SLOVENSKI STANDARD
oSIST prEN 50388-2:2017

01-junij-2017

Nadomešča:
SIST EN 50388:2012
SIST EN 50388:2012/AC:2013

Železniške naprave - Stabilne naprave električne vleke in voznih sredstev - Tehnična merila za uskladitev med elektronapajalnimi postajami in elektrovlečnimi vozili za doseganje medobratovalnosti - 2. del: Stabilnost in harmoniki

Railway Applications - Fixed installations and rolling stock - Technical criteria for the coordination between power supply 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

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

Ta slovenski standard je istoveten z: **prEN 50388-2:2017**

ICS:

29.280	Električna vlečna oprema	Electric traction equipment
45.060.01	Železniška vozila na splošno	Railway rolling stock in general

oSIST prEN 50388-2:2017 **en**

EUROPEAN STANDARD
NORME EUROPÉENNE
EUROPÄISCHE NORM

DRAFT
prEN 50388-2

April 2017

ICS 29.280; 45.060.01

Will supersede EN 50388:2012 (PART)

English Version

Railway Applications - Fixed installations and rolling stock - Technical criteria for the coordination between power supply 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

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This draft European Standard is submitted to CENELEC members for enquiry.
Deadline for CENELEC: 2017-07-07.

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). A version in any other language made by translation under the responsibility of a CENELEC member into its own language and notified to the CEN-CENELEC Management Centre has the same status as the official versions.

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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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CENELEC

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

CEN-CENELEC Management Centre: Avenue Marnix 17, B-1000 Brussels

Project: 60245

Ref. No. prEN 50388-2:2017 E

Contents

European foreword

This document (prEN 50388-2:2017) has been prepared by CLC/SC 9XC, “Electric supply and earthing systems for public transport equipment and auxiliary apparatus (Fixed installations)”, of Technical Committee CLC/TC 9X, “Electrical and electronic applications for railways”. It also concerns the 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)

This document will partly supersede EN 50388:2012.

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 the relationship with EU Directive 2008/57/EC, see informative Annex ZZ, which is an integral part of this document.

For TSI lines, modification and amendments should be made within a procedure which is related to the legal status of the HS and CR TSIs.

1 Scope

This European Standard, part 2 of EN 50388 is linked to prEN 50388-1 which describes the general items on technical criteria for the coordination between power supply and rolling stock to achieve interoperability

This part 2 establishes the acceptance criteria according to prEN 50388-1:2017, 10.4 step 7 for compatibility between traction units and power supply, in relation to:

— co-ordination between controlled elements and between them and resonances in the electrical infrastructure in order to achieve network system stability;

— co-ordination of harmonic behaviour with respect of 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 is out of scope. Railway dedicated grid is included.

This European Standard is applied in accordance with the requirements in prEN 50388-1:2017, Clause 10. It does not apply retrospectively to rolling stock 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. However, it is still admissible to use the process as defined in part 1 instead. The process of part 1 shall be applied if the case studied is not covered by part 2.

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

Main phenomena identified and treated in this standard are:

— electrical resonance stability;

— low frequency stability;

— overvoltages caused by harmonics.

This European Standard is structured as showed in Table 1 (Table 1 only shows references to the most important sections).

Table 1 — Structure of this European Standard

Topic	Requirements		Tests and documentation	
	Section	**Main requirements**	**Section**	**Most important elements**
Electrical resonance stability	4.1	Definition of a limit frequency f_L - Lowest power system resonance frequency shall not be < f_L - All controlled elements shall be passive for all frequencies > f_L - Requirements for filter capacitors	5.1	For controlled elements, in most cases measurement of frequency response of input admittance is required. 5.1.1.2 Defines in which cases input admittance shall be measured and how it shall be measured. 5.1.1.3 Defines in which cases simulation is sufficient and specifies the requirements for the simulator. 5.1.1.4 Defines in which cases declaration of conformity is sufficient. 5.1.2 Defines the methods to be used to assess the lowest resonant frequency of the power supply.
	A.1	Technical background about Electrical resonance stability		
	B.1	Examples of experienced electrical resonance instability		
Low frequency stability	4.2	Stable operation shall be demonstrated for a predefined set of combinations of power source(s), electrical network and one or several vehicles at one single location	5.2	Investigation either by — directly in time domain simulation — the dq method based on characterization from time domain simulation
	A.2	Technical background about Low frequency stability A.2.2 System definition A.2.3 Definition of signals for the dq method A.2.4 Small signal model for one component A.2.5 Feedback loop A.2.6 Determination of frequency responses A.2.7 Stability criterion		
	B.2	Examples of experienced low frequency power oscillations		

Topic	**Requirements**		**Tests and documentation**	
	Section	**Main requirements**	**Sect ion**	**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. 4.3.2.2 Overvoltage detection/protection. 4.3.3 Defines the overvoltage limits for static converters and specifies the overvoltage calculation method by combining the converter with a line of variable length. 4.3.4 Infrastructure related topics	5.3	5.3.1 Demonstration of compliance for rolling stock by: - Calculation of line current spectrum incl. plausibilisation by measurement - Calculation of harmonic voltage using method given in 4.3, assessment - Check of interlacing between units as specified in 4.3.2.1 - Check of overvoltage protection as specified in 4.3.2.2 - If diode rectifying is used to reduce risk of overvoltages (see A.3.3) check of correct transition between pulsing and blocking of line converter
	A.3	Technical background about overvoltages caused by harmonics		
	B.3	Examples of experienced overvoltages caused by harmonics		
Topics related to all phenomenon	A.4	Depot cases		
	Annex C	Data related to the compatibility study of harmonics and dynamic effects		
	Annex D	Examples experienced in DC system		

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.

CLC/TS 50238-2:2015, *Railway applications - Compatibility between rolling stock and train detection systems - Part 2: Compatibility with track circuits*

CEN/TS 50535:2010, *Railway applications - Onboard auxiliary power converter systems*

prEN 50388-1:2017, *Railway Applications - Fixed installations and rolling stock - Technical criteria for the coordination between traction power supply and rolling stock to achieve interoperability - Part 1: general*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in prEN 50388-1:2017 and the following apply.

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

- transformer;
- HV cable;
- filter;
- converter

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
generation or distribution system for electrical power for the 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
harmonic
voltage or current with frequency other than the fundamental frequency

Note 1 to entry: In this Standard, applied for explicit generation of such voltages or currents only. Instabilities (caused by feedback loop effects) create voltages and currents at frequencies different from the fundamental frequency as well, but these are normally not referred to as harmonics.

3.5
stability
property of a system such that, for a given operation point, the system always returns to this operation point if a small deviation in one signal occurs

Note 1 to entry: The system is referred to as a stable system.

3.6
instability
property of a system such that any small deviation from an operation point leads to an amplification and, therefore, further increase of the deviation

Note 1 to entry: The system is referred to as an unstable system.

Note 2 to entry: Signals (voltages and / or currents) increase until they are limited by explicit controller action, protective actions, limiting devices (such as surge arrestors) or damage to the system.

3.7
small-signal behaviour
reaction of a system to an infinitesimally small deviation from an operation point

Note 1 to entry: The system can then be linearised for each operation point, with the approximation that its behaviour is equal to the operation point plus the small signal behaviour.

Note 2 to entry: For the given sort of systems, typically up to 1 or 2 % of the nominal values can be regarded as small signals.

3.8
active element

element which is able to excite instabilities in a system, i.e. it is able to bring in energy into the system on certain frequencies

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

Note 2 to entry: The definition of active or passive behaviour is not known for elements in the dq system (coupling of four small signal behaviours). Definition of dq system: see A.2.3.

3.9
passive element

element which is not able to bring energy into the system on a defined frequency or frequency range

Note 1 to entry: The above definitions of “active” and “passive” apply throughout this standard 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 of this Standard that will typically be power electronic converters on infrastructure or rolling stock. Controlled elements can be active or passive at different frequencies.

3.11
traction unit

unit that comprises all traction subsystems including auxiliary supplies, which can be collectively switched off by one current collector / pantograph

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: The above definition is not identical with the definition in CLC/TS 50238-2.

3.13
inverter converter
auxiliary converter

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

3.14
UIC train busbar
heating train line
train power supply line

electrical cable running throughout the train and supplying the heating or the services on each coach

Note 1 to entry: See UIC leaflet 552 (Electrical power supply for trains — standard technical characteristics of the train line).

3.15
AT system or autotransformer power supply system
traction power supply system in which energy transportation is at double voltage and uses autotransformers to feed the overhead line

4 Requirements

4.1 Electrical resonance stability

Electrical resonance stability deals with the excitation of electrical resonances in the power systems caused by feedback loop effects in the line converter controllers of rolling stock or static converter for power supply systems. Background information and examples can be found in Annexes A and B.

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.

- The power system includes the power supply system with all its components in addition to parked trains with filters or cables which are connected directly to the power supply system. The requirement affects both design and operation of the power system (including degraded modes of feeding). If resonances below f_L are unavoidable (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 degrees

  NOTE The stability margin is defined to be zero degrees, as 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 UIC train busbar as well as stationary static converters feeding the power supply system.

- For equipment connected to the UIC busbar (1000 V, 16,7 Hz or 1500 V, 50 Hz), CLC/TS 50535 already makes reference to EN 50388 for stability. In this case, the requirement is applicable for the input admittance seen between train busbar 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 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 this it shall remain possible to actively anticontrol larger distortions of the line voltage up to the 5th harmonic, which 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 nonlinearity 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 different values 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 different from the above needs to be chosen by the infrastructure manager, justification shall be given.

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

Example: 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 track circuits, no anti-control is needed, and f_L can remain on the standard value of 90 Hz.

With respect to filter capacitors on board of rolling stock the following requirement applies. This requirement applies to new rolling stock only (no modification on existing rolling stock as long as no problems are observed): If no traction converter is being pulsed, the value of c (capacitance per MW installed power at wheel, so that Im(Y(f_L)) = 2*pi*f_L*c) based on the imaginary part of the admittance at f_L shall not exceed the value as defined as shown in Table 3.

Table 3 — Values for c

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

[a] MW is the maximum power at wheel

NOTE This requirement will be necessary in order to guarantee that e.g. 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.

The following Figure 1 illustrates the requirements for the frequency response of a traction unit.

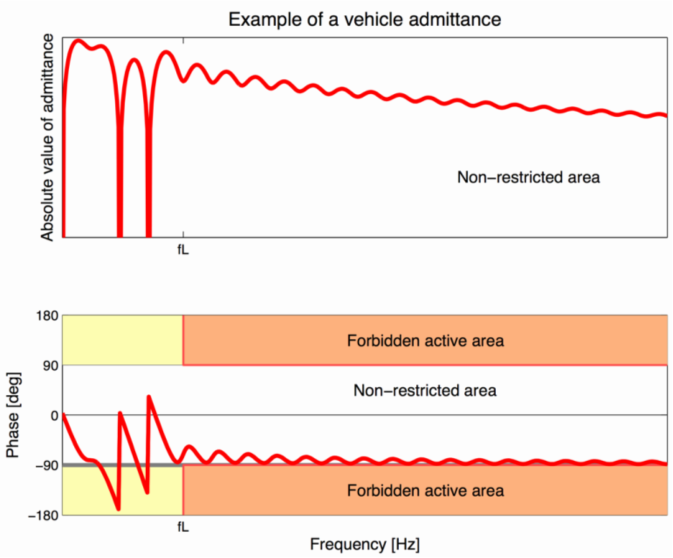

Figure 1 — Example of a frequency response of input admittance of a traction unit and forbidden zones of phase angle

For assessment of the above stipulated requirements, see 5.1.

4.2 Low-frequency stability

Low frequency stability concerns oscillations at a frequency below the line frequency, (50 Hz or 16,7 Hz). These oscillations appear between rolling stock and power supply containing inductive and capacitive elements and are initiated by feedback loops as well as limitations and protection functions within the system. Consequences may be serious interruptions even if no limit of overvoltages are reached.

Since low-frequency stability is multi-dimensional (coupled feedback loops for both magnitude and phase of voltage and current), no simple interface requirements for single components are defined so far.

The system to be analysed is a simplified case of a railway system which consists of:

- a constant or controlled voltage source (power supply system);
- a linear network (power supply system);
- one or several vehicles at one single location.

Stability shall be maintained for a simplified system for a number of predefined cases.

Table 4 shows the standardized cases which shall be used for stability analysis. The two columns to the right define which cases have to be analysed. Table 5 shows the data which shall be used.

Table 4 — Low frequency stability cases

Case	**Description**	**System**		**To be checked for the following new elements**	
		16,7 Hz	50 Hz	Rolling stock	Infra components
A	High line impedance / one or two trains [b]	X	X	X	
B	Depot / large number of trains [b]	X	X	X	
C	Rotary converters against trains [a]	X		X	X
D	Static converters / compensators against rolling stock 2)	X	X	X	X
E	Converters / compensators against other converters / compensators [b]	X	X		X

[a] Applicable to Sweden and Norway only (rotating synchronous to synchronous converters without damping windings). Dynamic characteristics for these rotary converters may be given by the infrastructure manager according to C.1.

[b] Cases (A and B in case of more than one vehicle type, D and E) defined for future revisions of this standard, requiring multi-component simulators or MIMO Nyquist stability analysis. Not covered any further in the present revision. For these cases, the process described in prEN 50388-1:2017, Clause 10 shall be applied.

Table 5 — Parameters for low frequency stability cases

Case	Description	f_line	U_line [kV]	abs(Z_L)	angle(Z_L)	Load	Installed power[a]
A1.1	High line impedance, one vehicle type	16,7	15,75	30 Ohm	35, 45, 55°	no load	at least 6 MW
A2.1	High line impedance, two vehicle types	16,7	15,75	30 Ohm	35, 45, 55°	no load	at least 3 MW each
A3.1	High line impedance, one vehicle type	16,7	17,25	17 Ohm	35, 45, 55°	50 % braking	at least 6 MW
A4.1	High line impedance, one vehicle type	16,7	14,25	7 Ohm	35, 45, 55°	80 % traction	at least 6 MW
A1.2	High line impedance, one vehicle type	50	26,25	60 Ohm	60, 70, 80°	no load	at least 6 MW
A2.2	High line impedance, two vehicle types	50	26,25	60 Ohm	60, 70, 80°	no load	at least 3 MW each
A3.2	High line impedance, one vehicle type	50	27,5	44 Ohm	60, 70~~, 80°~~	50 % braking	at least 6 MW
A4.2	High line impedance, one vehicle type	50	23,75	38 Ohm	60, 70, 80°	80 % traction	at least 6 MW
B1.1	Depot, one vehicle type	16,7	15,75	1.5 Ohm	90°	depot mode	at least 90 MW
B2.1	Depot, two vehicle types	16,7	15,75	1.5 Ohm	90°	depot mode	at least 45 MW + 22,5 MW of ref. vehicle in normal mode
B3.1	Depot, one vehicle type	16,7	15,75	7 Ohm	55°	depot mode	at least 27 MW
B4.1	Depot, two vehicle types	16,7	15,75	7 Ohm	55°	depot mode	at least 13,5 MW + 7 MW of ref. vehicle in normal mode
B1.2	Depot, one vehicle type	50	26,25	4.5 Ohm	90°	depot mode	at least 90 MW
B2.2	Depot, two vehicle types	50	26,25	4.5 Ohm	90°	depot mode	at least 45 MW + 22,5 MW of ref. vehicle in normal mode
B3.2	Depot, one vehicle type	50	26,25	10 Ohm	75°	depot mode	at least 27 MW
B4.2	Depot, two vehicle types	50	26,25	10 Ohm	75°	depot mode	at least 13,5 MW + 7 MW of ref. vehicle in normal mode
C1	Rotary converter type Q38, one vehicle type	16,6667	15,75	30 Ohm	35, 45, 55°	no load	at least 6 MW
C2	Rotary converter type Q38, one vehicle type	16,6667	17,25	17 Ohm	35, 45, 55°	50 % braking	at least 6 MW
C3	Rotary converter type Q38, one vehicle type	16,6667	14,25	7 Ohm	35, 45, 55°	80 % traction	at least 6 MW

[a] Maximum trainset power, but at least the values stipulated in the columns (power at wheel)

NOTE 1 In cases B1.1 to B4.2 no prove needed if diode rectification is applied

NOTE 2 There is no additional stability margin defined since this is included in the above parameters (impedance).

NOTE 3 Depot means sum of maximum power at wheel of rolling stock is equal to the value in column “installed power”, e.g. for the case installed power 90 MW, 15 traction units à 6 MW maximum power at wheel. On board circuit breakers switched on without traction power.

For parked trains, pulsing of the line-side traction converters should be switched off if the consumed power (e.g. for auxiliaries) is lower than 12 … 15 % of the rated power at wheel. These values were derived from energy loss considerations in the substation transformer, see A.4.3. However, if this would lead to over dimensioning of the auxiliary converters, the values can be adapted. Auxiliary converters may be supplied via diode rectifiers in this case. This can serve to improve stability if the requirements for a large number of trains cannot be met otherwise.

In case of special events onboard a traction unit, such as starting a compressor, reacting to line-side DC currents saturating the transformer, or violating harmonic current limits, short-term pulsing periods of line-side converters are still permitted.

For assessment of the above stipulated requirements, see 5.2.

4.3 Overvoltages caused by harmonics

4.3.1 General

Harmonic currents, produced by the pulsing of line converters in rolling stock, may be amplified by electrical resonances in the power systems. Overvoltages may be the result. Other than for the stability phenomena, no feedback loop effect is present in this case. Background information and examples can be found in Annex A.

4.3.2 Rolling stock

4.3.2.1 Generation of harmonic currents

In order to prevent overvoltages caused by harmonics to occur in a.c. railway power systems, the following requirements shall be fulfilled by rolling stock:

For a number of N independent influencing units (IU) of identical type, the expected r.m.s. value for the harmonic line voltage U_H at any resonance frequency shall be below U_{maxH} according to the values in Table 6:

Table 6 — Values for U_{maxH}

Power supply system	15 kV, 16,7 Hz system	25 kV, 50 Hz system
U_{maxH}	3,2 kV	6,4 kV
with $U_{maxH} = U_{peak}/\sqrt{2} — U_{max2}$ and U_{peak} = max. allowed peak voltage of the supply system according to prEN 50388-1:2017, 10.4. U_{max2} = max. voltage according to EN 50163.		

This limit applies to an IU in all its operation modes. Requirements for degraded modes (e.g. one bogie out of operation due to a hardware failure) are relaxed by means of a different definition of factor N.

N is calculated from the maximum power at wheel of the influencing unit, and rounded to the next higher integer number. Two cases shall be considered (roughly representing the different conditions in an interconnected or an isolated network). The IU shall hold the limit for all six cases contained in Table 7.

Table 7 — Influencing units (IU)

Number of IUs	Interconnected network	Isolated system
N (normal operation)	150 MW / $P_{max,wheel}$	50 MW / $P_{max,wheel}$
N (degraded operation)	6	2
N (standstill and no tractive effort; applies for both pulsed line converters or diode rectifying)	200 MW / $P_{max,wheel}$	150 MW / $P_{max,wheel}$

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