EN 50124-1 and based on the device's rated impulse voltage (U_{Ni}).

After the test, the device shall be un-damaged.

5.4.2.3.2.2 Wet test for outdoor devices

Any outdoor device with insulation containing circuits carrying traction supply system voltage shall be subjected to a short duration power frequency wet test based on test method and arrangements given in EN 60044.

The power frequency test voltage shall be in accordance with EN 50124-1 and based on the device's power frequency withstand voltage (U_a) and selected based on the device's rated impulse voltage (U_{Ni}).

5.4.2.3.3 Low voltage circuits insulation type tests

5.4.2.3.3.1 Insulation measurement

Low voltage circuits shall be subjected to insulation measurement in accordance with EN 50155:2007, 12.2.9.1.

5.4.2.3.3.2 Voltage withstand tests

Low voltage circuits other than analogue sensors shall be subjected to voltage withstand test in accordance with EN 50155:2007, 12.2.9.2.

5.4.2.4 Access control

Any device with accessible data, software or system parameters shall be tested for conformance with the requirements of EN 50463-1:2012, 4.3.2.2.

The relevant part of the following test procedure shall be undertaken:

a) use the correct procedure to have access to the device under test. Confirm that access is granted and logged;

b) change an allowable parameter. Confirm if change is logged. If other requirements are agreed (e.g. creating a flag), check if these requirements are fulfilled;

c) attempt to access the device using an invalid authorisation procedure (e.g. using an incorrect password). Check that access is prohibited, the request for access has been logged, and that access was prohibited.

If multiple access levels are implemented, additional tests shall be undertaken as follows:

d) for each access level check that access is correctly granted and correctly denied and that the events are recorded along with details of the respective access level;

e) try to change a parameter. Confirm that this is only executed for correct access levels and change is logged. Confirm that this is prohibited (if not permitted for access level) and log attempt.

5.4.3 Sensor type test

5.4.3.1 General

In addition to the type tests in 5.4.2, sensors shall also be subjected to the following specific type tests.

5.4.3.2 Voltage withstand tests for analogue sensors

Low voltage circuits of electronic analogue sensors shall be subjected to impulse withstand voltage and where applicable power frequency withstand voltage tests, based on test methods and arrangements given in EN 60044.

The test voltage for low voltage circuits of passive analogue sensors shall be in accordance with 4.3.2.1.1.

The test voltage for low voltage circuits of electronic analogue sensors shall be in accordance with EN 50155 and, if the sensor has multiple low voltage circuits having galvanic insulation between them, with 4.3.2.1.2.

5.4.3.3 Test of response time ($t_{s,r}$)

5.4.3.3.1 Test of response time ($t_{s,r}$) for d.c. voltage sensors

To prove compliance with 4.3.3.1.4 a voltage step, intended to produce a change in output signal from 0 % to 100 % of the output range, shall be applied to the input of the sensor. The time for the output to change from 0 % to 90 % of the output range shall be not greater than the response time specified in 4.3.3.1.4.

NOTE If it is not possible to generate a voltage step where the initial part introduces an insignificant delay, the test entity can take this into account. The rise time of the step should be a maximum 1 % of the permitted response time.

5.4.3.3.2 Test of response time ($t_{s,r}$) for d.c. current sensors

To prove compliance with 4.3.4.1.6 a current step, intended to produce a change in output signal from 0 % to 100 % of the output range, shall be applied to the input of the sensor. The time for the output to change from 0 % to 90 % of the output range shall be no greater than the response time specified in 4.3.4.1.6.

NOTE If it is not possible to generate a current step where the initial part introduces an insignificant delay, the test entity can take this into account. The rise time of the step should be a maximum 1 % of the permitted response time.

5.4.3.4 Accuracy tests

5.4.3.4.1 Basic accuracy tests for VMF

To prove compliance with 4.3.3.4, tests shall be made at each value of voltage given in Table 4: U_{min2}, U_{min1}, U_{max2} and at rated primary voltage ($U_{n,VMF}$).

The test shall be carried out under reference conditions specified in Table 2 in 4.2.3.3.

Under reference conditions, the measured error at each measuring point shall be within the limits for the relevant accuracy class, as specified in 4.3.3.4.

5.4.3.4.2 Basic accuracy tests for CMF

To prove compliance with 4.3.4.3, tests shall be made at each value of current given in Table 8 and Table 9: 1 %, 5 %, 10 %, 20 %, 100 %, 120 % of rated primary current ($I_{n,CMF}$) for each polarity.

The test shall be carried out under reference conditions specified in Table 2 in 4.2.3.3.

Under reference conditions the measured error of every measuring point shall be within the limits of the relevant accuracy class defined in 4.3.4.3.

5.4.3.4.3 Accuracy tests with temperature influence quantity

5.4.3.4.3.1 Limits of error including the effect of ambient temperature variation

Compliance with Table 5 in 4.3.3.5.1 for VMFs and Table 10 in 4.3.4.4.1 for CMFs shall be demonstrated by the following tests:

The lowest and highest temperatures test point for each class during testing shall be in accordance with the device's temperature class as defined in EN 50155 for electronic equipment or EN 50125-1 for other equipment.

The test shall be carried out in accordance with EN 50155:2007, 12.2.3 and 12.2.4 under the reference conditions specified in Table 2 in 4.2.3.3 but at each of the following ambient temperatures:

a) lowest temperature;

b) - 10 °C;

c) 60 °C, if below the highest temperature;

d) highest temperature.

For a VMF, the measured error at the primary voltages U_{min2}, U_{min1}, $U_{n,VMF}$ and U_{max2} shall be within the error limits given in Table 5.

For a CMF, the measured error at 1 %, 5 % , 10 %, 100 % and 120 % of the rated primary current $I_{n,CMF}$ shall be within the error limits given in Table 10.

If an electronic VMF or CMF is partially indoor and partially outdoor, the tests shall be made on the indoor and outdoor parts concurrently, each one at both extremes of the relevant temperature.

If the supplier has declared a lower maximum error limit at reference temperature than allowed for the relevant accuracy class (see 4.3.3.5.1 and 4.3.4.4.1), the error due solely to ambient temperature variation shall be determined for each ambient temperature test point given in list a) to d) above.

This shall be established by calculating the difference in error measured during the two testing conditions as follows:

a) error measured at the ambient temperature conditions as specified in this sub-clause, and

b) error measured under the reference conditions in Table 2 during the tests specified in 5.4.3.4.1 and 5.4.3.4.2, and with the same signal input conditions used in this clause.

These results shall be included in the test report.

5.4.3.4.3.2 Mean temperature coefficient

Compliance with the mean temperature coefficient requirements in Table 6 in 4.3.3.5.2 for VMFs and Table 11 in 4.3.4.4.2 for CMFs shall be demonstrated by the following test:

Tests shall be carried out under the reference conditions specified in Table 2 in 4.2.3.3.

For electronic equipment, testing to determine the temperature coefficient shall be undertaken over the temperature range stated in EN 50155 or EN 50125-1 for other. The range shall correspond to the device's specified temperature class.

The temperature coefficient shall be determined for the entire temperature class range.

The temperature range to be tested shall be divided into bands of not more than 20 K wide. The mean temperature coefficient shall then be determined for these bands by taking measurements at the middle and extreme limits of each band (e.g. ± 10 K). During the test, the temperature shall not be outside the specified temperature range of the temperature class.

For a VMF, the error shall be measured at the primary voltages U_{min2}, $U_{n,VMF}$ and U_{max2}.

For a CMF, the error shall be measured at 1 %, 5 %, 10 %, 100 % and 120 % of the rated primary current $I_{n,CMF}$.

The mean temperature coefficient shall be calculated by linear regression for the entire temperature range.

The mean temperature coefficient shall not exceed the limits given in Table 6 for VMFs and Table 11 for CMFs.

5.4.3.5 Test of the influence of harmonics on an a.c. CMF

For an a.c. CMF, the accuracy in the presence of harmonic currents shall comply with the accuracy requirement specified in Table 12 in 4.3.4.5.

In an ideal case, tests with harmonics should be made with the rated primary current $I_{n,CMF}$ at the rated frequency plus a percentage of the rated primary current at each specified harmonic frequency. Such a primary current should provide a realistic image of the dynamic performance of the sensor and will yield a good image of some non-linear phenomena which can happen in the sensor (intermodulation, for example).

However, it can be difficult to achieve a test circuit which generates such primary current. For practical considerations, it is accepted that the accuracy tests can be made with only one single harmonic frequency applied at the primary side for each measurement.

The test circuit shall be defined by agreement between supplier and purchaser.

NOTE The preferred test circuit is described in EN 60044-8.

For each specified harmonic frequency, a current according to Table 20 is applied.

Table 20 – Test current for harmonics

Magnitude of harmonic currents (percentage of rated primary current $I_{n,CMF}$)	
2^{nd} to 5^{th} harmonic	6^{th} harmonic and above
10 %	5 %

5.4.3.6 Accuracy tests with auxiliary power supply influence quantities

For electronic voltage and current sensor subjected to variations in auxiliary power supply, the accuracy shall remain within the limits specified in 4.3.3.6 for VMFs and 4.3.4.6 for CMFs.

Accuracy tests shall be made at reference conditions given in Table 2, except for auxiliary power supply.

a) The auxiliary power supply variation during the test shall be in accordance with EN 50155:2007, 12.2.2a.

1. For a voltage sensor, variation of error during the test shall not exceed the values given in Table 7.

2. For a current sensor, variation of error during the test shall not exceed the values given in Table 13.

b) Auxiliary power supply overvoltage during the test shall be in accordance with EN 50155:2007, 12.2.6.

1. For a voltage sensor, variation of error during the test shall not exceed the values given in Table 7.

2. For a current sensor, variation of error during the test shall not exceed the values given in Table 13.

c) Auxiliary power supply interruptions during the test shall be in accordance with EN 50155:2007, 12.2.2.b.

1. For a voltage sensor, the measured error at $U_{n,VMF}$ shall not change from the value before test by more than 0,1 x N, where N is the allowable error for the accuracy class in accordance with Table 4 in 4.3.3.4;

2. For a current sensor, the measured error at $I_{n,CMF}$ shall not change from the value before test by more than 0,1 x N, where N is the allowable error for the accuracy class in accordance with Table 8 and Table 9 in 4.3.4.3.

5.4.3.7 Test on influence of input overvoltages for VMF

Compliance with 4.3.3.1.3 shall be demonstrated by the following test:

The input of the VMF shall be subjected to an overvoltage of U_{max3} in accordance with EN 50163:2004, Table A.1.

After removal of the overvoltage the VMF shall show no visual damage.

After application of the overvoltages, the measured error at $U_{n,VMF}$ shall not change from the value before test by more than 0,1 x N, where N is the allowable error for the accuracy class in accordance with Table 4 in 4.3.3.4.

5.4.3.8 Accuracy test with magnetic induction of external origin

Compliance with the external magnetic induction requirements in Table 7 in 4.3.3.6 for voltage sensors and in Table 13 in 4.3.4.6 for current sensors shall be demonstrated by the following test:

The test shall be carried out under reference conditions specified in Table 2 in 4.2.3.3.

NOTE The purpose of this test is to measure the influence of a current flowing through a conductor situated near the sensor.

The supplier shall specify the maximum field under which the sensor can operate without exceeding the maximum permitted error for its accuracy class, taking account of the preferred field values given below.

The external magnetic induction of an external conductor can be calculated with the formula:

$$B = \frac{\mu_0}{2 \times \pi \times R} \times I$$

with

B: is the external magnetic field generated by an external conductor [T];

μ_0: is the permeability ($\mu_0 = 4\pi 10^{-7}$ T m A^{-1});

R: is the distance between external conductor and sensor [m];

I: is the maximum rated current in the external conductor [A].

Both a.c. and d.c. external field tests shall be performed on a sensor.

The preferred values of external magnetic induction during the tests are:

- 0,5 mT, 2 mT, 4 mT, 6 mT, 8 mT, 10 mT for d.c. fields;
- 2 mT for a.c. fields.

The test shall be carried out according to the test procedure described in Annex A.

Sensors that require an auxiliary power supply shall be continuously energised at nominal auxiliary voltage during the tests.

Depending on the traction supply system type the sensor's primary input shall be:

- voltage sensor (d.c.) 0 V and U_n (d.c.);
- current sensor (d.c.) 0 A and I_n (d.c.);
- voltage sensor (a.c.) 0 V and U_n (a.c.);
- current sensor (a.c.) 0 A and I_n (a.c.).

Following the superposition principle of error and depending on the laboratory's capabilities, the magnetic field tests can be undertaken with alternative input conditions (e.g. no primary input).

For voltage sensor the offset value of the sensor outputs with no input present shall not be higher than the value of the permitted accuracy error at U_{min1} in 4.3.3.4.

The variation of error at $U_{n,VMF}$ during the test shall not be greater than the values given in Table 7.

For current sensor the offset value of the sensor outputs with no input present shall not be higher than the starting current specified under 4.2.3.5, and the minimum starting current of an ECF for which the sensor is intended to operate.

The variation of error at $I_{n,CMF}$ during the test shall not be greater than the values given in Table 13.

5.4.3.9 EMC tests

Compliance with the EMC requirements in EN 50463-1:2012, 4.3.6.12 shall be demonstrated by the following tests on the voltage and current sensors:

The tests shall be carried out under reference conditions as specified in Table 2 in 4.2.3.3 and shall be made on the complete CMF or VMF function.

To verify the EMC emission level, the sensor shall be tested in accordance with EN 50121-3-2:2006, Tables 4, 5 and 6 under the following conditions:

- sensor in operating conditions;
- for voltage sensors, inputs connected to the rated primary voltage;
- for voltage sensors, inputs with rated primary current;
- where applicable, with auxiliary power supply.

Following the superposition principle of error and depending on the laboratory's capabilities, the EMC tests can be undertaken with alternative input conditions (e.g. no primary input).

To verify the EMC immunity level the following tests shall be performed for voltage and current sensors:

a) surges in accordance with EN 50121-3-2:2006, Table 7;

b) electrostatic discharges (ESD) in accordance with EN 50121-3-2:2006, Table 9;

c) fast transient in accordance with EN 50121-3-2:2006, Tables 7 and 8;

d) radiated disturbances induced by radio frequencies fields in accordance with EN 50121-3-2:2006, Table 9;

e) conducted disturbances induced by radio frequencies fields in accordance with EN 50121-3-2:2006, Tables 7 and 8.

The surge test shall also be applied to the sensor's auxiliary power supply input port.

If the sensor response is linear from 0 to maximum value, the test can be performed without any primary input. If not the test shall be performed with primary input corresponding to linear response of the sensor.

Following the superposition principle of error and according to the laboratory capabilities, the EMC tests can be undertaken with alternative input conditions (e.g. no primary input).

For each EMC test, the sensor shall be checked to ensure that it is operational according to the specified performance criteria in EN 50121-3-2.

For voltage sensor, the variation of error during the tests c) to e) shall not be greater than the values given in Table 7. For tests performed without any primary voltage, the additional measured offset shall not exceed the allowed error for U_{min1} of the relevant accuracy class.

For current sensor, the variation of error during the tests c) to e) shall not be greater than the values given in Table 13. For tests performed without any primary current, the additional measured offset shall not exceed the permitted error for 10 % of $I_{n,CMF}$ for the relevant accuracy class.

After all the tests the additional measured error shall be less than 0,1 x N, where N is the limit of error for the relevant accuracy class.

5.4.3.10 Temperature-rise test

Compliance with the temperature rise requirements in 4.3.3.3 for voltage sensors and 4.3.4.2 for current sensors shall be demonstrated by the following tests:

For the purpose of this test, the test-site ambient temperature shall be between 10 °C and 30 °C and the sensor shall be deemed to have attained a steady temperature when the rate of temperature rise is less than 1 K per hour.

The test shall be carried out:

- where applicable with the auxiliary power supply under conditions which will cause the largest temperature rise in the sensor;
- for voltage sensors at U_{max2} and at the rated frequency;
- for current sensors at the rated continuous thermal current according to 4.3.4.1.2.

The sensor shall be deemed to have passed this test if:

a) the temperature rise of the sensor conforms to the requirements in 4.3.3.3 for voltage sensors and 4.3.4.2 for current sensors taking into account the maximum allowable temperature of the selected temperature class;

b) after cooling to ambient temperature, it satisfies the following requirements:

   1. It is not visibly damaged;

   2. The error at rated voltage and current do not differ from that recorded before the test by more than 0,1 x N, where N is limit of error specified for the sensor's accuracy class.

5.4.3.11 Short circuit withstand test

5.4.3.11.1 Short circuit withstand test for current sensors

Compliance with the short circuit withstand test requirements in 4.3.4.1.3 and 4.3.4.1.4 shall be demonstrated by the following tests:

For the short circuit withstand tests, the current sensor shall initially be at a temperature between 10 °C and 40 °C.

The shapes of the short circuit current waveforms are detailed in:

- EN 50123-1:2003, Annex A: Shape of the short circuit in d.c.;
- EN 60077-4:2003, Annex B: Shape of the short circuit in a.c.

The rated short-time thermal current $I_{CMF,th}$ test shall be carried out:

- on current sensors with analogue output with the combination of auxiliary power supply voltage and secondary burden which causes the maximum internal power dissipation of the secondary converter;
- on current sensors with digital output with the maximum permissible auxiliary power supply voltage;
- and at a current and for a time, which gives a (I^2t) not less than the maximum values specified in 4.3.4.1.3. The maximum test duration shall not exceed 5 s.

The rated dynamic current $I_{CMF,dyn}$ test shall be carried out:

- on current sensors with analogue output with the combination of auxiliary power supply voltage and secondary burden which causes the maximum internal power dissipation of the secondary converter;
- on current sensors with digital output with the maximum permissible auxiliary power supply voltage;
- and with a primary current the peak value of which is not less than the rated dynamic current $I_{CMF,dyn}$ according to 4.3.4.1.4.

The dynamic test may be combined with the thermal test above provided the first major peak current of that test is not less than the rated dynamic current ($I_{CMF,dyn}$).

The current sensor shall be deemed to have passed these tests if, after cooling to ambient temperature (between 10 °C and 40 °C), it satisfies the following requirements:

a) it is not visibly damaged;

b) it withstands the dielectric tests specified in 5.5.3.1.1 but with the test voltages reduced to 90 %;

c) on examination, the insulation next to the surface of the conductor does not show significant deterioration (for example, carbonisation).

The sensor error at rated voltage and current do not differ from that recorded before the test by more than 0,1 x N, where N is limit of error specified for the sensor's accuracy class.

Acceptance criteria b) and c) may not be relevant depending on the design.

The examination c) is not required if the current density in the primary conductor, corresponding to the rated short-time thermal current, does not exceed

- 180 A/mm² where the primary conductor is of copper of conductivity not less than 97 % of the value given in IEC 60028;

- 120 A/mm² where the primary conductor is of aluminium of conductivity not less than 97 % of the value given in IEC 60121.

5.4.3.11.2 Short circuit withstand test for analogue output voltage sensors

Compliance with the short circuit withstand test requirements in 4.3.3.2 shall be demonstrated by the following test:

Short circuit tests shall be made in accordance with the test method and arrangements in EN 60044-2:2002, 8.2.

After testing the sensor shall be declared undamaged if it satisfies the requirements stated in EN 60044-2:2002, 8.2, criteria a) to d).

5.4.4 ECF type test

5.4.4.1 General

In addition to the common type tests in 5.4.2, ECFs shall also be subjected to the following specific type tests.

The current and voltage values stated in this clause are primary input values of the EMF unless otherwise stated. Input signals corresponding to these primary values shall be used as inputs to the ECF.

5.4.4.2 Tests of electrical requirements

5.4.4.2.1 Test on ECF with analogue inputs

5.4.4.2.1.1 Power consumption test of measuring inputs

Compliance with the power consumption test requirements in 4.4.3.1.1 and 4.4.3.1.2 shall be demonstrated by the following test:

The power consumption of the voltage and current circuit shall be measured at reference conditions as given in Table 2 in 4.2.3.3 by any suitable method.

5.4.4.2.1.2 Tests of the effects of power supply voltage interruptions and overvoltages

Compliance with the power supply voltage interruptions and overvoltage requirements in 4.4.3.2.2 shall be demonstrated by the following test:

The tests shall be carried out according to EN 50155:2007, 12.2.2.b) and 12.2.6.

5.4.4.2.1.3 Test of influence of short-time input overcurrent

Compliance with the short-time input overcurrent requirements in 4.4.3.3 shall be demonstrated by the following test:

The test circuit shall be practically non-inductive.

After the application of the short-time overcurrent, the device shall be allowed to return to the initial temperature with the input circuit energised (about 1 h).

5.4.4.2.1.4 Test of influence of self-heating

Compliance with the self-heating requirements in 4.4.3.4 shall be demonstrated by the following test:

After the voltage circuits have been energised at rated voltage for at least 2 h, without any current in the current circuits, 120 % of I_n shall be applied to the current circuits. The ECF error shall be measured (a.c. PF = 1, PF = 0,85 inductive and sin φ = 1) immediately after the current is applied and then at intervals short enough to allow a correct drawing to be made of the curve of error variation as a function of time. The test shall be carried out for at least 1 h, and in any event until the variation in percentage error for a period of 20 min does not exceed 0,1 x N where N is limit of error appropriate to its accuracy class. A stable error shall be reached within 2 h.

The maximum variation in percentage error, measured as specified, shall not exceed the values given in Table 15.

5.4.4.2.2 Temperature-rise test

Compliance with the temperature rise requirements in 4.4.3.5 shall be demonstrated by the following test:

For the purpose of this test, the device carrying the ECF shall be deemed to have attained a steady temperature when the rate of temperature rise does not exceed 1 K per hour.

The test-site ambient temperature shall be between 10 °C and 30 °C.

The ECF shall be deemed to have passed this test if:

a) the temperature of the sensor conforms with the requirements in 4.4.3.5 taking into account the maximum allowable temperature of the selected temperature class;

b) after cooling to ambient temperature, it satisfies the following requirements:

   1. it is not visibly damaged;

   2. the error after testing at rated voltage and rated current do not differ from that recorded before the test by more than 0,1 x N, where N is limit of error specified for the ECF's accuracy class.

5.4.4.3 Accuracy tests

5.4.4.3.1 Type test of the accuracy requirements

To test the accuracy requirements of the ECF as specified in 4.4.4, tests shall be carried out under the reference conditions specified in 4.2.3.3.

The percentage error shall be measured at the 16 points identified in Figure 8 by inputting appropriate signals at the input test points of the ECF.

The percentage error shall not exceed the limits given in Table 16.

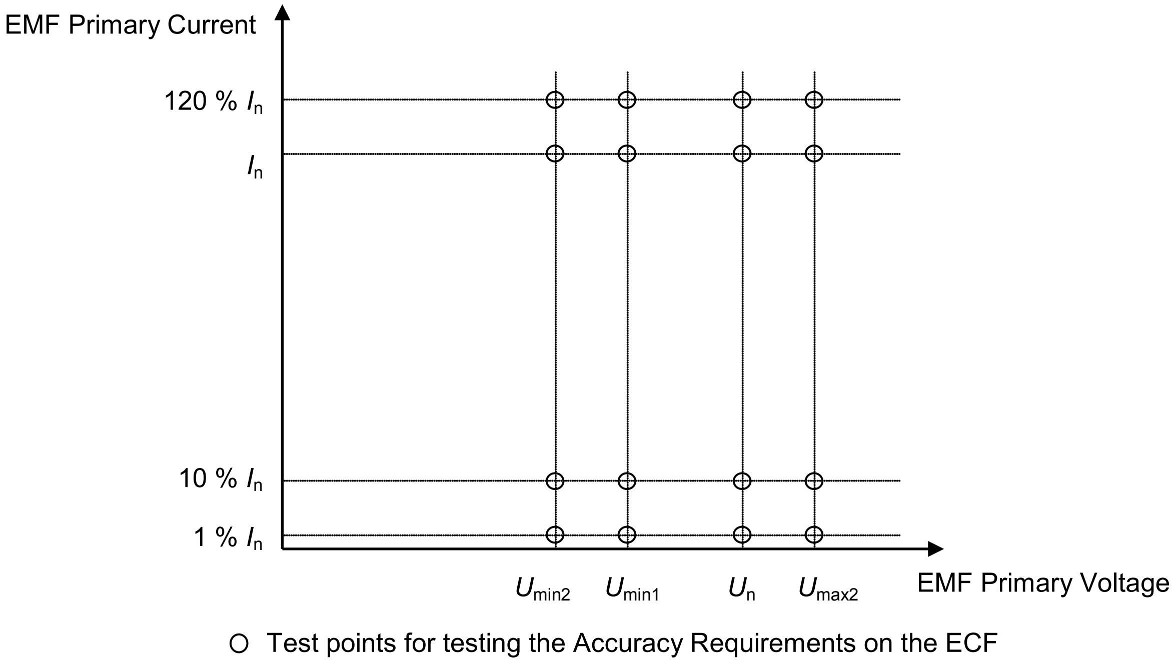


Figure 8 – Test point matrix for ECF accuracy tests (type test)

5.4.4.3.2 Accuracy tests with temperature influence quantity

5.4.4.3.2.1 Limits of error including the effect of ambient temperature variation

Compliance with the accuracy requirements in Table 17 in 4.4.5.1 shall be demonstrated by the following tests:

The lowest and highest temperatures test point for each class shall be in accordance with device's temperature class as defined in EN 50155.

The test shall be carried out in accordance with EN 50155:2007, 12.2.3 and 12.2.4 under the reference conditions specified in Table 2 in 4.2.3.3, but with the following ambient temperature:

a) lowest temperature;

b) – 10 °C;

c) 60 °C, if below the highest temperature;

d) highest temperature.

The error shall be measured at the 3 points identified in Figure 9 by inputting appropriate signals with a phase influence function of 1 into the input test points of the ECF.

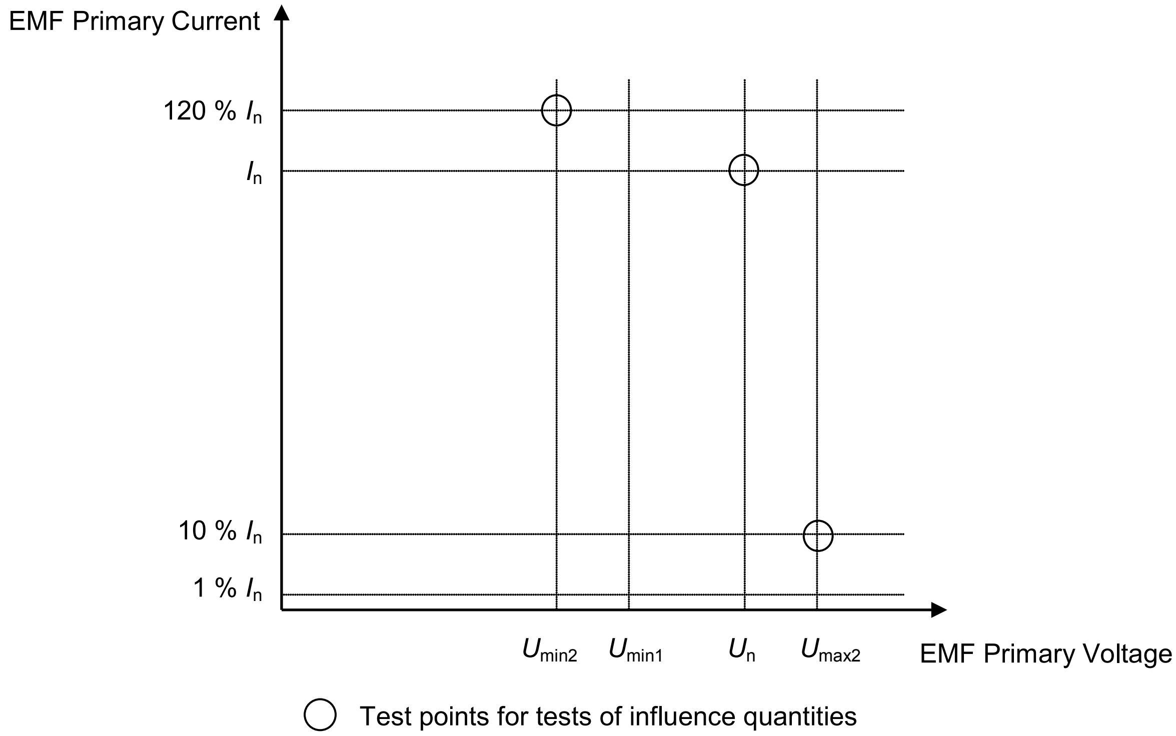


Figure 9 – Test point matrix for tests of ambient temperature variation and influence quantities

The measured error shall be within the error limits given in Table 17. If the supplier has declared a lower maximum error limit at reference temperature than allowed for the relevant accuracy class (see 4.4.5.1), the error due solely to ambient temperature variation shall be determined for each ambient temperature test point given in list a) to d) above.

This shall be established by calculating the difference in error measured during the two testing conditions as follows:

a) error measured at the ambient temperature conditions as specified in this clause, and

b) error measured under the reference conditions in Table 2 during the tests specified in 5.4.4.3.1, and with the same signal input conditions used in this clause.

These results shall be included in the test report.

5.4.4.3.2.2 Mean temperature coefficient

Compliance with the mean temperature coefficient requirements in Table 18 in 4.4.5.2 shall be demonstrated by the following test:

Tests shall be carried out under the reference conditions specified in Table 2 in 4.2.3.3.

Testing to determine the temperature coefficient shall be undertaken over the temperature range stated in EN 50155. The range shall correspond to the device's specified temperature class.

The temperature coefficient shall be determined for the entire temperature class range.

The temperature range to be tested shall be divided into bands of not more than 20 K wide. The mean temperature coefficient shall then be determined for these bands by taking measurements at the middle and extreme limits of each band (e.g. ±10 K). During the test, the temperature shall not be outside the specified temperature range of the temperature class.

The error shall be measured at the 3 points identified in Figure 9 by inputting appropriate signals with a phase influence function of 1 into the input test points of the ECF.

The mean temperature coefficient shall be calculated by linear regression for the entire temperature range.

The mean temperature coefficient shall not exceed the limits given in Table 18.

5.4.4.3.3 Test of no-load condition

Compliance with the no-load requirements as specified in 4.2.3.5 shall be demonstrated by the following test:

Tests shall be carried out under the reference conditions specified in Table 2 in 4.2.3.3.

If the ECF has analogue inputs, the following test conditions shall apply:

- current: Zero;
- voltage: U_{max2}.

If the ECF has digital inputs, the following test conditions shall apply:

- current: Signal equivalent to Zero Current;
- voltage: Signal equivalent to U_{max2}.

The minimum test period shall be 24 h.

During this test the ECF shall not produce a change in the register of more than *x* as determined in accordance with 4.4.3.2.2.

5.4.4.3.4 Test of starting condition

Compliance with the starting requirements as specified in 4.2.3.5 shall be demonstrated by the following test:

Tests shall be carried out under the reference conditions specified in Table 2 in 4.2.3.3.

The ECF shall increment energy values when input signals equivalent to 0,4 % I_n and U_{min2} are injected at the input test points of the ECF.

5.4.4.4 Test of influence quantities

5.4.4.4.1 General

Compliance with the limits for additional percentage errors as specified in Table 19 in 4.4.6 shall be demonstrated by the tests in the following clauses.

Tests for variation caused by influence quantities shall be performed independently with all other influence quantities at their reference conditions specified in Table 2 in 4.2.3.3. If the tests are made at a temperature other than the reference temperature, including permissible tolerances, the tests shall be corrected by applying the appropriate temperature coefficient.

The variations caused by influence quantities shall be tested by injecting signals equivalent to the combinations of EMF primary rated voltage and primary currents as shown in Table 19 in 4.4.6 at the input test points of the ECF. In case of a measuring range for the primary current in Table 19 tests shall be performed by injecting signals equivalent to the limit values of the specified measuring range. Phase influence function shall be in accordance with Table 19.

5.4.4.4.2 Test of the influence of auxiliary voltage variations

The auxiliary power supply voltage variations during the test shall be in accordance with EN 50155:2007, 12.2.2 a).

5.4.4.4.3 Test of the influence of frequency variations

The ECF shall be tested at the following frequencies:

- for a rated frequency of 50 Hz: 50 Hz – 2 %, 50 Hz, 50 Hz + 2 %;
- for a rated frequency of 16,7 Hz: 16,7Hz – 3 %, 16,7 Hz, 16,7 Hz + 2 %.

5.4.4.4.4 Accuracy test in the presence of harmonics (ECF with a.c. inputs only)

ECFs shall be tested under the following test conditions:

- fundamental frequency current: I_o = 50 % I_n;
- fundamental frequency voltage: $U_o = U_n$;
- fundamental frequency Power Factor: 1 (Regenerated energy);
- content of 5th harmonic voltage: U_5 = 10 % of U_n;
- content of 5th harmonic current: I_5 = 40 % of fundamental current;
- harmonic Power Factor: 1;
- fundamental and harmonic voltages are in phase at positive zero crossing.

NOTE Resulting harmonic power and total power due to the 5th harmonic P_5 is determined by the following formula:

$P_5 = 0{,}1\ U_0 \times 0{,}4\ I_0 = 0{,}04\ P_0$

and the total power is 0,96 P_0.

5.4.4.4.5 Tests of the influence of odd harmonics and sub-harmonics (ECF with a.c. inputs only)

The ECF shall be tested for the influence of odd harmonics. For ECFs with an analogue input this shall be done with the circuit shown in Figure 10 or with other equipment able to generate the required waveforms, and the current waveforms as shown in Figure 11, having a harmonic content as shown in Figure 12. For ECFs with a digital input, the test signal used shall be correctly replicate the presence of the harmonics content.

The ECF shall be tested for the influence of sub-harmonics. For ECFs with an analogue input this shall be done with the circuit shown in Figure 10 or with other equipment able to generate the required waveforms, and the current waveforms as shown in Figure 13, having a harmonic content as shown in Figure 14. For ECFs with a digital input, the test signal used shall be correctly replicate the presence of the harmonics content.

This test does not apply to d.c. measurements.

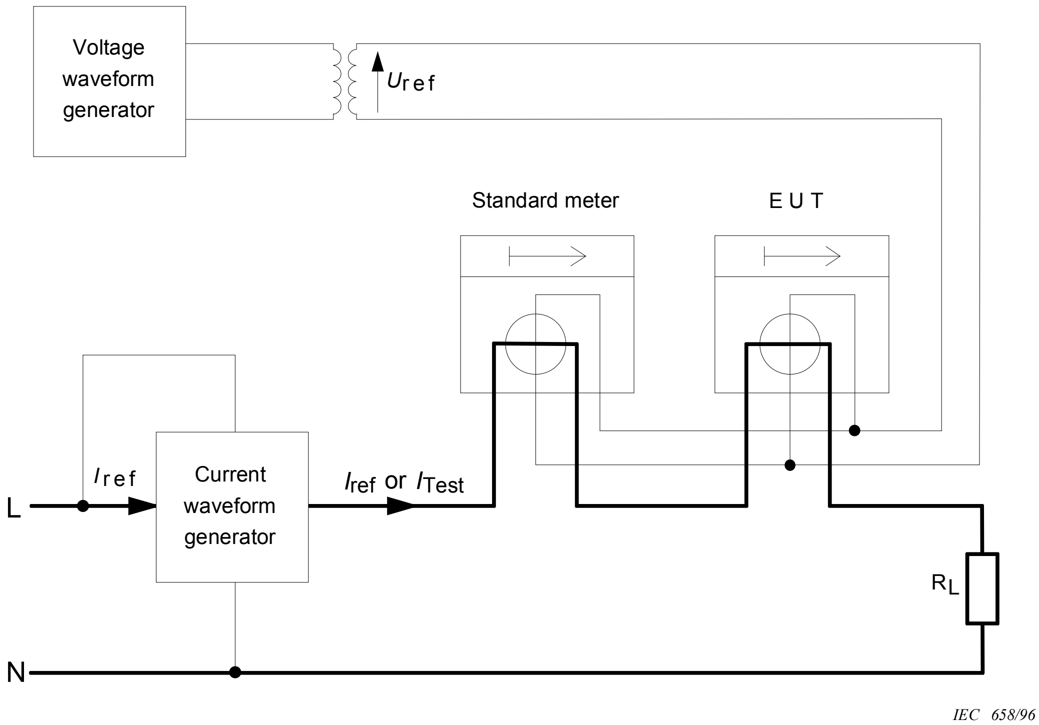
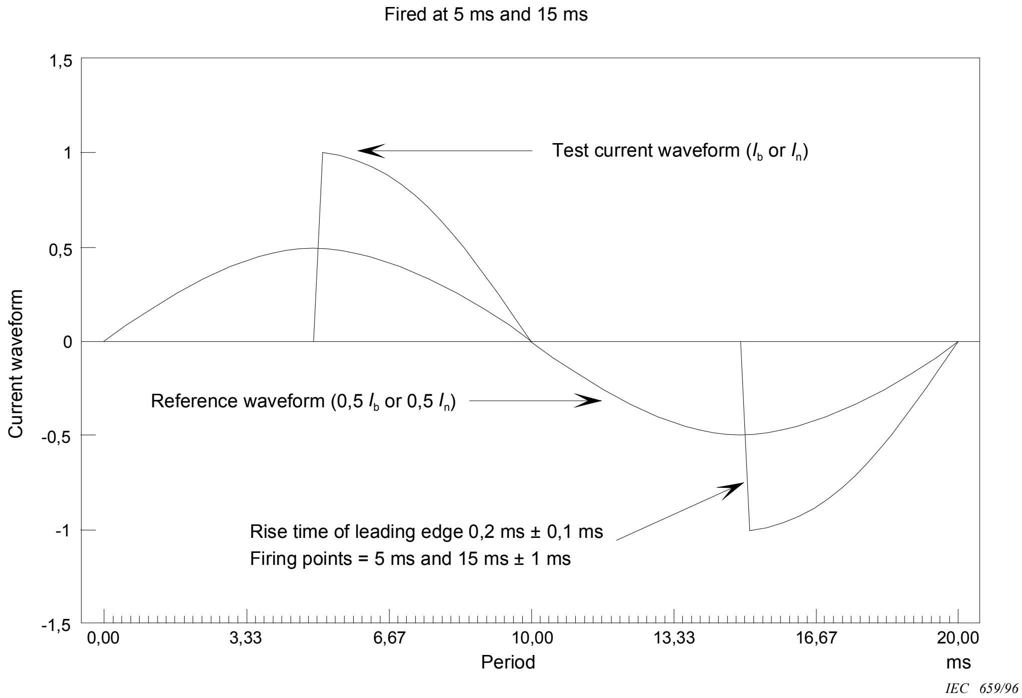
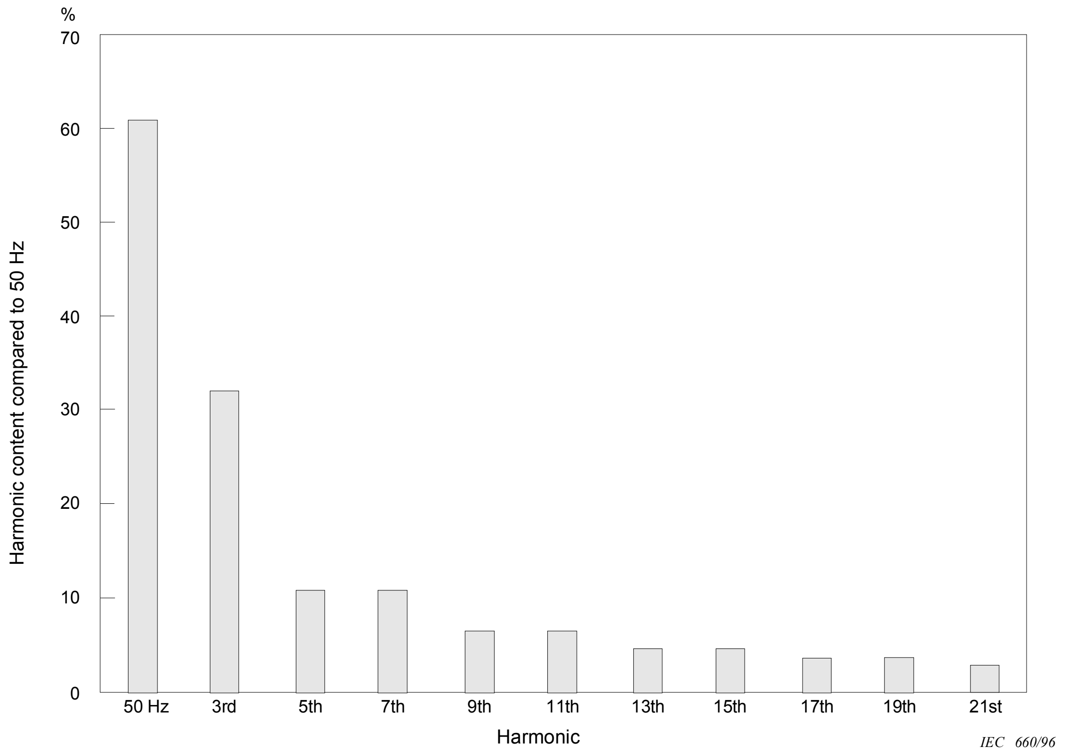


Figure 10 – Test circuit diagram for determining the influence on accuracy of odd harmonics or sub-harmonics in the current circuit



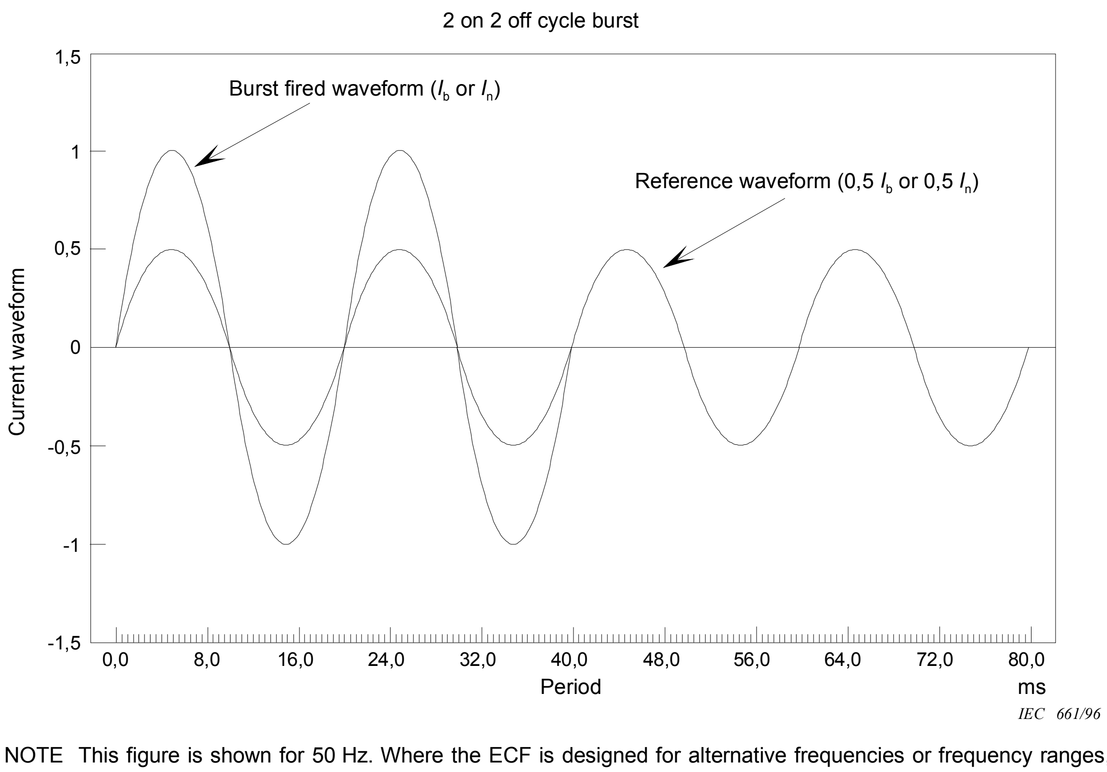
NOTE This figure is shown for 50 Hz. Where the ECF is designed for alternative frequencies or frequency ranges, the above should be adjusted to match the reference frequency.

Figure 11 – Phase-fired waveform (shown for 50 Hz)



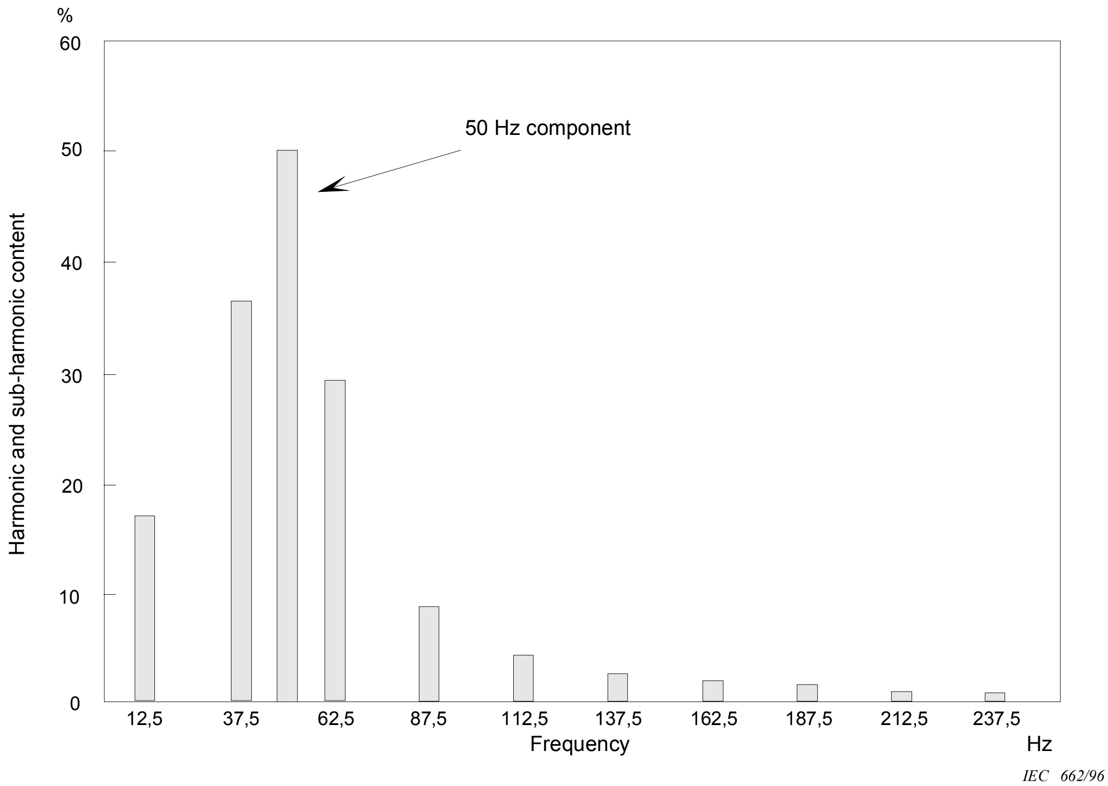
NOTE This figure is shown for 50 Hz. Where the ECF is designed for alternative frequencies or frequency ranges, the above should be adjusted to match the reference frequency.

Figure 12 – Analysis of harmonic content of phase-fired waveform (shown for 50 Hz)



NOTE This figure is shown for 50 Hz. Where the ECF is designed for alternative frequencies or frequency ranges, the above should be adjusted to match the reference frequency.

Figure 13 – Burst fire waveform (shown for 50 Hz)



NOTE This figure is shown for 50 Hz. Where the ECF is designed for alternative frequencies or frequency ranges, the above should be adjusted to match the reference frequency.

Figure 14 – Analysis of harmonics (shown for 50 Hz)

5.4.4.4.6 Continuous magnetic induction of external origin

This test does not apply to d.c. ECFs.

The test of the influence of external magnetic induction shall be carried out according to the test procedure described in Annex A.

During the test the magnetic induction shall have the value specified in Table 19.

5.4.4.4.7 Magnetic induction of external origin

The test of the influence of external magnetic induction shall be carried out according to the test procedure described in Annex A.

During the test the magnetic induction shall have the value specified in Table 19.

For an a.c. ECF the magnetic induction shall be produced by a current of the same frequency as that of each traction supply system for which the ECF is intended. For a d.c. ECF a magnetic induction shall be produced by a d.c. current.

5.4.4.5 Tests for electromagnetic compatibility

Compliance with the EMC requirements as specified in 4.4.7 shall be demonstrated by the following tests.

The tests shall be carried out according to EN 50121-3-2.

5.4.4.5.1 General test conditions

Tests for EMC shall be performed independently with all other influence quantities at their reference conditions specified in Table 2 in 4.2.3.3

Unless otherwise specified for all these tests, the ECF shall be in its normal working position with the cover and terminal covers in place. All parts intended to be earthed shall be earthed.

5.4.4.5.2 Test of immunity to electrostatic discharges

The ECF shall be tested in accordance with EN 50121-3-2:2006, Table 9, and EN 61000-4-2 under the following conditions:

- device in operating condition;
- voltage and auxiliary circuits energised with reference voltage;
- current measuring circuits open circuited;
- contact discharge;
- number of discharges of 10 (using the most sensitive polarity).

5.4.4.5.3 Test of immunity to electromagnetic RF fields

The ECF shall be tested in accordance with EN 50121-3-2:2006, Table 9, and EN 61000-4-3 with voltage and auxiliary circuits energised at the reference voltage.

ECFs shall be tested in their operating condition:

a) without any current in the current circuits and with the current terminals on open circuit;

b) with rated current I_n, Power Factor: 1.

5.4.4.5.4 Fast transient burst test

The ECF shall be tested in accordance with EN 50121-3-2:2006, Table 7 and 8, and EN 61000-4-4, under the following conditions.

Equipment will be designed and manufactured in accordance with the electromagnetic environment requirements as stated in EN 50121-3-2:2006, Table 7 and 8. Higher values are known to exist in practice. Therefore burst amplitudes greater than 6 kV should be considered.

The test voltage shall be applied in common mode to earth to:

- the voltage measuring circuits, all inputs simultaneously;
- the auxiliary supply voltage circuits;
- the current measuring circuits, if separated from the voltage measuring circuits in normal operation, all inputs simultaneously;
- the communications ports if fitted, all ports simultaneously;
- the pulse and other auxiliary outputs if fitted, all outputs simultaneously;
- any other auxiliary circuits if fitted and, if separated from the voltage measuring circuits in normal operation, all inputs simultaneously.

Any ports which might in normal use be connected directly to the power system shall be directly coupled to the test voltage. Ports which are not directly connected to the power system shall be tested using a capacitive coupling clamp. The ECF shall be tested under the conditions in a) and b):

a) with rated current I_n, and phase influence function = 1:

  - ECF in operating condition;
  - voltage measurement and auxiliary circuits energised with reference voltage;

- test voltage on the current and voltage circuits: 4 kV;
- test voltage on the auxiliary circuits with a reference voltage over 40 V: 2 kV;
- for capacitively coupled inputs the test voltage shall be 2 kV;
- duration of the test: 60 s at each polarity.

b) without any current in the current measurement circuits and with these circuits in an open circuit condition:

- ECF in operating condition;
- voltage measurement and auxiliary circuits energised with reference voltage;
- test voltage on the current and voltage circuits: 4 kV;
- test voltage on the auxiliary circuits with a reference voltage over 40 V: 2 kV;
- for capacitively coupled inputs the test voltage shall be 2 kV;
- duration of the test: 60 s for each polarity.

5.4.4.5.5 Test of immunity to conducted disturbances, induced by radio-frequency fields

The ECF shall be tested in accordance with EN 50121-3-2:2006, Table 7 and 8, and EN 61000-4-6, under the following conditions:

- ECF in operating condition:
  - voltage and auxiliary circuits energised with reference voltage;
  - with rated current I_n and phase influence function = 1.

5.4.4.5.6 Surge immunity test

The ECF shall be tested in accordance with EN 50121-3-2:2006, Table 7, and EN 61000-4-5, under the following conditions:

- ECF in operating condition:
  - voltage and auxiliary circuits energised with reference voltage;
  - without any current in the current circuits and the current terminals open circuit;
- tested in differential mode (line to line);
- for an ECF with a.c. input, phase angle pulses to be applied at 60° and 240° relative to zero crossing of a.c. supply;
- test voltage on the current and voltage circuits (mains lines): 4 kV, generator source impedance: 2 Ω;
- test voltage on auxiliary circuits with a reference voltage over 40 V: 1 kV; generator source impedance: 42 Ω;
- number of tests: 5 positive and 5 negative;
- repetition rate: maximum 1/min.

5.4.4.5.7 Radio interference measurement

The ECF shall be tested in accordance with EN 50121-3-2:2006, Tables 4, 5 and 6 under the following conditions:

- ECF in operating conditions;
- voltage and auxiliary circuits energised with reference voltage;

- with rated current.

5.5 Routine test

5.5.1 General

Where a device has multiple input interfaces and/or multiple output interfaces, then the performance of all interfaces shall be tested. If identical performance of different interfaces has been verified, only a simple functional check is required at the additional interfaces. If this is not the case, full tests shall be conducted on each interface.

5.5.2 Visual Inspection

Visual inspection shall be undertaken on each device in accordance with EN 50155:2007, 12.2.1.

5.5.3 Insulation test

5.5.3.1 HV circuit insulation type tests

5.5.3.1.1 Power frequency test

Any device with insulation subject to traction supply system voltage shall be subjected to a power frequency test based on test methods, test durations and arrangements given in EN 60044.

The power frequency test voltage shall be in accordance with EN 50124-1 and based on the device's power frequency withstand voltage (U_a) and selected based on the device's rated impulse voltage (U_{Ni}).

After the test, the device shall be un-damaged.

If applicable, voltage sensors shall be tested in accordance with 4.3.3.1.6.

5.5.3.1.2 Partial discharge test

This test is only applicable to devices with galvanic isolation where partial discharge current can be measured.

Any device containing circuits carrying traction system voltage and which are insulated shall be subjected to a partial discharge test based on test method and arrangements given in EN 60044.

The partial discharge test voltage shall be U_{max3} in accordance with EN 50163.

The partial discharge limits shall be in accordance with EN 60044.

5.5.3.2 Low voltage circuits insulation tests

Insulation measurement and tests according to EN 50155:2007, 12.2.9 shall be carried out.

5.5.4 Accuracy tests

5.5.4.1 Accuracy tests for VMF

Compliance with the accuracy requirements of 4.3.3.4 shall be demonstrated by the following tests:

Tests shall be carried out at U_{min1}, U_n and U_{max2} with all other variables at the reference conditions specified in Table 2 in 4.2.3.3.

NOTE For single voltage sensors for traction units suitable for multiple traction supply systems, the U_{min1} value applies to the lowest rated primary voltage and the U_{max2} value to the highest rated primary voltage.

The errors measured at each measuring point shall be within the limits of the relevant accuracy class as defined in 4.3.3.4.

If the supplier has declared, in accordance with 4.3.3.5.1, a lower maximum error limit at reference temperature than is allowed for the relevant accuracy class as defined in 4.3.3.4, verify that:

a) the measured error at reference temperature does not exceed this lower maximum error limit;

b) the sum of (i) the error measured under each signal input condition above, and (ii) the additional error solely due to ambient temperature variation calculated during the type testing (see 5.4.3.4.3.1), does not exceed the maximum error given in Table 5.

If the supplier has declared lower maximum error limit is applicable, this limit shall be stated in the test report.

5.5.4.2 Accuracy tests for CMF

Compliance with the accuracy requirements of 4.3.4.3 shall be demonstrated by the following tests:

Tests shall be carried out at 10 %, 100 % and 120 % of rated primary current I_n for each polarity with all other variables at the reference conditions specified in Table 2 in 4.2.3.3.

NOTE For single current sensors for traction units suitable for multiple traction supply systems the 10 % value applies to the lowest rated primary current and the 120 % value only to the highest rated primary current. The errors measured at each measuring point shall be within the limits of the relevant accuracy class as defined in 4.3.4.3.

If the supplier has declared, in accordance with 4.3.4.4.1, a lower maximum error limit at reference temperature than is allowed for the relevant accuracy class as defined in 4.3.4.3, verify that:

a) the measured error does not exceed this lower maximum error limit,

b) the sum of (i) the error measured under each signal input conditions above, and (ii) the additional error solely due to ambient temperature variation calculated during the type testing (see 5.4.3.4.3.1), does not exceed the maximum error given in Table 10.

If the supplier declared lower maximum error limit is applicable, this limit shall be stated in the test report.

5.5.4.3 Accuracy tests for ECF

Compliance with the accuracy requirements of 4.4.4 shall be demonstrated by the following tests:

Tests shall be carried out at the reference conditions specified in Table 2 in 4.2.3.3.

The accuracy shall be measured at the 5 points identified in Figure 15 by inputting appropriate signals at the input test points of the ECF.

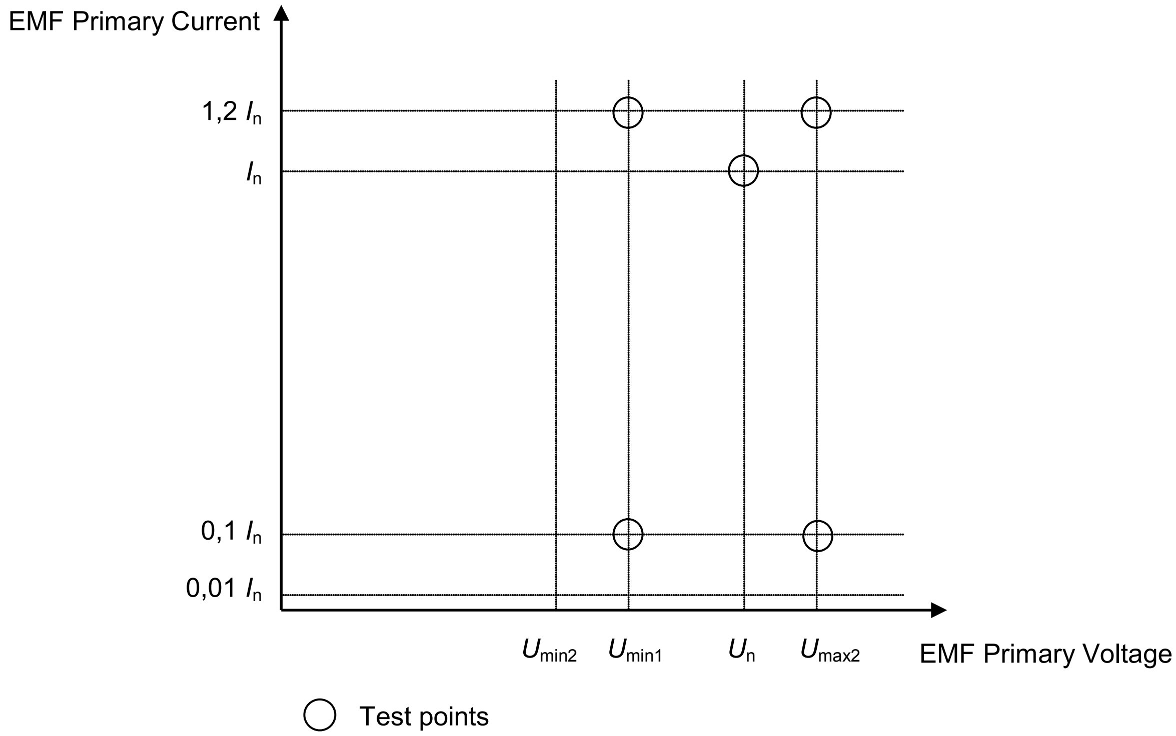


Figure 15 – Test point matrix for ECF Accuracy Tests (type test)

The errors measured at each measuring point shall be within the limits of the relevant accuracy class as defined in 4.4.4.1.

NOTE 1 For an ECF for traction units suitable for multiple traction supply systems, the U_{min1} value applies to the lowest rated primary voltage and the U_{max2} value to the highest rated primary voltage.

NOTE 2 For an ECF for traction units suitable for multiple traction supply systems having single current sensor, the 10 % value applies only to the lowest rated primary current and the 120 % value only to the highest rated primary current.

If the supplier has declared, in accordance with 4.4.5.1, a lower maximum error limit at reference temperature than is allowed for the relevant accuracy class as defined in 4.4.4.1, verify that:

a) the measured error does not exceed this lower maximum error limit,

b) the sum of (i) the error measured under each signal input conditions above, and (ii) the additional error solely due to ambient temperature variation calculated during the type testing (see 5.4.4.3.2.1), does not exceed the maximum error given in Table 17.

If the supplier declared lower maximum error limit is applicable, this limit shall be stated in the test report.

Annex A
(normative)

Test with magnetic induction of external origin

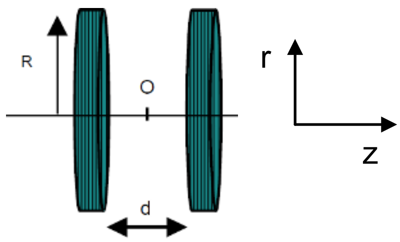
A.1 General

The magnetic induction test shall be carried out with either one of the two test setups described below:

The method to be used shall be agreed between the supplier and the entity in charge of the test.

A.2 Test method 1

This test setup consists of two circular coils of the same radius, mounted parallel and placed face to face at a distance equal to their radius. By passing a current through the coils, a magnetic field is created which has a uniform characteristic at the centre ‘O’ of the test setup. The EUT shall be positioned near point O.



EXAMPLE: 2 coils: R = 250 mm, d = 250 mm, N = 1000 turns; Permeability: $\mu_0 = 4\pi 10^{-7}$ T m A^{-1}

Figure A.1 – Test configuration for test method 1

B(r,z) near O, along z axis:

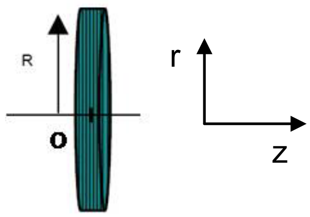
$$B_0 = \frac{\mu_0 \times N \times I \times R^2}{\left(R^2 + \left(\frac{d}{2}\right)^2\right)^{3/2}}$$

For B_0 = 4 mT at point O, the current in the coil is equal to I = 1,11 A

For B_0 = 2 mT at point O, the current in the coil is equal to I = 0,555 A

A.3 Test method 2

This test setup consists of a single circular coil. By passing a current in the coil, a magnetic field is created which has a uniform characteristic at the centre O of the coil. The EUT shall be placed at the centre O of the coil.



EXAMPLE: 1 coil: R = 250 mm, N = 1000 turns, Permeability: $\mu_0 = 4\pi 10^{-7}$ T m A^{-1}

Figure A.2 – Test configuration for test method 2

B(r,z) near O, along z axis:

$$B_0 = \frac{\mu_0 \times N \times I}{2 \times R}$$

For B_0 = 4 mT at point O, the current in the coil is equal to I = 1,59 A

For B_0 = 2 mT at point O, the current in the coil is equal to I = 0,795 A

The EUT shall be positioned in the continuous uniform magnetic field generated by the coil or coils. The magnetic field strength shall be measured with a suitable instrument with an accuracy better than 0 to +10 %. Tests are performed in all three directions of the EUT's three perpendicular axis X, Y, Z.

Depending on the size of the EUT, it may be necessary to move the magnetic field test setup (by moving its centre O across the EUT) in order to ensure that the EUT is fully subjected to the effects of the magnetic field.

Annex B
(normative)

EMF Configurations

B.1 Background

Depending on how vehicles are formed into a traction unit (e.g. traction equipment may be in just one vehicle or distributed across several) and on how the measuring system is implemented, an EMF may be made up of one or multiple VMFs, CMFs and ECFs. For such configurations, it is essential that the error values (used in the r.m.s error calculation formula in 4.2.3.2) are correctly derived. This annex defines how these error functions are to be calculated.

An example of such a complex EMF configuration is a traction unit composed of several vehicles, each equipped with a current collector. The current in each current collector is measured with a current sensor. The voltage of the Contact Line is measured with a single voltage sensor. Thus the EMF is composed of one VMF, one ECF but several CMFs.

This annex defines the requirements for different complex EMF configurations and provides formulae for calculating the overall errors.

B.2 General

Each individual VMF and CMF which form part of a complex EMF configuration shall meet the requirements as defined in 4.3.

Each individual ECF which forms part of a complex EMF configuration shall fulfil the requirements as defined in 4.4.

B.3 EMF with several CMF's in parallel

If several CMFs are used in parallel to measure the total current of a traction unit as shown in Figure B.1, the currents of all the CMFs shall be summed in the ECF.

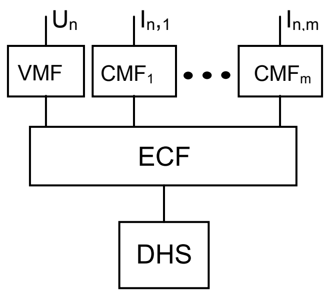


Figure B.1 – EMF with several CMF's in parallel

Each CMF can have a different rated current, a different accuracy class and a different k-factor. If the CMF's have different k-factors, the multiplication by the k-factor shall be executed in the ECF and not in the DHS.

The overall percentage error for the set of CMF's shall be determined in accordance with the following formula:

$$\varepsilon_{CMF} = \sum_{x=1}^{m} \frac{I_{n,x} \cdot \varepsilon_{CMFx}}{\sum_{x=1}^{m} I_{n,x}}$$

Where

x is the continuous numbering of the CMF's;

m is the quantity of CMF's that are measuring the currents in parallel;

$I_{n,x}$ is the rated current of the CMF with number x;

ε_{CMF} is the calculated maximum percentage error of the complete set of m CMFs;

ε_{CMFx} is the maximum percentage error of the CMF with number x allowed in accordance with the selected accuracy class under the reference conditions.

NOTE The formula for ε_{CMF} averages the percentage error of the CMFs measuring the currents in parallel by weighting the CMFs with higher rated current I_n more than those with lower rated current I_n.

ε_{CMF} shall be used in the formula of 4.2.3.2 to determine the error for the complete EMF.

B.4 EMF with several VMF's connected to one ECF

A configuration with several VMFs connected to one ECF (as shown in Figure B.2), is only practical if each VMF is used to measure a different traction supply system voltage. A configuration with several VMFs measuring the voltage of one traction voltage system in parallel shall be avoided.

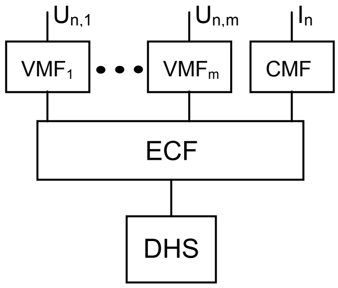


Figure B.2 – EMF with several VMF's connected to one ECF

Each VMF can have a different accuracy class and a different k-factor.

Each VMF_x together with the CMF and the ECF shall fulfil the requirements for the limits of error according to 4.2.3.4 determined in accordance with the formula in 4.2.3.2.

B.5 EMF with several pairs of VMF and CMF

If the EMF consists of several pairs of VMF and CMF (as shown in Figure B.3), the energy shall be calculated by the ECF for each pair VMF_x and CMF_x.

NOTE An example of such a system is a traction unit suitable for multiple traction supply systems.

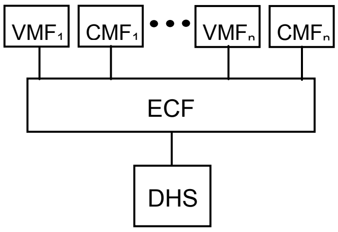


Figure B.3 – EMF with several pairs of VMF and CMF

There are two different types of configuration:

a) Several pairs of VMF and CMF are measuring voltage and current in parallel on the same traction voltage system. The calculated energy of these pairs shall be summed in the ECF.
b) Each pair of VMF and CMF is measuring on a different traction supply system. In this case, the energy data shall be stored either in separate registers for each traction supply system or in one register independent from the traction supply system. In the latter case, the energy data shall be flagged with the used traction supply system if this information is available.

If the k-factor changes with a change of the traction supply system, the k-factor change shall be handled either in the ECF or in the DHS.

Each pair of VMF and CMF together with the ECF shall fulfil the requirements for the limits of error according to 4.2.3.4 determined in accordance with the formula in 4.2.3.2.

B.6 Several EMF's in parallel

If several EMFs, each consisting of one VMF, one CMF and one ECF (as shown in Figure B.4), are installed on a traction unit, each EMF and its functions shall fulfil the requirements specified in Clause 4.

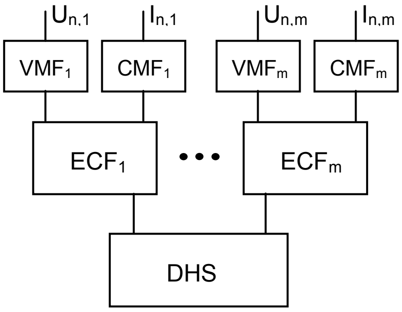


Figure B.4 – EMF with several ECF's

Each ECF shall be compatible with the intended DHS. The DHS shall handle the energy data of all ECFs.

Each ECF shall have a specific identification number. The identification number shall be transferred to the DHS with the energy data.

B.7 One VMF or CMF connected to several ECFs

One VMF or CMF may be connected to several ECFs. An example is where one voltage sensor is capable of being used on two traction voltage systems, but the energy calculation is done in different ECFs one for each traction voltage system (as shown in Figure B.5).

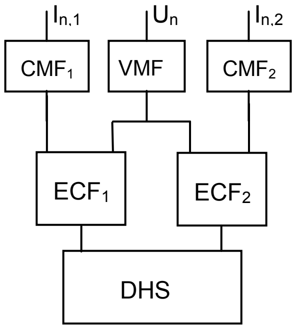


Figure B.5 – One VMF connected to two ECF's

The VMF or CMF is then part of several EMFs. Each EMF and its functions shall fulfil the requirements specified in Clause 4.

B.8 EMF without VMF

In traction units, designed for operation on traction supply system voltages of 600 V d.c. or 750 V d.c., it is possible that the EMF has no VMF and the traction supply system voltage is directly connected to the ECF voltage input as shown in Figure B.6.

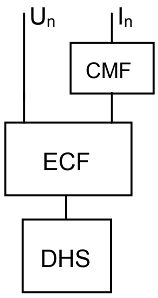


Figure B.6 – EMF without VMF

In such cases, the maximum percentage error ε_{VMF} of the VMF in the formula of 4.2.3.2 shall be considered as Zero.

Annex C
(informative)

Expressing EMF accuracy

C.1 Summary

The EMF consists of a maximum of 3 functional components (voltage measurement, current measurement, and energy calculation). The overall measurement error at any time is the algebraic sum of the independent errors; and for a.c. systems includes errors caused by phase variations.

Each functional component has its own error. Each error varies independently dependant on input signal, environmental and other conditions. For a.c. systems, the error of the metering element performing the energy calculation also varies according to the phase difference between the voltage and the current as presented to this element. Thus, it is affected by any phase displacements between voltage and current measurement.

In theory, by carrying out a multi-variable analysis of the errors of each component and simply summing the results, it should be possible to calculate the total error. The value of such a calculation is however doubtful. In 'real world' situations such as those associated with rail vehicle applications, errors continuously change as input signals and environmental conditions vary. A random change in errors will also occur over time, both in absolute value and in the reaction to external stimuli.

Overall, the variation of the effective total system error is a random function, namely it is not possible to meaningfully quantify the effect of variable input signals, external stimuli and time on total system error.

C.2 Error limits or uncertainty

Overall system error at any instant is the sum of the individual errors. Overall system error variation over time is effectively random.

As the overall system error is a random function, we can presume (unless we have specific knowledge to the contrary) that the accuracy of measurements will follow a Gaussian (or normal) distribution around the correct value. Thus the uncertainty of measurement (or the accuracy limits) can be given by the standard deviation.

Standard deviation is the square root of the mean squared deviation of the measurement from the true value. Therefore, the r.m.s. of the individual error limits of the individual components is the standard deviation of the measurement, the uncertainty or expected overall error limits. This approach has been used within this standard (see 4.2.3.2) and it is considered to be an appropriate methodology which allows a simplified but realistic approach to express the overall accuracy of the EMF.

An alternative method for expressing overall system error, namely the sum of the absolute error limits of the individual components, could be valid if individual measurement errors were predictable rather than purely random. An illustration of this approach as applied to a.c. measurement is given below (for information only).

C.3 Presentation of error limits

At any instant, the error introduced by any system component – like the overall system error – is the result of multiple individual errors. Each affects the component error in its own way, and in a direction that is generally not determinable; effectively the component error is the sum of a set of random contributions. This random effect is reinforced since the total system error is the sum of the errors of multiple individual components (whether internal to a device or external components of the system).

In order to simplify performance specification, and with overall error variation over time being effectively random, error limits are commonly described by an 'Accuracy Class'. This 'Accuracy Class' can be considered as a headline representation of the error and defines the maximum permitted error, both of amplitude and phase displacement, under specific standardised conditions. It also defines the maximum permissible variations in errors due to external effects such as temperature, harmonic content, etc. 'Accuracy Class' is also, in practice, the maximum % error under the standard conditions.

Since Error Limits are defined by 'Classes', in the definition of which both amplitude and phases displacements are considered and where the contribution of individual components is random, the Accuracy Class of the system — the uncertainty of measurement or the expected maximum errors — can be given by:

$$\varepsilon_{EMF} = \sqrt{(\varepsilon_{VMF})^2 + (\varepsilon_{CMF})^2 + (\varepsilon_{ECF})^2}$$

where

$\varepsilon_{\mathrm{EMF}}$	is the calculated maximum percentage error of the EMF;
$\varepsilon_{\mathrm{VMF}}$	is the maximum percentage (ratio) error allowed in accordance with the selected accuracy class for the VMF under the reference conditions;
$\varepsilon_{\mathrm{CMF}}$	is the maximum percentage (ratio) error allowed in accordance with the selected accuracy class for the CMF under the reference conditions;
$\varepsilon_{\mathrm{ECF}}$	is the maximum percentage error allowed in accordance with the selected accuracy class for the ECF under the reference conditions.

NOTE 1 The term "root mean square" is often used as a synonym for 'Standard Deviation' when referring to the square root of the mean squared deviation of a signal from a given value. Thus, in the above formula, $\varepsilon_{\mathrm{EMF}}$ gives the standard deviation of the actual measurements provided by the EMF in comparison with the (unknown) correct measurement.

NOTE 2 In addition to expressing the variability of a population, standard deviation is commonly used to measure confidence in statistical conclusions. For example, the margin of error in polling data is determined by calculating the expected standard deviation in the results if the same poll were to be conducted multiple times. (Typically the reported margin of error is about twice the standard deviation, the radius of a 95 % confidence interval.) In science, researchers commonly report the standard deviation of experimental data, and only effects that fall far outside the range of standard deviation are considered statistically significant – normal random error or variation in the measurements is in this way distinguished from causal variation.

C.4 Uncertainty calculations

C.4.1 a.c. active power

Active power is a function of the voltage, current and phase angle between the voltage and current waveforms. Sinusoidal current and voltage are presumed (all harmonics are ignored).

$$P = f(U,I,\varphi) = U \times I \times \cos\varphi$$

Where U and I are given by:

$U = U_{pk} / \sqrt{2}$ where U_{pk} = Peak value of voltage
$I = I_{pk} / \sqrt{2}$ where I_{pk} = Peak value of current

C.4.2 Primary values

Measurements of the primary values (voltage or current) include measurement uncertainties, both in amplitude and phase (for a.c.).

For voltage: $U_{measured} = U_{real} + \mathcal{E}U$ and $\varphi U_{measured} = \varphi U_{real} + \mathcal{E}\varphi U$

For current: $I_{measured} = I_{real} + \mathcal{E}I$ and $\varphi I_{measured} = \varphi I_{real} + \mathcal{E}\varphi I$

Where:

$\mathcal{E}$ is uncertainty in amplitude measurement (Volt or Ampere)

$\mathcal{E}\varphi$ is uncertainty in phase measurement (radians)

C.4.3 Uncertainty in the measurement of active power (Watts)

The uncertainty when calculating power depends on the measurement uncertainties of the primary values (namely voltage and current):

$$P_{measured} = U_{measured} \times I_{measured} \times \cos(\varphi I_{measured} - \varphi U_{measured})$$

$$= (U_{real} + \mathcal{E}U) \times (I_{real} + \mathcal{E}I) \times \cos[(\varphi I_{real} - \varphi U_{real}) + (\mathcal{E}\varphi I - \mathcal{E}\varphi U)]$$

$$= (U_{real} + \mathcal{E}U) \times (I_{real} + \mathcal{E}I) \times [\cos(\varphi I_{real} - \varphi U_{real}) \cos(\mathcal{E}\varphi I - \mathcal{E}\varphi U) - \sin(\varphi_{Ireal} - \varphi U_{real}) \sin(\mathcal{E}\varphi I - \mathcal{E}\varphi U)]$$

Since both φU and φI are small, the following approximations can be made:

$$\cos(\mathcal{E}\varphi I - \mathcal{E}\varphi U) \to 1$$

$$\sin(\mathcal{E}\varphi I - \mathcal{E}\varphi U) \to (\mathcal{E}\varphi I - \mathcal{E}\varphi U)$$

Thus:

$$P_{measured} = (U_{real} + \mathcal{E}U) \times (I_{real} + \mathcal{E}I) \times [\cos(\varphi I_{real} - \varphi U_{real}) - (\mathcal{E}\varphi I - \mathcal{E}\varphi U) \times \sin(\varphi I_{real} - \varphi U_{real})]$$

$$= U_{real} \times I_{real} \times \cos(\varphi I_{real} - \varphi U_{real}) - U_{real} \times I_{real} \times (\mathcal{E}\varphi I - \mathcal{E}\varphi U) \times \sin(\varphi_{Ireal} - \varphi U_{real}) + (U_{real} \times \mathcal{E}I + I_{real} \times \mathcal{E}U) \times \cos(\varphi I_{real} - \varphi U_{real}) -$$

$$(U_{real} \times \mathcal{E}I + I_{real} \times \varepsilon U) \times (\mathcal{E}\varphi I - \mathcal{E}\varphi U) \times \sin(\varphi I_{real} - \varphi U_{real}) + \mathcal{E}U \times \mathcal{E}I \times \cos(\varphi I_{real} - \varphi U_{real}) - \mathcal{E}U \times \mathcal{E}I \times (\mathcal{E}\varphi I - \mathcal{E}\varphi U) \times \sin(\varphi I_{real} - \varphi U_{real})$$

Now:

$$U_{real} \times I_{real} \times \cos(\varphi I_{real} - \varphi U_{real}) = P_{real}$$

With uncertainties being small (say $\mathcal{E}I \approx 0{,}001 \times I_{real}$ and $\mathcal{E}U \approx 0{,}001 \times U_{real}$ — namely 0,1%)

$$\mathcal{E}U \times \mathcal{E}I \rightarrow 0$$

And with the Power Factor being better than 0,85, namely:
$\varphi \leq 32^{o}$ ($\leq 0{,}56$ radians), $\cos \varphi \geq 0{,}85$ and $\sin \varphi \leq 0{,}53$

With small phase uncertainties, namely:

$\mathcal{E}\varphi I \approx \mathcal{E}\varphi U \approx \pm 0{,}1^{o} \approx \pm 0{,}0017$ radian

$\mathcal{E}I \approx \pm 0{,}1\%\ I_{real}$

$\mathcal{E}I \approx \mathcal{E}U \approx \pm 0{,}1\%\ U_{real}$

Then at 50 % load:

$$U_{real} \cdot \mathcal{E}I \approx I_{real} \times \mathcal{E}U \approx 0{,}0005\ I_{real} \times U_{real}$$

NOTE Uncertainties are small at precision devices.

Then:

$$(U_{real} \times \mathcal{E}I + I_{real} \times \mathcal{E}U) \times (\mathcal{E}\varphi I - \mathcal{E}\varphi U) \times \sin(\varphi I_{real} - \varphi U_{real})$$

also tends to 0 [1)] even if worst case polarities are presumed.

Thus:

$$P_{measured} = P_{real} - U_{real} \times I_{real} \times (\mathcal{E}\varphi I - \varepsilon\varphi U) \times \sin(\varphi I_{real} - \varphi U_{real}) + (U_{real} \times \mathcal{E}I + I_{real} \times \mathcal{E}U) \times \cos(\varphi I_{real} - \varphi U_{real}) \quad (1)$$

C.4.4 Relative uncertainty

Relative uncertainty of the measurement of active power is given by:

$$\mathcal{E}P_R = (P_{measured} - P_{real}) / P_{real}$$

Thus substituting from (1) above:

$$\mathcal{E}P_R = [P_{real} - U_{real} \times I_{real} \times (\mathcal{E}\varphi I - \mathcal{E}\varphi U) \times \sin(\varphi I_{real} - \varphi U_{real}) + (U_{real} \times \mathcal{E}I + I_{real} \times \mathcal{E}U) \times \cos(\varphi I_{real} - \varphi U_{real})] - P_{real}) / P_{real}$$

---

1) At the values given, the function resolves to: $(0{,}0005\ I_{real} \times U_{real} + 0{,}0005\ I_{real} \times U_{real}) \times (0{,}001 + 0{,}001) \times (0{,}53) = 1{,}06 \times 10^{-6}$.

$$= [-U_{real} \times I_{real} \times (\mathcal{E}\varphi I - \mathcal{E}\varphi U) \times \sin(\varphi I_{real} - \varphi U_{real}) + (U_{real} \times \mathcal{E}I + I_{real} \times \mathcal{E}U) \times \cos(\varphi I_{real} - \varphi U_{real}] \; / \; U_{real} \times I_{real} \times \cos(\varphi I_{real} - \varphi U_{real})$$

i.e.:

$$\mathcal{E}P_R = (\mathcal{E}I/I_{real}) + (\mathcal{E}U/U_{real}) - \tan(\varphi I_{real} - \varphi U_{real}).(\mathcal{E}\varphi I - \mathcal{E}\varphi U)$$

Thus the maximum Relative Uncertainty in measuring power ($\mathcal{E}P_{R\,max}$ or AP_{EMAmax}) is given by:

$$\mathcal{E}P_{R\,max} = |\mathcal{E}I/I_{real}| + |\mathcal{E}U/U_{real}| + |\tan(\varphi I_{real} + \varphi U_{real})| \times (|\mathcal{E}\varphi I| + |\mathcal{E}\varphi U|)$$

(Phase uncertainties are summed to ensure worst case conditions)

If:

$AP_{EMAmax} = \mathcal{E}P_{R\,max}$ (Active power maximum relative uncertainty)

$A_{CSmax} = (\mathcal{E}I/I_{real})$ (Current sensor maximum relative uncertainty)

$A_{VSmax} = (\mathcal{E}U/U_{real})$ (Voltage sensor maximum relative uncertainty)

And since:

a) $(\varphi I_{real} - \varphi U_{real})$ will be small (maximum of ~30°, or 0,52 radian), $\tan(\varphi I_{real} - \varphi U_{real}) \leq 0{,}62$ [2];

b) $\mathcal{E}\varphi I$ and $\mathcal{E}\varphi U$ are both small [3] (also normally similar in value and in sign).
A $\mathcal{E}\varphi$ of 0,1° ≈ 0,00175 radians. Thus $(|\mathcal{E}\varphi I| + |\mathcal{E}\varphi U|) \approx 0{,}0035$;

c) $|\tan(\varphi I_{real} - \varphi U_{real})| \times (|\mathcal{E}\varphi I - \mathcal{E}\varphi U|) \leq 0{,}62 \times 0{,}0035 \approx 0{,}002$ (namely 0,2 %)

Thus: $\mathcal{E}P_{R\,max} \approx |\mathcal{E}I/I_{real}| + |\mathcal{E}U/U_{real}| + 0{,}002$

Namely: $AP_{EMAmax} \approx A_{CSmax} + A_{VSmax} + 0{,}002$ (2)

C.4.5 Uncertainty in the measurement of reactive power (var) [4]

The uncertainty when calculating reactive power also depends on the measurement uncertainties of the primary values (namely Voltage and Current):

$$\varepsilon Q_R = (Q_{measured} - Q_{real}) / Q_{real}$$

$$Q_{measured} = U_{measured} \times I_{measured} \times \sin(\varphi I_{measured} - \varphi U_{measured})$$

$$= (U_{real} + \mathcal{E}U) \times (I_{real} + \mathcal{E}I) \times \sin[(\varphi I_{real} + \mathcal{E}\varphi I) - (\varphi U_{real} + \mathcal{E}\varphi U)]$$

---

[2] At PF=0,85, φ ≈ 32° and tan 32° ≈ 0,62.

[3] Since current and voltage sensors will be class 0,5 or better, phase errors will be less than 0,5°, thus the uncertainty will be much less than this; say 0,05° or possibly 0,1°.

[4] Reactive power measurement accuracy is specified at values around a Power Factor of Zero (sin φ = 1) as is normal in all metering standards. Specification of reactive power accuracy where the Power Factor is in the order of unity is not possible as the errors will tend to infinity.

$$= (U_{real} + \mathcal{E}U) \times (I_{real} + \mathcal{E}I) \times \sin [(\varphi I_{real} - \varphi U_{real}) + (\mathcal{E}\varphi I - \mathcal{E}\varphi U)]$$

$$= (U_{real} + \mathcal{E}U) \times (I_{real} + \mathcal{E}I) \times [\sin (\varphi I_{real} - \varphi U_{real}) \times \cos (\mathcal{E}\varphi I - \mathcal{E}\varphi U) - \cos (\varphi I_{real} - \varphi U_{real}) \times \sin (\mathcal{E}\varphi I - \mathcal{E}\varphi U)]$$

Since both φU and φI are small, the following approximations can be made:

$$\cos (\mathcal{E}\varphi I - \mathcal{E}\varphi U) \rightarrow 1$$

$$\sin (\mathcal{E}\varphi I - \mathcal{E}\varphi U) \rightarrow (\mathcal{E}\varphi I - \mathcal{E}\varphi U)$$

Thus:

$$Q_{measured} = (U_{real} + \mathcal{E}U) \times (I_{real} + \mathcal{E}I) \times [\sin (\varphi I_{real} - \varphi U_{real}) - \cos (\varphi I_{real} - \varphi U_{real}) \times (\mathcal{E}\varphi I - \mathcal{E}\varphi U)]$$

$$\begin{aligned} = \; & U_{real} \times I_{real} \times \sin (\varphi I_{real} - \varphi U_{real}) - U_{real} \times I_{real} \times \cos (\varphi I_{real} - \varphi U_{real}) \times (\mathcal{E}\varphi I - \mathcal{E}\varphi U) \\ & + (U_{real} \times \mathcal{E}I + I_{real} \times \mathcal{E}U) \times \sin (\varphi I_{real} - \varphi U_{real}) \\ & - (U_{real} \times \mathcal{E}I + I_{real} \times \mathcal{E}U) \times \cos (\varphi I_{real} - \varphi U_{real}) \times (\mathcal{E}\varphi I - \mathcal{E}\varphi U) \\ & + \mathcal{E}U \times \mathcal{E}I \times \sin (\varphi I_{real} - \varphi U_{real}) - \mathcal{E}U \times \mathcal{E}I \times \cos (\varphi I_{real} - \varphi U_{real}) \times (\mathcal{E}\varphi I - \mathcal{E}\varphi U) \end{aligned}$$

Now:

$$U_{real} \times I_{real} \times \sin (\varphi I_{real} - \varphi U_{real}) = Q_{real}$$

With uncertainties being small (say $\varepsilon I \approx \varepsilon U \approx 0{,}001$ — namely 0,1 %)

$$\mathcal{E}U \times \mathcal{E}I \rightarrow 0$$

And with sinφ being better than 0,85, namely:

$\varphi \leq 32^\circ$ ($\leq$ 0,56 radians), $\sin \varphi \leq 0{,}53$ and $\cos \varphi \geq 0{,}85$

With small phase uncertainties, namely:

$\mathcal{E}\varphi I \approx \mathcal{E}\varphi U \approx \pm 0{,}1^\circ \approx \pm 0{,}0017$ radian

$\mathcal{E}I \approx \mathcal{E}U \approx \pm 0{,}1\ \% \approx \pm 0{,}001$

Then at 50 % load: $U_{real} \times \mathcal{E}I \approx I_{real} \times \mathcal{E}U \approx 0{,}0005$

NOTE Uncertainties are small since we are dealing with precision devices.

Then:

$$(U_{real} \times \mathcal{E}I + I_{real} \times \mathcal{E}U) \times (\mathcal{E}\varphi I - \mathcal{E}\varphi U) \times \cos (\varphi I_{real} - \varphi U_{real})$$

also tends to 0 [5] even if worst case polarities are presumed.

Thus:

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[5] At the values given, the function resolves to: (0,0005 I_{real} ×× U_{real} + 0,0005 I_{real} × U_{real}) × ×(0,001 + 0,001) × ×(0,53) = 1,06 x 10^{-6} I_{real} ×× U_{real} .

$$Q_{measured} = Q_{real} - U_{real} \times I_{real} \times (\varepsilon\varphi I - \varepsilon\varphi U) \times \cos(\varphi I_{real} - \varphi U_{real}) + (U_{real} \times \varepsilon I + I_{real} \times \varepsilon U) \times \sin(\varphi I_{real} - \varphi U_{real}) \quad (3)$$

C.4.6 Relative uncertainty

Relative uncertainty of the measurement of reactive power is given by:

$$\varepsilon Q_R = (Q_{measured} - Q_{real}) / Q_{real}$$

Thus substituting from (3) above:

$$\varepsilon Q_R = [Q_{real} - U_{real} \times I_{real} \times (\varepsilon\varphi I - \varepsilon\varphi U) \times \cos(\varphi I_{real} - \varphi U_{real}) + (U_{real} \times \varepsilon I + I_{real} \times \varepsilon U) \times \sin(\varphi I_{real} - \varphi U_{real})] - Q_{real}) / Q_{real}$$

$$= [-U_{real} \times I_{real} \times (\varepsilon\varphi I - \varepsilon\varphi U) \times \cos(\varphi I_{real} - \varphi U_{real}) + (U_{real} \times \varepsilon I + I_{real} \times \varepsilon U) \times \sin(\varphi I_{real} - \varphi U_{real})] / U_{real} \times I_{real} \times \sin(\varphi I_{real} - \varphi U_{real})$$

I.e.:

$$\varepsilon Q_R = (\varepsilon I/I_{real}) + (\varepsilon U/U_{real}) - \cot(\varphi I_{real} - \varphi U_{real}) \times (\varepsilon\varphi I - \varepsilon\varphi U)$$

Thus the maximum Relative Uncertainty in measuring reactive power (εQ_{Rmax} or AQ_{EMAmax}) is given by:

$$\varepsilon Q_{Rmax} = |\varepsilon I/Ir_{eal}| + |\varepsilon U/U_{real}| + |\cot(\varphi I_{real} + \varphi U_{real})| \times (|\varepsilon\varphi I| + |\varepsilon\varphi U|)$$

(Phase uncertainties are summed to ensure worst case conditions)

If:

$AQ_{EMAmax} =$	$\varepsilon Q\ max$	(Reactive power maximum relative uncertainty)
$A_{CSmax} =$	$(\varepsilon I/I_{real})$	(Current sensor maximum relative uncertainty)
$A_{VSmax} =$	$(\varepsilon U/U_{real})$	(Voltage sensor maximum relative uncertainty)

And since:

a) $(\varphi I_{real} - \varphi U_{real})$ will be small (maximum of ~ 58°, or 0,91 radian), $\cot(\varphi I_{real} - \varphi U_{real}) \leq 0{,}62$ [6)]

b) $\varepsilon\varphi I$ and $\varepsilon\varphi U$ are both small [7)] (also normally similar in value and in sign).
A $\varepsilon\varphi$ of 0,1° ≈ 0,00175 radians. Thus $(|\varepsilon\varphi I| + |\varepsilon\varphi U|) \approx 0{,}0035$;

c) $|\cot(\varphi I_{real} - \varphi U_{real})| \times (|\varepsilon\varphi I - \varepsilon\varphi U|) \leq 0{,}62 \times 0{,}0035 \approx 0{,}002$ (namely ~ 0,2 %)

Thus: $\varepsilon Q_{Rmax} \approx |\varepsilon I/I_{eal}| + |\varepsilon U/U_{real}| + 0{,}002$

Namely: $AQ_{EMAmax} \approx A_{CSmax} + A_{VSmax} + 0{,}002$ (4)

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6) At sin φ = 0,85, φ ≈ 58° and cot 58° ≈ 0,62.

7) Since current and voltage sensors will be Class 0,5 or better, phase errors will be less than 0,5°, thus the uncertainty will be much less than this, i.e. 0,05° or possibly 0,1°.

Annex D
(informative)

Re-verification and defining of its regime recommendations

D.1 Re-verification

D.1.1 Introduction and background

Because the device (or devices) forming the EMF may be subject to legal metrological control (see EN 50463-1) and the measured data produced is used as the basis of fiscal transactions, the performance of the metrological aspects during the device design life is important. The re-verification regimes adopted historically within Europe in the energy supply and rail sector, for devices which contain the energy measuring function, and in particular the Energy Calculation Function (commonly known as metering equipment) use a number of different approaches. In most cases the regime and arrangements adopted are subject to oversight by a responsible national body. It is also worth noting that where metering equipment for energy measurement is covered by other European Norms produced by CENELEC (for example the EN 50470 series and EN 62053 series) re-verification activity falls outside the scope of such standards.

This annex seeks to set out informative information relating to re-verification in the context of the rail sector environment.

D.1.2 Approaches to re-verification

Most existing re-verification regimes are based around the concept that once a device (which is subject to metrological control) has been placed into service it can remain in use for a designated period, beyond which it cannot remain in service unless (i) specified re-verification activities are undertaken to ensure that it is suitable for ongoing use, or (ii) it is replaced by a new device. In some cases, where the longer term metrological performance of a device is not in doubt, no planned re-verification is undertaken during the design life of the device. For example, it is not uncommon for technology such as inductive measurement transformers to be operated for their entire design life without re-verification testing.

Where re-verification is considered necessary, one possible regime is to undertake re-verification on each device after ‘n’ years in service and test 100 % of devices on a relatively frequent basis (e.g. every few years). Alternatively, the period before re-verification of each device can be considerably longer when an accompanying surveillance regime is also employed. In such a case a statistical approach is employed whereby sample surveillance tests are undertaken, at much shorter period, on a small percentage of the total population each year. If the outcome of the surveillance sample tests is positive then the population can continue in service up to planned re-verification. However, if the results of the surveillance sample tests indicate a possible problem then the surveillance regime is escalated, additional surveillance testing is undertaken, and if problems are confirmed, the time before re-verification can be shortened. In very extreme cases the population may be removed from service.

In making recommendations about re-verification activity to the purchaser the supplier should consider the following constrains which are typical of the rail sector environment:

- traction units have high availability, spend only short periods out of service for maintenance; and the interval between major maintenance activities can be several years;
- traction units are operated and maintained under a strict safety regime so any on board re-verification testing and disturbance of cabling is to be strictly controlled;
- devices mounted on traction units can be difficult to access, for example sensors can be roof mounted in a high voltage environment and special arrangements can be required to access them;
- implementing safety procedures and safeguards to allow testing on board, particularly when high voltage supplies are involved, can be onerous;

- the environmental conditions on a traction unit are typically different from those used during type testing and routine testing, consequently any comparisons with tests made under reference condition needs to take account of these factors.

When re-verification testing is necessary a number of methodologies are conceptually possible, including:

- testing on board the traction unit during maintenance (for example by injection testing);
- device removal or exchange during maintenance and device testing off the traction unit;
- on board comparison testing by testing the installed device against reference device;

When making recommendations to the purchaser, the supplier should consider:

- device technology and likelihood of change in metrological performance change during the design life;
- likely constraints imposed when undertaking re-verification in a railway sector environment.

D.2 Defining re-verification regime recommendations

D.2.1 General approach

The following aspects should be considered when defining and describing the recommended re-verification regime for a device.

D.2.1.1 Documents review

To be able to perform the re-verification procedure, the original Conformity Assessment File (see EN 50463-5) and documentation covering any subsequent re-verification activity should be available:

- to allow comparison of the results from any results from previous tests;
- for checking of device against previous configuration records.

D.2.1.1.1 Recommended re-verification regime and periodicity

The recommended re-verification regime should include a definition of the design life of the device, the maximum periodicity before undertaking the re-verification and the proposed re-verification procedure.

Aspects to consider when defining the periodicity:

- it is envisaged that some devices may not be susceptible to change in their metrological properties due to aging. The supporting rational for this could be based, for example, on technical justifications and/or service experience that demonstrates that the device is not expected to have any significant change in metrological performance resulting in the maximum error limit being exceeded during a specified time period or for the complete design life of the device. Such devices could then be partially or completely removed from the re-verification testing regime;
- if in addition to re-verification testing, surveillance testing is also to be employed, the re-verification periodicity should take account of the following item;
- the re-verification periodicity should state the maximum period considered appropriate based on technical justifications only. However, the supplier should note that, for other non-technical reasons (e.g. traction unit maintenance cycles) the maximum period adopted when in commercial service might be shorter than the recommended technical maximum.

NOTE Highly Accelerated Life Time Test (HALT) methods can be used to simulate the possible change introduced over a given period of time by one or more influence factor(s) on a device or function. Test results are often the basis for contractual guaranties of endurance from supplier and may be helpful in demonstrating product life. Results from this type of testing may help provide evidence to demonstrate the durability of a device. For further information on testing see Annex E.

D.2.2 Testing regime

The supplier should provide a list of device characteristics and define which are vulnerable to change in metrological performance due to aging. For these characteristics, the supplier should provide a set of re-verification test procedures and, if applicable, procedures for surveillance tests. The results from these tests should be comparable to those from the original test procedures when the device was new. In some cases the supplier may wish to undertake a special test (in addition to the mandatory type and routine accuracy tests) when new, in order to act as a reference point against which re-verification test results can be compared Test reports of these additional tests should be part of the Conformity Assessment File (see EN 50463-5).

D.2.2.1 Testing approach

For any testing associated with the re-verification regime where a statistical approach is to be adopted it should include an escalation system, where the number of devices tested is increased at each level together with pass / fail criteria for each level.

Example of escalation:

Level 1: test 5 devices of a given type	*Pass criteria: 100 %*
Level 2: test 20 more devices of a given type	*Pass criteria: 95 %*
Level 3: test all devices of a given type	*Pass criteria: 98 %*

The test is initiated using the quantities defined in level 1. If the test is not passed successfully, then the test is escalated using the quantity of devices defined in level 2. If this test also fails, then the test is escalated using the quantity of devices defined in level 3. If the test still fails the device design may be withdrawn from use and its conformity assessment withdrawn or more stringent re-verification and surveillance arrangements put in place.

Annex E
(informative)

Durability test

E.1 Durability test

To determine durability, the stability of metrological characteristics may be tested by applying stresses to the complete EMF or to individual components. Such tests can be derived from the EN 62059-32-1 and/or other relevant supplier standards. In either case, the supplier should demonstrate the relationship between the standards used and the stresses applied to determine stability of metrological characteristics.

Whichever standard used, a relationship should be established between durability test, stability of metrological characteristics and design life.

The test should be carried out on a complete EMF or individual components, e.g. sensors and meter submitted for type testing (EUT).

Unless otherwise specified in the test schedule all tests should be carried out on a complete EMF or individual components fully assembled according to the supplier’s instructions.

As an example, the test procedures in Annex E are based on an EN 62059-32-1 test procedure and can be applied to the complete EMF or to individual components. The test procedure consists of initial measurements on the equipment under test (EUT), operational conditioning at the maximum temperature, voltage and current of the specified operating range – during which intermediate measurements are taken – followed by recovery and final measurements.

E.1.1 Initial measurements

Initial measurements errors should be made according to the applicable clauses of this European Standard at the corresponding following point:

- value of voltage: U_{max2};
- value of current for direct connected meters: 120 % of Rated Primary Current In;
- value of Power Factor for a.c. meters for active energy: PF = 0,85 ind.;
- value of Power Factor for a.c. meters for reactive energy: PF = 0,5 ind..

For EUT consist of complete EMF, the actual percentage error should be measured as the formula given in 4.2.3.1 does not provide a real value suitable for this test.

E.1.2 Conditioning

The EUT should be pre-conditioned at an elevated temperature according to EN 60068-2-2:2007 as follows:

- test Be according to EN 60068-2-2:2007, 5.4: dry heat for heat-dissipating specimens with gradual change of temperature that are required to be powered throughout the test;
- air velocity: low preferred (see EN 60068-2-2:2007, 4.2);
- temperature: the upper limit of the operating temperature range specified by the supplier;
- duration of the test: 1 000 h (with the exception indicated below);
- EUT in operating conditions, with test load:
- value of voltage: U_{max2}. If the equipment is intended for several reference voltages, then the highest reference voltage should be taken into account;
- value of current: 120 % of Rated Primary Current In (with the exception indicated below);
- value of Power Factor:
- for a.c. meters for active energy PF = 0,85;
- for a.c. meters for reactive energy PF = 0,5;

To facilitate testing, the rated primary current I_n may be used, with the duration of the test increased accordingly to 1 250 h.

The EUT shall be mounted as for normal operation.

The EUT shall be connected as specified by the supplier.

The EUT is placed in the test chamber, which is at laboratory temperature. The voltages and currents specified above are then applied, and the EUT is checked to ascertain that it is functioning correctly.

If necessary, a test shall be performed to check if the test chamber meets the requirements of a low air velocity chamber. See EN 60068-2-2:2007, 4.2.

The temperature is then raised to the test temperature. The rate of change of the temperature within the test chamber shall not exceed 1 K per minute, averaged over a period of not more than 5 min.

The test period as defined above shall not commence until the EUT has reached a stable temperature.

NOTE The temperature is considered to be stable when the variation of percentage error at 120 % of rated primary current I_n over 20 min does not exceed 1/5th of the limit of percentage error at reference conditions as specified in the relevant standard. This may be determined using the test output and a reference standard equipment, or by applying a stable load and measuring the test output.

E.1.3 Intermediate measurements

During the pre-conditioning process, the EUT should be monitored to ensure that it does not exhibit any unusual behaviour in energy measurement and registration.

NOTE 1 Examples of irregular behaviour are significant negative or positive measurement errors.

To verify correct performance, the error should be measured at regular intervals.

For a EUT consisting of an ECF or a complete EMF, the value measured is energy. The energy registered by the ECF during a given interval is read from the register of the EUT.

The true value is determined by using reference equipment of the same type of the EUT with known errors and the same reference values.

NOTE 2 It is assumed, that the effect of influence quantities and disturbances is the same for the EUT and the reference.

Special care should be taken to ensure that the load on the reference equipment and the EUT is the same.

Before the test, the percentage error of the reference equipment under the test conditions (voltage, current and phase influence function) should be measured. The absolute value of this percentage error of the reference equipment is denoted e_r.

The maximum percentage error is:

$$e_{max} = 2\sqrt{(e_0 + e_r)^2}$$

where

- e_0 the maximum permissible percentage error at the test conditions (voltage, current and phase influence function) and at the test temperature as defined by the applicable standard;
- e_r the absolute value of the percentage error of the reference equipment at the test conditions as measured above.

Where the EUT is an a.c. ECF or complete EMF, the test should be performed at *PF* = 0,85 and *PF* = 0,5 inductive.

The values of e_0 should be the value applicable at PF = 0,5.

If the percentage error during the test exceeds e_{max} then the EUT is considered to have failed and the test can be terminated.

EXAMPLE:

The EUT is a meter of accuracy class 1 R. The reference temperature is +23 °C. The upper limit of the operating temperature range is +55 °C.

According to Table 17, at the test load:

- the limit of percentage error at I_n and U_n is (+1 % + (0,01 %/K × 32 K)) = 1,32 %;
- the absolute value of the percentage error of the reference meter is, for example 0,3 %.

Thus, if the percentage error exceeds $2\sqrt{(1{,}32+0{,}3)^2} = \pm 2{,}55\%$, the EUT failed.

E.1.4 Final temperature ramp

At the end of the test, the EUT should remain in the test chamber – with the voltage and/or current still applied – while the temperature is gradually lowered to reference temperature ± 2 °C.

The rate of change of the temperature within the test chamber should not exceed 1 K per minute, averaged over a period of not more than 5 min.

The EUT should remain for 2 h in the test chamber at the final temperature, with voltage and/or current still applied.

E.1.5 Final measurements and acceptance criteria

The percentage error of the EUT should be measured again in the same way as the initial measurements (see E.1.1).

The EUT should preferably remain connected in the test chamber. It is recommended that the same test equipment as used for the initial measurements is used.

The measured error at each test point should not change from the value before test by more than 0,1 x N, where N is the allowable error for the accuracy.

Example:

The EUT is a current sensor of accuracy class 0,5R, the change limit of percentage error at each point should not exceed 0,25.

The EUT is considered to have passed, if no unusual behaviour in measurement and registration was noted and if the change in percentage error does not exceed the values specified above.

E.1.6 Information to be given in the test report

As a minimum, the test report should show the information specified in EN 60068-2-2:2007, Clause 8, in particular:

- reference to this European Standard and to the type test standards relevant for the EUT;
- tidentification of the EUT, including all elements necessary to identify the device type;
- reference input value (voltage and/or current);

- Power Factor for meter or complete EMF;
- results of ascertaining high or low air velocity in the test chamber (see EN 60068-2-2:2007, 4.2);
- specified operating temperature range;
- results of the change of the percentage error after conditioning at each test point;
- result of a visual inspection. Any damage that may affect the proper functioning of the meter should be reported;
- final conclusion if the test is passed or not.

Annex ZZ
(informative)

Coverage of Essential Requirements of EU Directives

This European Standard has been prepared under a mandate given to CENELEC by the European Commission and the European Free Trade Association and within its scope the standard covers all relevant essential requirements as given in Annex III of the EU Directive 2008/57/EC.

Compliance with this standard provides one means of conformity with the specified essential requirements of the Directive(s) concerned.

WARNING: Other requirements and other EU Directives may be applicable to the products falling within the scope of this standard.

Bibliography

EN 60359:2002, *Electrical and electronic measurement equipment — Expression of performance (IEC 60359:2001)*

EN 62059-32-1:201X[8], *Electricity metering equipment — Dependability — Part 32-1: Durability — Testing of the stability of metrological characteristics by applying elevated temperature (IEC 62059-32-1:2011)*

IEC 60050 (all parts), *International Electrotechnical Vocabulary*

[8] At draft stage.

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