DC Energy Measurement for EV Charging Stations

- Existing application: railway on-board energy meter
  - Energy Measurement Function (EMF)
  - Voltage measurement (DV)
  - Current measurement (ITC)
- Application requirements
- Legal requirements
- Standards

Railway - Energy measurement Function

- > 15.000 devices in operation
- > 10 years experience

ERESS customer Forum, Copenhagen / 1st June 2010

EM4T

DV
(Class 0.5R)

ITC
(Class 0.5R)

Class Accuracy for Energy Measurement System

General requirements, error calculation

(EN 50463)

4.1.4.1 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}	the calculated maximum percentage error of the energy measurement function
ε_{VMF}	the maximum percentage (ratio) error of the voltage sensor under the reference conditions
ε_{CMF}	the maximum percentage (ratio) error of the current sensor under the reference conditions
ε_{ECF}	the maximum percentage error of the energy calculation function under the reference conditions

Class Accuracy for Energy measurement Function

Compliance with the railway standard EN 50463

AC and DC Railway Applications – Energy metering on-board trains (prepared by CENELEC-TC9X working Group11)

Class Accuracy for Energy measurement Current and Voltage Measurement

Compliance with the standard EN 50463: AC and DC Railway Applications – Energy metering on-board trains

- LEM **ITC** and **DV** transducers compliant to EN 50463
  - Our standard current transducers are not compliant with this standard: stringent accuracy and vibration requirements
  - DV is compliant to this standard (Class 0.5R)
  - ITC is compliant to this standard (Class 0.5R), no primary losses and it will be compliant to this new standard for Energy measurement on DC network.
  - **Solution for fixed installations: based on IT & DVL-series**

DC Voltage Network Limits According to EN 50163

Tableau 1 — Tensions nominales et leurs limites admissibles en valeur et en durée

Système d'électrification	Tension non permanente la plus basse U_{min2} V	Tension permanente la plus basse U_{min1} V	Tension nominale U_n V	Tension permanente la plus élevée U_{max1} V	Tension non permanente la plus élevée U_{max2} V
courant continu (valeurs moyennes)	400	400	600 [a]	720	800
	500 [c]	500	750	900 [c]	1 000
	1 000	1 000	1 500	1 800 [c]	1 950
	2 000	2 000	3 000	3 600	3 900 [b]

Voltage dynamic range: 1:1.95

In practice, EN 50463 is respected for 2 subsequent voltage levels, e.g. 750 V and 1500 V
→ voltage dynamic range 1:3.9

EN 50463-2 Requirements for Voltage Transducers

Accuracy class	± Maximum percentage voltage (ratio) error at voltage defined in EN 50163			± Maximum phase displacement at voltage defined in EN 50163 a.c. sensor (minutes) at rated frequency		
	U_{min2}	U_{min1}	U_{max2}	U_{min2}	U_{min1}	U_{max2}
0,2 R	0,4	0,2	0,2	10’	10’	10’
0,5 R	1	0,5	0,5	30’	20’	20’
0,75 R	1,5	0,75	0,75	45’	30’	30’
1 R	2	1	1	60’	40’	40’

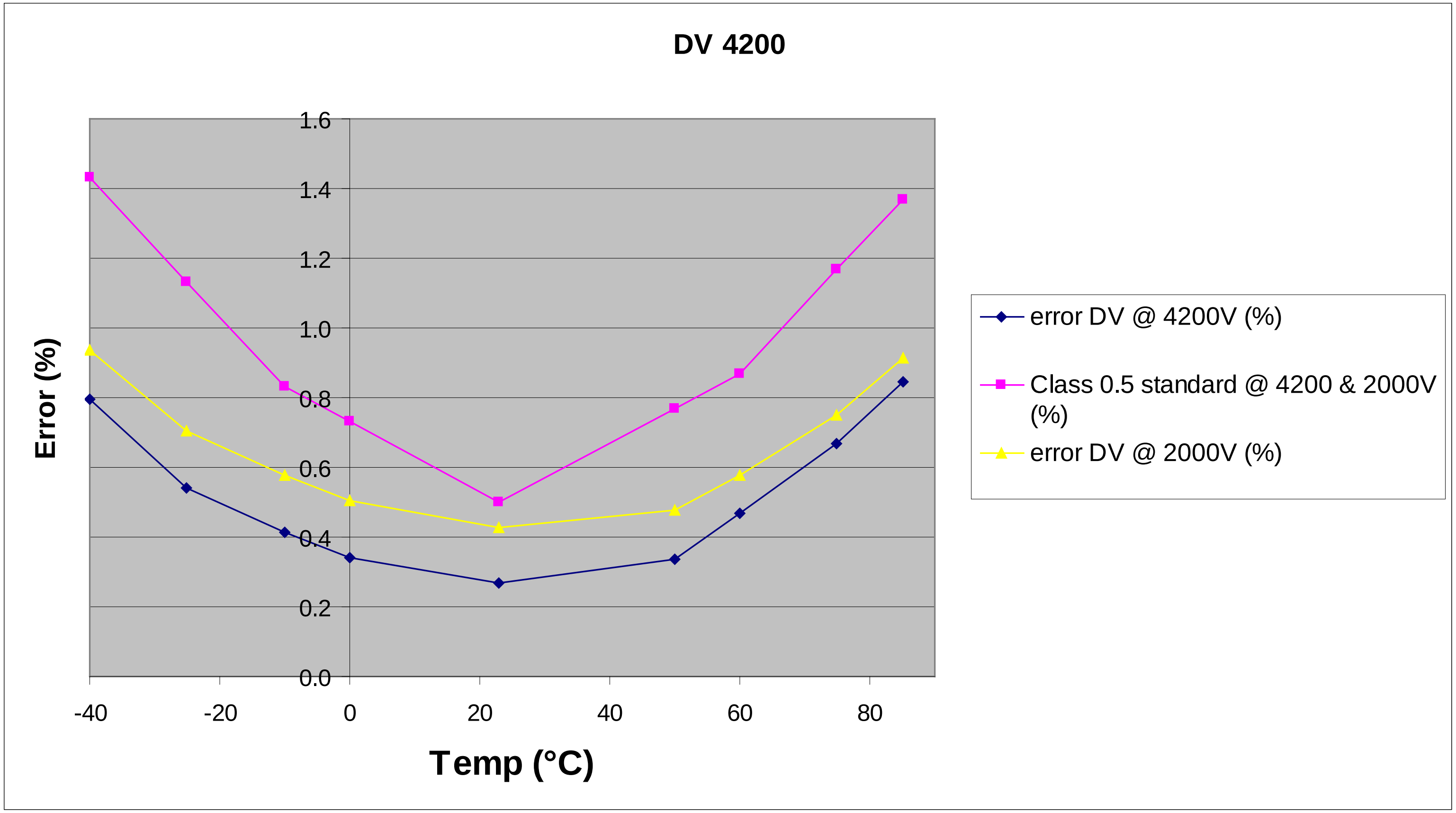
Table 4 - Percentage error limits — voltage sensor

Influence quantity	Value of voltage	System type	Functional component temperature coefficient [%/K]
Ambient temperature variation (main range) -10 °C to +50 °C (+60 °C for indoor)	$U_{min1} \leq U \leq U_{max2}$	a.c. and d.c.	0,01
Ambient temperature variation (extended range) -40 °C to – 10 °C and	$U_{min1} \leq U \leq U_{max2}$	a.c. and d.c.	0,02
+60 °C to +75 °C (for indoor)			

Table 5- Influence quantities for voltage sensors

Voltage transducer for EMF

DV voltage transducer



EN 50463-2 Requirements for Current Transducers

The following table shall be used for d.c. current sensors:

Accuracy class	± Maximum percentage current (ratio) error at percentage of rated current shown below, d.c. sensors					
	1 % (2 %)[1)]	5 % (10 %)[1)]	10 % (20 %)[1)]	20 %	100 %	120 %
0,2 R	2	0,4	0,2	0,2	0,2	0,2
0,5 R	5	1	0,5	0,5	0,5	0,5
0,75 R	7,5	1,5	0,75	0,75	0,75	0,75
1 R	10	2	1	1	1	1

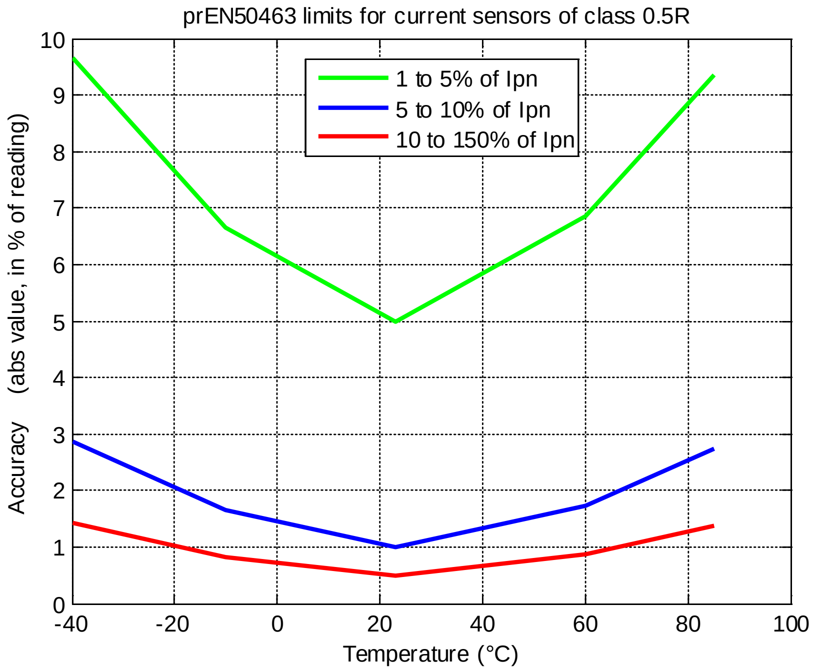
Table 7 – Percentage error limits — d.c. current sensor

Value of current	System type	Sensor temperature coefficient [%/K]	
		Ambient temperature variation (main range) -10 °C to +50 °C (+60 °C for indoor)	Ambient temperature variation (extended range) -40 °C to –10 °C and +60 °C to +75 °C (for indoor)
$0,1I_n \leq I \leq 1,2I_n$	a.c. and d.c.	0,01	0,02
$0,05I_n \leq I \leq 0,1I_n$	a.c. and d.c.	0,02	0,04
$0,01I_n \leq I \leq 0,05I_n$	a.c.	0,05	0,1
	d.c.	0,1	0,2

Table 8 – Influence quantities for current sensors

ITC 4000 Requirements

EN 50463 (energy measurement)
Requirements for Class 0.5R DC current sensors:



Error: 0.5 % at 10 % of I_{PN} and 23 °C

10 % at 1 % of I_{PN} over temp. range

Ambient temperature: −40 °C ... 75 °C

Short circuit current:

100 kA / 400 ms

ITC 4000

Proven design with significant field experience, ITC 4000 passed validation in acc. to EN 50463

- ✓ Excellent accuracy
- ✓ EMC issues solved
- ✓ Thermally ok without bulky heatsink
- ✓ Software performs all required functions

Proposal for Fixed Installations

Existing transducers can be used, examples:

LEM — IT 605-S ULTRASTAB

Electrical data

At T_A = 25 °C, $\pm U_C$ = ±15 V, unless otherwise noted.
Lines with a * in the comment column apply over the −40 … 85 °C ambient temperature range.

Parameter	Symbol	Unit	Min	Typ	Max		Comment
Primary continuous direct current	$I_{PN\,DC}$	A	−600		600	*	
Primary nominal rms current	I_{PN}	A			600	*	
Primary current, measuring range	I_{PM}	A	−849		849	*	Peak limit
Measuring resistance over supply voltage range	R_M	Ω	0		5		See graph page 4
Secondary current	I_S	mA	−566		566	*	Peak limit
Secondary nominal rms current	I_{SN}	mA			400	*	
Conversion ratio	K_N			1:1500		*	
Resistance of secondary winding	R_S	Ω		11			
Overload capability [1]	$\hat{I}_P$	A	−3000		3000		@ pulse of 100 ms
Supply voltage DC	U_C	V	±14.25	±15	±15.75	*	
Current consumption	I_C	mA		122	128		Add I_S for total current consumption
				131	139	*	
Output rms noise current 0 … 10 Hz [2]	I_{no}	ppm			0.05		
Output rms noise current 0 … 100 Hz [2]					0.5		
Output rms noise current 0 … 1 kHz [2]					1		
Output rms noise current 0 … 10 kHz [2]					3		
Output rms noise current 0 … 50 kHz [2]					6		
Re-injected rms noise on primary bus bar		µV			5		0 … 50 kHz
Electrical offset current + self magnetization + effect of earth magnetic field [2]	I_{OE}	ppm		±25	±32		
				±28	±36	*	
Offset stability [2]		ppm/month			1		
Linearity error [2]	ε_L	ppm		±3	±7		@ $\pm I_{PN\,DC}$ range
				±4	±8	*	

LEM — DVL 1000

Electrical data

At T_A = 25 °C, $\pm U_C$ = ±24 V, R_M = 100 Ω, unless otherwise noted.
Lines with a * in the conditions column apply over the −40 … 85 °C ambient temperature range.

Parameter	Symbol	Unit	Min	Typ	Max		Conditions
Primary nominal rms voltage	V_{PN}	V		1000		*	
Primary voltage, measuring range	V_{PM}	V	−1500		1500	*	
Measuring resistance	R_M	Ω	0		133	*	See derating on figure 2. For $\lvert V_{PM} \rvert$ < 1500 V, max value of R_M is given on figure 1
Secondary nominal rms current	I_{SN}	mA		50		*	
Secondary current	I_S	mA	−75		75	*	
Supply voltage	$\pm U_C$	V	±13.5	±24	±26.4	*	
Rise time of U_C (10-90 %)	t_{rise}	ms			100		
Current consumption @ U_C = ±24 V at V_P = 0 V	I_C	mA		20	25		
Offset current	I_O	µA	−50	0	50		100 % tested in production
Temperature variation of I_O	I_{OT}	µA	−120 −150		120 150		−25 … 85 °C −40 … 85 °C
Theoretical sensitivity	G_{th}	µA/V		50			50 mA for primary 1000 V
Sensitivity error	ε_G	%	−0.2	0	0.2		
Thermal drift of sensitivity	ε_{GT}	%	−0.5		0.5	*	
Linearity error	ε_L	% of V_{PM}	[illegible]		0.5	*	
Overall accuracy	X_G	% of V_{PN}	−0.5 −1		0.5 1	*	25 [illegible]; 100 % tested in production −40 … 85 °C
Output rms current noise	I_{no}	µA		10			1 Hz to 100 kHz
Reaction time @ 10 % of V_{PN}	t_{ra}	µs		30			
Response time @ 90 % of V_{PN}	t_r	µs		50	60		0 to 1000 V step, 6 kV/µs
Frequency bandwidth	BW	kHz		14 8 [illegible]			−3 dB −1 dB [illegible]

Legislation

Europe

MID 2014/32/EU; standard list: 2012/C 218/08

Mandate M/541 (EU commission, 2015-12-15)
mentions meters for EV charging; results except -41?

Germany

MessEG implements (amongst others) the MID in Germany

MessEV details organization, conformity assessment bodies, type examination (B), product examination (F), manufacturing/final inspection based on quality assurance (D), use of instruments, reverification period (4 years for DC meters)

Standards

EN 50463-2 – only “modern” standard for DC meters (railway applications)

International

OIML R 46 – from EU website: “The EU recognizes standards issued by OIML”; many examples, R 46 ?

IEC/EN 62052-11 – general requirements for electricity meters

IEC 62053-41 – electricity meters for DC (to be published)

IEC 61851-23 – charging station (up to 1500 V DC)

Europe

EN 50470 (-1 and -3 for static meters) – no DC part

EN 62058-11, -31 (acceptance inspection); EN 62059-32 (durability)

WELMEC guides 7.2 (SW requirements), 11.2 (interval metering)

Standards

Germany

PTB REA 6-A document details German requirements for EV (charger) meters; refers to MessEG, MessEV, WELMEC 7.2, details:

- SW requirements incl. SW ID, updates, interface
- To be stored during reverification period:
  - Time (stamps),
  - Customer ID and/or transaction ID,
  - Load profiles (energy for each transaction) and logbook (events),
  - Digital signature (when data is transmitted via the interface)
  - Tariff ID if applicable
- To be displayed (at minimum):
  - Energy (value and unit symbol)
  - Date, time
- Errors (MPE): MID class A for DC meters – applicable from 2020 (REA 6-A 4)?
- Internal clock: 1 % (~5 ppm in international standards);
  clock probably to be periodically adjusted via the interface
- Anti-tampering? (strong magnetic DC fields, radiated EM fields, other?)

Application Requirements

Worldwide acceptance (OIML standards accepted by NIST, Asia-Pacific states?)

Power supply by measured voltage? (Probably not necessary)

Ambient operating temperature range: larger than −40 °C … 70 °C, RH up to 95 %

MPE in the “core region” rather MID class B or C than A

Single quadrant (1Q, charging only) operation sufficient?

Frequency range? Probably kHz; see IEC 61851-23

Limit [a]	Frequency
1,5 App	below 10 Hz
6 App	below 5 000 Hz
9 App	below 150 kHz

[a] difference between positive peak top and negative peak top at full scale output

peak currents of 3 A for small currents?

Voltage range: 150 V to 1000 V; maybe up to 1500 V nominal (IEC 61851-23)

Currents smaller than 5 A mentioned in IEC 61851-23

Insulation level: charging station designed for OV cat. I or II; 4 kV or 6 kV surge?

EMC test levels (no-load test etc.)?

Load profiles: detection of start and end of transaction → new transaction ID sent via interface, voltage to be measured below / above threshold?

Possibilities Today

EN50463-2 MPE requirements

Voltage transducer, class 0,5R: $U_{min1\ a}$…$U_{max2\ b}$ (2 U_n values 1:2), dyn. range ~4
→ 0.5 % from 250 V … 1000 V

Current transducer, class 0,5R: 10 %...120 % (2 I_n values 1:2), dyn. range 24
→ 0.5 % from 23 A …550 A;
maybe (0,2R) 0.4 % from 11.5 A …550 A (or 0.5 % from 10 A to 550 A, dyn. range 50)

Electricity meter: class 0.5R; 0.5 % from 250 V … 1000 V, 23 A (10 A?) … 550 A
starting current: $I_{st} = 0.4\ \% \cdot I_n = 0.167\ \% \cdot I_{max\ b}$ → 0.92 A

Total error class (formula with sum of squares): 1 %

MID classes (AC direct connected, example: I_{max} = 550 A):
$I_{tr} = I_{max}$ / 50 (11 A, dyn. range 50);
$I_{st} = 4\ \% \cdot I_{tr} = 0.08\ \% \cdot I_{max}$ (0.44 A, 0.55 A for class A)

Comparison: lower starting current in MID; current dynamic range may be sufficient

MID requirements for voltage range not adapted (U_n +/− 10 %)

Thank you for your attention !

Questions & remarks are welcome

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