SLOVENSKI STANDARD
oSIST prEN 50388-2:2024

01-februar-2024

Fiksni postroji in vozna sredstva za železniške naprave - Tehnični kriteriji za uskladitev med napajalnimi viri in voznimi sredstvi za doseganje interoperabilnosti - 2. del: Stabilnost in harmoniki

Fixed installations and rolling stock for railway applications - Technical criteria for the coordination between electric traction power supply systems and rolling stock to achieve interoperability - Part 2: Stability and harmonics

Bahnanwendungen - Ortsfeste Anlagen und Bahnfahrzeuge - Technische Kriterien für die Koordination zwischen Anlagen der Bahnenergieversorgung und Fahrzeugen zum Erreichen der Interoperabilität - Teil 2: Stabilität und Oberschwingungen

Installations Fixes et Matériel Roulant pour les Applications ferroviaires - Critères techniques pour la coordination entre les installations fixes de traction électrique et le matériel roulant pour réaliser l'interopérabilité

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Fixed installations and rolling stock for railway applications - Technical criteria for the coordination between electric traction power supply systems and rolling stock to achieve interoperability - Part 2: Stability and harmonics

Applications ferroviaires - Installations fixes et matériel roulant - Critères techniques pour la coordination entre les installations fixes de traction électrique et le matériel roulant pour réaliser l¿interopérabilité - Partie 2: stabilité et harmoniques

Bahnanwendungen - Ortsfeste Anlagen und Bahnfahrzeuge - Technische Kriterien für die Koordination zwischen Anlagen der Bahnenergieversorgung und Fahrzeugen zum Erreichen der Interoperabilität - Teil 2: Stabilität und Oberschwingungen

This draft European Standard is submitted to CENELEC members for enquiry.
Deadline for CENELEC: 2024-03-15.

It has been drawn up by CLC/SC 9XC.

If this draft becomes a European Standard, CENELEC members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration.

This draft European Standard was established by CENELEC in three official versions (English, French, German).
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Recipients of this draft are invited to submit, with their comments, notification of any relevant patent rights of which they are aware and to provide supporting documentation.

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European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
Europäisches Komitee für Elektrotechnische Normung

CEN-CENELEC Management Centre: Rue de la Science 23, B-1040 Brussels

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European foreword

This document (prEN 50388-2:2023) has been prepared by CLC/SC 9XC, “Electric supply and earthing systems for public transport equipment and auxiliary apparatus (Fixed installations)”, of CLC/TC 9X, “Electrical and electronic applications for railways”.

It is also relevant to the scope and expertise of CLC/SC 9XB, “Electromechanical material on board of rolling stock”.

This document is currently submitted to the Enquiry.

The following dates are proposed:

• latest date by which the existence of this document has to be announced at national level	(doa)	dor + 6 months
• latest date by which this document has to be implemented at national level by publication of an identical national standard or by endorsement	(dop)	dor + 12 months
• latest date by which the national standards conflicting with this document have to be withdrawn	(dow)	dor + 36 months (to be confirmed or modified when voting)

EN 50388 “Railway applications – Fixed installations and rolling stock - Technical criteria for the coordination between traction power supply and rolling stock to achieve interoperability” consists of the following parts:

— Part 1: General

— Part 2: Stability and harmonics

This document has been prepared under a standardization request addressed to CENELEC by the European Commission. The Standing Committee of the EFTA States subsequently approves these requests for its Member States.

For the relationship with EU Legislation, see informative Annex ZZ, which is an integral part of this document.

Introduction

To improve readability, this document is structured as shown in Table 1, which only shows references to the most important sections.

Table 1 — Structure of this document

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5.1.1.2 Defines in which cases input admittance shall be measured and how it shall be measured.
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Topic	Requirements		Tests and documentation	
	Section	**Main requirements**	**Section**	**Most important elements**
Overvoltages caused by harmonics	4.3	4.3.2 Rolling stock Defines the limit of the overvoltage and specifies the calculation method by using line current spectrum, bandpass filtering, summation methods and standardized power supply impedances. 4.3.2.3 Overvoltage detection. Suggests methods of overvoltage detection. 4.3.3 Defines applicability and the overvoltage limits for static converter stations. 4.3.4 Infrastructure related topics	5.3	5.3.1 Demonstration of compliance for rolling stock by: - Calculation of line current spectrum including plausibility check by measurement - Calculation of harmonic voltage assessment using the method given in 4.3 - Check of interlacing between units as specified in 4.3.2.2 - Check of overvoltage protection as specified in 4.3.2.3 - If diode rectification is used to reduce risk of overvoltages check of correct transition between pulsing and blocking of line converter 5.3.2 Demonstration of compliance for static converters by: - Assessing the overvoltage by combining the converter with a line of variable length - defining the assessment method in time domain - plausibility check of the simulation model by measurement
	A.3	Technical background relating to overvoltages caused by harmonics including example calculations for rolling stock		
	B.3	Examples of real overvoltage experiences caused by harmonics		
Topics related to all phenomena	A.3	Depot cases		
	Annex C	Data related to the compatibility study of harmonics and dynamic effects		
	Annex D	Examples experienced in DC systems		

1 Scope

This document is linked to EN 50388-1:2022, which describes the general technical criteria for the coordination between power supply and rolling stock to achieve interoperability.

This Part 2 establishes the acceptance criteria according to EN 50388-1:2022, 10.2 for compatibility between traction units and power supply, in relation to:

— co-ordination between controlled elements and also between these elements and resonances in the electrical infrastructure in order to achieve network system stability.

— co-ordination of harmonic behaviour with respect to excitation of electrical resonances.

The following electric traction systems are within scope:

— railways;

— guided mass transport systems that are integrated with railways;

— material transport systems that are integrated with railways.

Public three-phase grid networks are out of scope, but grid networks which are dedicated to railways are included.

This document is applied in accordance with the requirements in EN 50388-1:2022, Clause 10. It does not apply retrospectively to rolling stock or railway power supply elements already in service.

It is the aim of this Part 2 to support acceptance of new elements (rolling stock or infrastructure) by specifying precise requirements and methods for demonstration of compliance. This document acts as “code of practice” quoted in EN 50388-1, 10.2. However, it is still admissible to use the process as defined in EN 50388-1:2022, 10.3 instead.

This version of the standard only applies to AC systems. Later versions might include similar effects in DC networks in addition, see Annex D.

The main phenomena identified and treated in this document are:

— electrical resonance stability.

— low frequency stability.

— overvoltages caused by harmonics.

The interaction with signalling (including track circuits) is not dealt with in this document.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

CLC/TS 50238-2:2020, *Railway applications - Compatibility between rolling stock and train detection systems - Part 2: Compatibility with track circuits*

EN 50388-1:2022, *Railway Applications - Fixed installations and rolling stock - Technical criteria for the coordination between electric traction power supply systems and rolling stock to achieve interoperability - Part 1: General*

EN 50163:2004,[1] *Railway applications - Supply voltages of traction systems*

EN 50160:2010, *Voltage characteristics of electricity supplied by public electricity networks*

3 Terms, definitions, abbreviations and symbols

For the purposes of this document, the terms and definitions given in EN 50388-1:2022 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1 Terms and definitions

3.1
new element
new, rebuilt or modified traction unit or power supply component (hardware or software) having a possible influence on the harmonic or dynamic behaviour of the power supply system

Note 1 to entry: This new element can be integrated in an existing power supply network with traction units e.g. for fixed installation:

— transformer;

— HV cable;

— filters;

— converter.

Note 2 to entry: Depot areas are a combination of equipment listed in note 1 associated with a large number of traction units and therefore very prone to harmonic and dynamic effects.

Note 3 to entry: New means also introduction of an existing element on another infrastructure system, i.e. “new to this infrastructure”.

3.2
power system
system which includes generation, distribution and consumption of electrical power, i.e. equal to the power supply system plus power circuits of all trains

3.3
power supply system
electrical power generation or distribution system for trains

Note 1 to entry: In railway systems this includes power stations and frequency converters, transmission lines, substations including HV impedance at the point of common coupling and contact line system as well as the return current circuits.

3.4
plausibility check
check of theoretical and calculation methods of assessment, generally based on measurement, to confirm that assessment predictions are credible and realistic

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[1] As impacted by EN 50163:2004/A1:2007, EN 50163:2004/Corrigendum May 2010, EN 50163:2004/AC:2013, EN 50163:2004/A2:2020, EN 50163/A3:2022.

3.5
anti-control
use of negative feedback control systems to reduce and limit the amplitude of a given harmonic frequency

3.6
static converter
converter having no moving parts and notably using semi-conductor rectifiers

Note 1 to entry: For the purpose of this document, this definition is used for fixed installations side only, example given frequency conversion, phase compensation, energy conversion.

[SOURCE: IEC 60050 811.19.05 – Modified: Note 1 to entry is added]

3.7
line converter
converter connected to the line or a line transformer which creates an intermediate link, mainly to supply a traction converter

Note 1 to entry: Derived from EN 61287-1:2014, 6.2.

3.8
active
behaviours of circuit elements which bring energy into the system at a defined frequency or frequency range

Note 1 to entry: In the given context, “active“(and also “passive“) is always defined for the small-signal behaviour only.

3.9
passive
behaviours which do not bring energy into the system at a defined frequency or frequency range

Note 1 to entry: The above definitions of “active” and “passive” apply throughout this document and differ from other definitions where “active” is used to designate a controlled element.

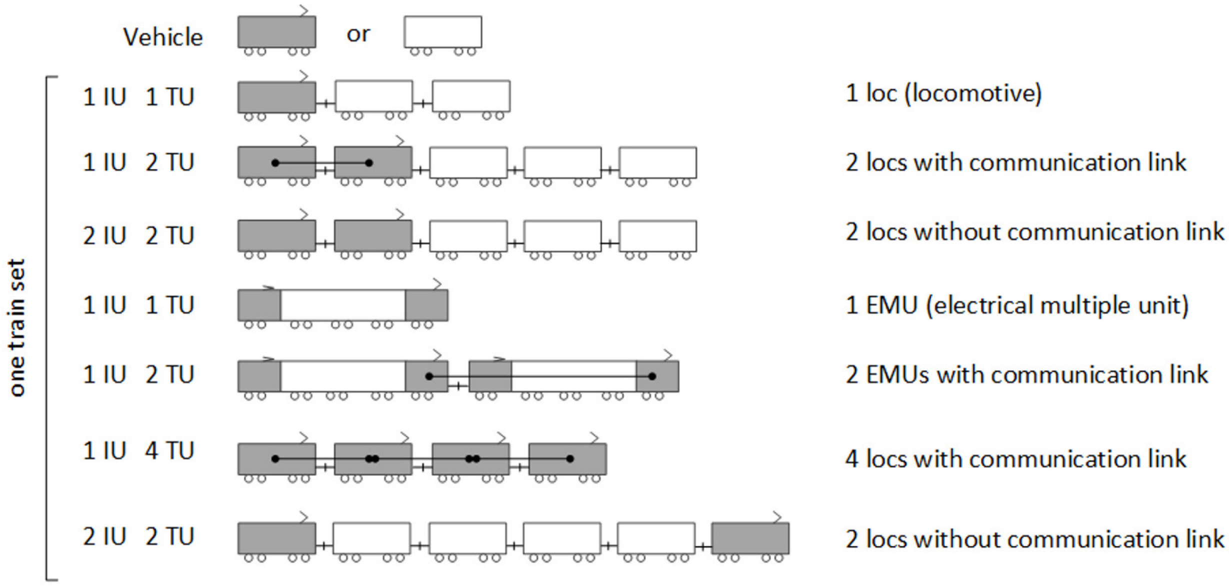
3.10
controlled element
electrical component or subsystem that has internal feedback loops controlling its output towards a set point

Note 1 to entry: In the scope in this document, controlled element will typically be power electronic converters on infrastructure or rolling stock. Controlled element can be active or passive at different frequencies.

3.11
traction unit
locomotive, motor coach or train unit

Note 1 to entry: Within this Part 2 a traction unit specifically comprises all traction subsystems including auxiliary supplies, which can be collectively switched off by one current collector / pantograph.

[SOURCE: IEC 60050-811:2017, 811-02-04, modified – The Note 1 to entry has been added.]



Key

motor vehicles shown in solid grey

unpowered vehicles shown in white

NOTE In the case of an EMU, motorized axles are typically distributed throughout vehicles.

Figure 1 — traction unit and influencing unit

3.12

influencing unit

set of traction units forming a train which has a communication link in the on-board control system for the purpose of interlacing between the traction units

Note 1 to entry: One influencing unit (IU) may consist of several traction units (TU). TUs and IUs are defined slightly different from CLC/TS 50238-2. Only those TUs which are controlled from or get their reference values from one single master control unit are part of one IU. Independently controlled TUs (individual train driver, or different vehicle type) are not part of one single IU.

3.13

auxiliary converter

system with power conversion from one frequency (power supply system) to another (traction motor, auxiliary systems) by means of devices with fast control, such as PWM (pulse width modulation)

3.14

train line

conductor which extends throughout the whole length of each vehicle of a train with couplers to maintain electric continuity throughout the train

[SOURCE: IEC 60050-811:2017, 811-25-21]

Note 1 to entry: Practically, for the understanding of this document, UIC train busbar, heating train line, train power supply line are similar. See also UIC leaflet 552 (Electrical power supply for trains – standard technical characteristics of the train line).

3.15

AT system

traction power supply system in which energy transmission is at double the overhead line voltage and uses autotransformers (AT) to feed the overhead line

3.2 Abbreviations and symbols

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

A/D	Analog/digital
AC	Alternating Current
AT	Autotransformer
DC	Direct Current
EMU	Electrical Multiple Unit
EC	European Commission
EU	European Union
ETCS	European Train Control System
HV	High Voltage
IGBT	Insulated Gate Bipolar Transistor
IM	Infrastructure Manager
IU	Influencing Unit
LRAS	Load Reference-Arrow System
MIMO	Multiple Input Multiple Output
PWM	Pulse width Modulation
RMS	Root mean square
RINF	Register of infrastructure
RL	Resistance of an Inductance,
RC	Resistance of a Capacitance
TSI	Technical specification for interoperability
TU	Traction Unit
U_{max2}	Highest non-permanent voltage defined in EN 50163:2004, 3.5
U_{max1}	Highest permanent voltage defined in EN 50163:2004, 3.4
U_n	Nominal voltage defined in EN 50163:2004, 3.3
U_{min1}	Lowest permanent voltage defined in EN 50163:2004, 3.7
U_{min2}	Lowest non-permanent voltage defined in EN 50163:2004, 3.8
v	Velocity

Other terms in the document are defined at the point of use within this document.

4 Requirements

4.1 Electrical resonance stability

Electrical resonance stability concerns the following phenomenon. The controllers of the line converters of rolling stock, but also the controllers of other line converters, containing feedback loops, which may make these systems active at certain frequencies. If such frequencies of active behaviour coincide with resonance frequencies of the power supply system, stability of the power system can be lost, depending on the damping at these frequencies.

The power system includes the power supply system with all its components in addition to all trains including running trains and parked trains with filters or cables which are connected directly to the power supply system. The requirements affect both design and operation of the power system (including degraded / emergency modes of feeding). Background information and examples can be found in A.1 and B.1.

In order to prevent electrical resonances in the power systems from being excited to oscillations and corresponding overvoltages, the following requirements shall be fulfilled:

— The lowest resonance in the power system shall not fall below the limit frequency f_L.

— If it is not reasonably practicable to avoid resonances below f_L (e.g. due to harmonic filters or reactive power compensators), sufficient damping shall be provided, based on a stability analysis (see A.1.2) for the specific case.

— All controlled elements shall be passive for all frequencies higher than f_L, which means that the phase for its frequency dependent input admittance lies between ± 90°. See non-restricted and forbidden areas in Figure 2.

NOTE 1 There is no need for a stability margin since experience has shown that this sufficiently takes into account inaccuracies from measurements.

The above requirement concerns rolling stock, traction units, auxiliary converters connected to the train line as well as static converters in fixed installations feeding the power supply system.

— For equipment connected to the train line (1 000 V, 16,7 Hz or 1 500 V, 50 Hz), CLC/TS 50535 already makes reference to EN 50388-1 and EN 50388-2 for stability. In this case, the requirement is applicable for the input admittance seen between train line and ground. For Electrical Multiple Units (EMUs) with networks for auxiliaries with internal supply and return current, only the requirement at the pantograph of the EMU is applicable.

The limit frequency f_L is defined in Table 2 as follows:

Table 2 — limit frequency for resonance stability

Power supply frequency	16,7 Hz	50 Hz
Limit frequency f_L for resonance stability	87 Hz	300 Hz

NOTE 2 These values correspond to the 5th harmonic plus some tolerance for control and prediction of resonances in real systems. The following reasons justify the limit at the 5th harmonic:

— Strong line voltage distortions at 3rd and 5th harmonic can be present today. This is mainly due to the operation of vehicles with line commutated rectifiers. These line voltage distortions can lead to excessive harmonic voltage components in the DC-link voltage on inverter vehicles. In order to prevent the excessive harmonic voltages, it shall remain possible to actively reduce larger distortions of the line voltage up to the 5th harmonic. This active reduction can make rolling stock active around these frequencies. Thus, it is not possible to reduce the limit frequency to the 5th harmonic or below.

— With weakly damped networks with resonance near the 5th harmonic (or lower) switching on / energizing under no-load conditions can lead to continuous oscillations which are excited by the non-linearity of transformers (saturation of the iron core).

— Experience has shown that the bandwidth between the 5th harmonic and the f_L needs to be larger for 50 Hz power supply than 16,7 Hz, hence the limit frequency is 300 Hz rather than 270 Hz for 50 Hz power supply frequency.

Infrastructure managers may specify higher values of f_L in case compatibility between rolling stock and signalling equipment can only be reached by anti-control on board of rolling stock (which normally makes traction units active). Also in these cases, one single f_L is always valid as requirement for the whole infrastructure segment (power supply, rolling stock, operation). If an f_L value higher than the above needs to be chosen by the infrastructure manager, justification shall be given.

NOTE 3 Examples for different values for f_L in 16,7 Hz systems are:

— f_L = 103 Hz if 100 Hz track circuits are present

— f_L = 120 Hz in networks where old signalling equipment requires anti-control of the 7th harmonic

Explanation: f_L = 103 Hz is necessary in case of networks having 100 Hz track circuits (100 Hz is a natural harmonic of the line frequency, which may lead to large harmonic currents during transients). In case of 95 Hz or 105 Hz_track circuits, no anti-control is needed, and f_L can remain on the standard value of 87 Hz.

Figure 2 illustrates the requirements for the frequency response of a traction unit.

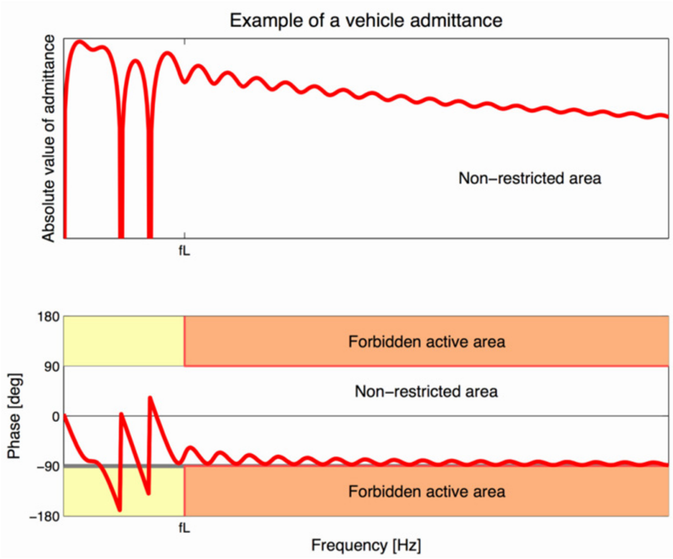


Figure 2 — Example of a frequency response of input admittance of a traction unit and forbidden zones of phase angle

With respect to line filter capacitors on board of rolling stock the following requirement applies to new rolling stock only (no modification on existing rolling stock as long as no problems are observed):

If there are no pulsed line converters in operation, the value of the effective capacitance per unit power (C_L) shall not exceed the value as defined in Table 3.

C_L is defined by the following formula using the imaginary part of the admittance at f_L and the installed power at wheel.

$C_L = \mathrm{Im}(Y(f_L)) / (2 . \pi . f_L) / P_{installed}$

Table 3 — Limits for C_L

Network frequency [Hz]	C_L [nF / MW] at f_L
16,7	210
50	25

NOTE 4 This requirement will be necessary in order to guarantee that, for example, parked trains do not lower the critical resonance frequency of a network too much. Values are selected so that the resonance frequency in a critical network (resonance around f_L) is not lowered by more than 3,4 Hz (in 16,7 Hz network) or 10 Hz (in 50 Hz networks) if the ratio between total installed power at wheel and substation power rating is 4. See A 4.2.

For infrastructure where compatibility with track circuit limits requires the installation of larger filters on vehicles, or if a large number of trains are stabled that have filters and/or cables which are connected directly to the power supply system, larger values of C may be allowed. If this is the case, the power supply might have to be adapted accordingly in order to maintain an acceptable value of f_L. This decision is the responsibility of the infrastructure manager.

For assessment of the above stipulated requirements, see 5.1.