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Railway applications — Three-phase train line voltage characteristics

National foreword

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Railway applications - Three-phase train line voltage characteristics

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Caractéristiques de la tension de la ligne
de train triphasée

Bahnanwendungen -
Eigenschaften der dreiphasigen
(Drehstrom-) Bordnetz-Spannung

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Contents

Figures

Tables

Foreword

This document (EN 50533:2011) has been prepared by Working Group 18 of SC 9XB, "Electromechanical material on board rolling stock", of Technical Committee CENELEC TC 9X, "Electrical and electronic applications for railways".

The following dates are fixed:

- latest date by which this document has to be implemented at national level by publication of an identical national standard or by endorsement (dop) 2012-10-10
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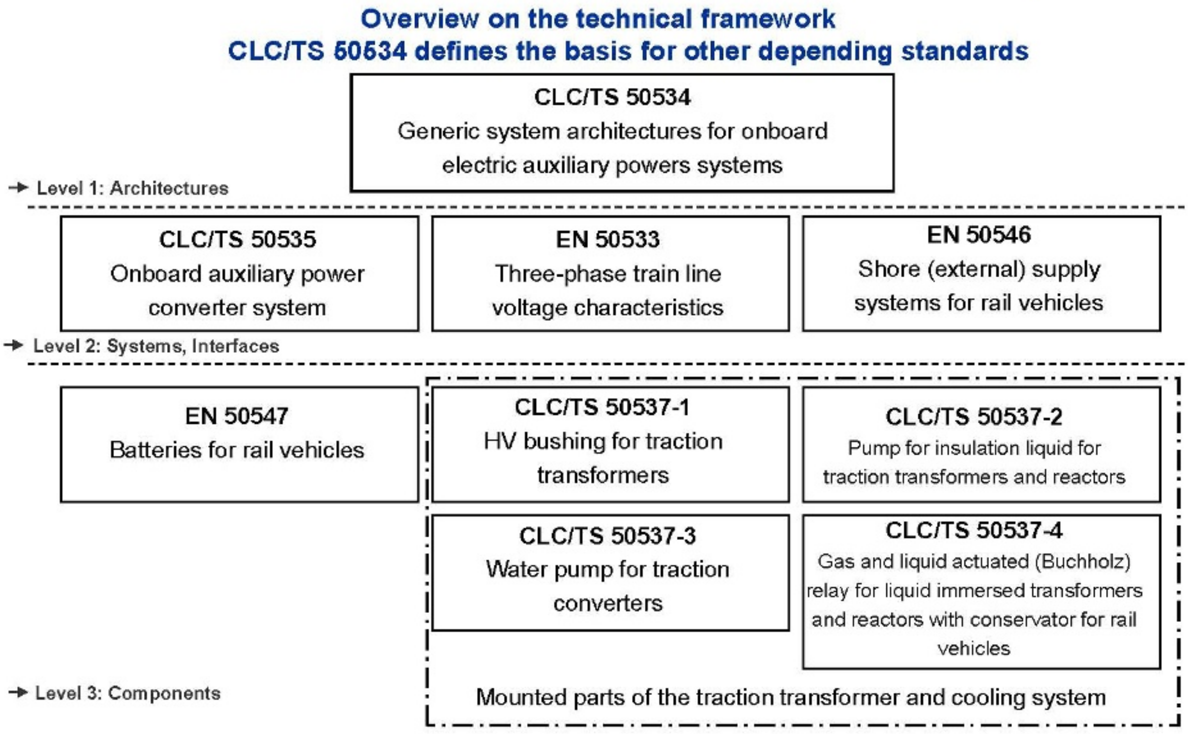
This standardization project was derived from the EU-funded Research project MODTRAIN (MODPOWER). It is part of a series of standards, referring to each other. The hierarchy of the standards is intended to be as follows:



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Introduction

This European Standard defines the characteristics of the on board three-phase train line which delivers the electrical energy to the auxiliary power system. The following European Standards and Technical Specifications refer to the defined target energy supply system in this European Standard:

CLC/TS 50534	Railway applications – Generic system architectures for onboard electric auxiliary power systems
CLC/TS 50535	Railway applications – Onboard auxiliary power converter systems *Auxiliary converter interfaces applicable for the different options defined in the target system architectures.*
CLC/TS 50537 (series)	Railway applications – Mounted parts of the traction transformer and cooling system *Standardized products used in conjunction with traction transformers and traction cooling systems.*
EN 50546 1)	Railway applications – Shore (external) supply system for rail vehicles *Interface description of the shore supply including protection functions.*
EN 50547 1)	Railway applications – Batteries for rail vehicles *Standardized batteries for rail vehicles and charging characteristics.*

The three-phase voltage characteristics depend on the performances of the auxiliary converters which supply the train line but also on the AC load characteristics connected to this train line. In railway applications the available auxiliary power of the train line is generally slightly higher than the power needed by the consumer loads, consequently tight interactions between the auxiliary power converter system and the loads are common and have to be taken into consideration for a proper operation at train system level.

The main objective followed by this European Standard is to define as much as possible the static characteristics and the dynamic behaviour of the on-board three-phase supply network to assure the best electrical compatibility with the AC loads connected to.

This European Standard is a guideline for specifying and designing the different parts of the auxiliary power supply system namely the different auxiliary converters and the AC loads (i.e. 3 AC motors, converters, filters, transformers, etc.) connected to the grid.

Some specific characteristics of the train line voltage may impact the reliability and the life time of the AC loads if they are not taken into consideration during the design phase of the AC loads.

The three-phase train line voltages are never perfectly balanced and pure sinusoidal waveform voltages, as examples:

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1) Under development.

- the switching of the semi-conductors within the static auxiliary converters may generate voltage harmonics and dU/dt steps on the train line;
- the line-to-earth voltage level can vary with the auxiliary supply architecture and the type of faults in the train line;
- a common mode voltage can appear to the star point of the 3 AC loads;
- the non linear AC loads can be a source of current harmonics, those currents combined with the train line impedance create voltage harmonics too (mainly the input rectifiers of certain AC loads).

In summary:

- voltage harmonics can generate noise, additional Joule or iron losses in auxiliary motors and transformers;
- high dU/dt and the common mode voltage are at the origin of motor bearing currents which may lead to a reduced bearing lifetime;
- voltage spikes and overvoltages may cause an early ageing of the winding insulation materials.

1 Scope

This European Standard describes the electrical characteristics of the three-phase train line which delivers the electrical energy from the auxiliary power converter system to the auxiliary loads. It applies to:

- locomotive hauled passenger trains,
- electric multiple units,
- diesel electric multiple units.

This European Standard may apply to other rolling stock types (e.g. light rail vehicles, tramways, metros, etc.) if they are not in the scope of another specific standard.

2 Normative references

The following referenced documents are indispensable for the application 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.

EN 50160:2007	*Voltage characteristics of electricity supplied by public distribution networks*
EN 50546 [2]	*Railway applications – Shore (external) supply system for rail vehicles*
EN 60034-26:2006	*Rotating electrical machines – Part 26: Effects of unbalanced voltages on the performance of three-phase cage induction motors (IEC 60034-26:2006)*
EN 60077-1:2002	*Railway applications – Electric equipment for rolling stock – Part 1: General service conditions and general rules (IEC 60077-1:1999, mod.)*
EN 60146-2:2000	*Semiconductor converters – Part 2: Self-commutated semiconductor converters including direct d.c. converters (IEC 60146-2:1999)*
EN 61000-2-2:2002	*Electromagnetic compatibility (EMC) – Part 2-2: Environment – Compatibility levels for low-frequency conducted disturbances and signalling in public low-voltage power supply systems (IEC 61000-2-2:2002)*
IEC/TS 60034-17:2006	*Rotating electrical machines – Part 17: Cage induction motors when fed from converters – Application guide*
IEC 60038:2009	*IEC standard voltages*
UIC 554-1:1979	*Power supply to electrical equipment on stationary railway vehicles from a local mains system or another source of energy at 220 V or 380 V, 50 Hz*

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2) Under development.

3 Terms, definitions and abbreviations

3.1 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1.1 three-phase train line

typically a 3-wire or 3-wire and neutral wire line which distributes all along the train the three-phase electrical energy to the auxiliary loads, namely the loads dedicated to the traction systems and the loads for passenger comfort

3.1.2 fundamental frequency

frequency in the spectrum obtained from a Fourier transform of a time function, to which all the frequencies of the spectrum are referred

For the purpose of this European Standard, the fundamental frequency is the one delivered by the auxiliary converters installed on board.

3.1.3 harmonic frequency

frequency which is an integer multiple of the fundamental frequency

3.1.4
harmonic component

component having a harmonic frequency. Its value is normally expressed as an r.m.s. value

3.1.5 interharmonic frequency

frequency which is not an integer multiple of the fundamental frequency, e.g. the switching frequency of the auxiliary converters and all the associated harmonics which are not multiple of the fundamental frequency

3.1.6 interharmonic component

component having an interharmonic frequency. Its value is normally expressed as an r.m.s. value

3.1.7 harmonic order

ratio of the harmonic to the fundamental frequency is the harmonic order

3.1.8 total harmonic distortion (*THD*)

ratio of the r.m.s. value of the sum of all the harmonic components up to a specified order to the r.m.s. value of the fundamental component:

$$THD = \sqrt{\frac{\sum_{h=2}^{h=40} U_h^2}{U_1^2}}$$

where

U_1 is the r.m.s. value of the fundamental voltage component;

h is the harmonic order;

U_h is the r.m.s. value of the harmonic voltage component of order h

3.1.9 total distortion content (*TDC*)

quantity remaining when the fundamental component is subtracted from an alternating quantity, all being treated as functions of time

$$TDC = \sqrt{Q^2 - Q_1^2}$$

where

Q_1	is the r.m.s. value of the fundamental component;
Q	is the total r.m.s. value;
Q	can represent either current or voltage. It includes both harmonic and interharmonic components.

In this European Standard *TDC* refers to the line voltages, that is:

$$TDC = \sqrt{U^2 - U_1^2}$$

where

U_1	is the r.m.s. value of the fundamental voltage component;
U	is the total r.m.s. value of voltage

3.1.10 total distortion ratio (*TDR*)

ratio of the r.m.s. value of the total distortion content of an alternating quantity to the r.m.s. value of the fundamental component of the quantity:

$$TDR = \frac{TDC}{Q_1} = \frac{\sqrt{Q^2 - Q_1^2}}{Q_1}$$

In this European Standard *TDR* refers to the line voltages, that is:

$$TDR = \frac{TDC}{U_1} = \frac{\sqrt{U^2 - U_1^2}}{U_1}$$

3.1.11 voltage unbalance

condition in a three-phase system in which the r.m.s. values of the line-to-line voltages (fundamental component), or the phase angle between consecutive line-to-line voltages, are not all equal. The degree of the inequality is usually expressed as the ratios of the negative sequence (U_2) and the zero sequence (U_0) components to the positive sequence component (U_1):

$$U_0 = \frac{1}{3}\left(U_{12} + U_{23} + U_{31}\right)$$

$$U_1 = \frac{1}{3}\left(U_{12} + a.U_{23} + a^2.U_{31}\right)$$

$$U_2 = \frac{1}{3}\left(U_{12} + a^2.U_{23} + a\ .U_{31}\right)$$

U_o, U_1, U_2 formula according to the Fortescue transformation

where

$U_{12,}$ $U_{23,}$ U_{31} are the line-to-line voltages;

a	phasor 120°	$a = e^{j\frac{2\pi}{3}}$;
a^2	phasor 240°	$a = e^{j\frac{4\pi}{3}}$

3.1.12 on board auxiliary power converter system

onboard subsystem which transforms electrical energy for traction auxiliary loads and comfort loads

3.1.13 linear loads

loads with a linear dependency between supply voltage and current. Additionally, loads producing negligible harmonic content compared to rated values are also regarded as linear loads in this European Standard, e.g. heating resistors, induction motors

3.1.14 non-linear loads

in contrast to linear loads, non-linear loads generate significant harmonic current or voltage content. These kinds of loads connected to a supply system with significant internal impedance will produce significant harmonic voltages, e.g. uncontrolled rectifiers and active front-end converters belong to this load group

3.1.15 unbalanced loads

loads which will cause unsymmetrical phase currents, i.e. currents that have different amplitudes and / or phase angles in the three phases of a 3 AC supply system. Single phase loads connected to a 3 AC system are a representative example of unbalanced loads

3.1.16 common mode voltage (U_{CM})

commonly defined as the arithmetic mean of the line-to-earth voltages, $U_{\mathrm{CM}} = 1/3\ (U_{\mathrm{L1\text{-}E}} + U_{\mathrm{L2\text{-}E}} + U_{\mathrm{L3\text{-}E}})$

3.2 Abbreviations

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

AC	Alternating current
3 AC	Three-phase Alternating Current
DC	Direct Current
E	Earth (or ground)
EDM	Electrostatic Discharge Machining
EMC	Electro-Magnetic Compatibility
L-E	Line-to-Earth
L-L	Line-to-Line
L-N	Line-to-Neutral
N	Neutral
r.m.s.	Root Mean Square
TDC	Total Distortion Content
TDR	Total Distortion Ratio
THD	Total Harmonic Distortion
U_{CM}	Common Mode Voltage at star point

4 Characteristics of the three-phase train line voltage

4.1 General

The characteristics of the three-phase train line are defined at the consumer side.

Figure 1 defines all the signals around a “Y” or “star” connected three-phase load taken as an example. It should be noted that all the signals have to be considered, not only the line-to-line voltages across the load terminals but also the voltages between lines (L1, L2, L3) and earth or between the star point and earth. In this case “earth” is referenced to the carbody potential.

The star-point-to-earth voltage, here $U_{0\text{-Earth,}}$ is identical to the co*mm*on mode voltage U_{CM}.

These definitions are used in the tables below:

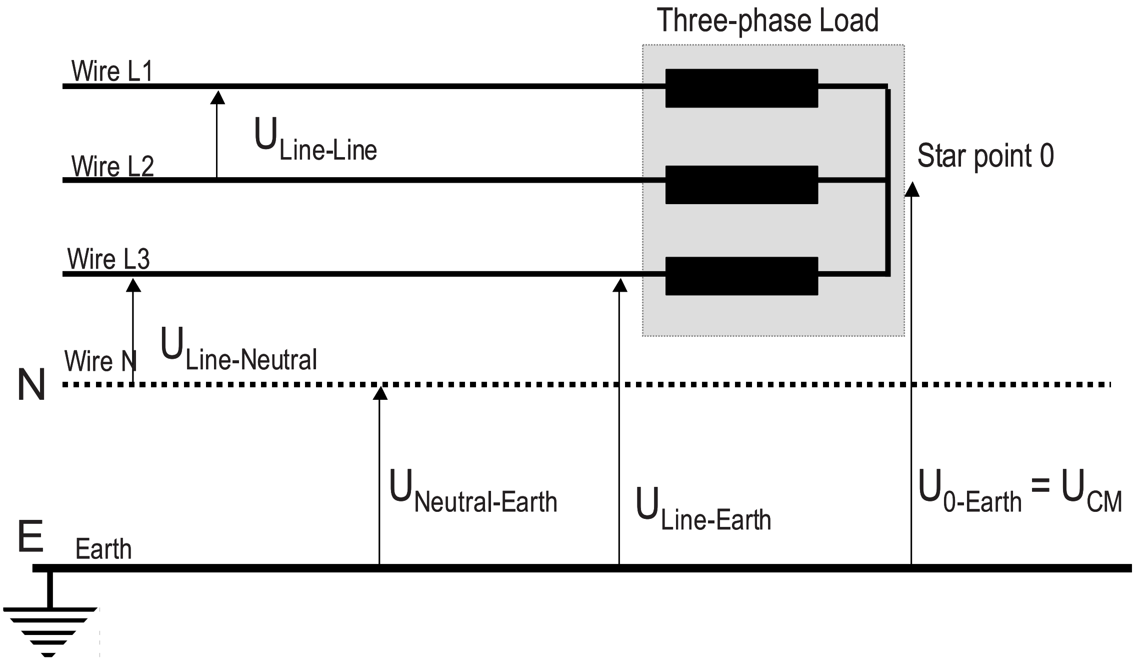

Figure 1 – The different voltages of the three-phase train line system

4.2 Frequency

The characteristics of the fundamental frequency of the train line are defined in Table 1. Two standard frequencies are possible 50 Hz or 60 Hz. The frequency variations are in line with the existing EN or IEC standards for non synchronized networks.

Table 1 — Frequency

Parameter	Name	Unit	Description	Value
Nominal frequency	F_1	Hz	Fundamental frequency delivered by the auxiliary converters	50 Hz or 60 Hz
Frequency tolerance	% F_1	%	Variations of the fundamental frequency F_1 (In accordance with EN 61000-2-2:2002, 4.8, and to EN 50160:2007, 4.1)	± 2 %

4.3 Voltage amplitude

Voltage amplitude and variations of the train line are given by Table 2. Two different line-to-line amplitudes are recommended depending on the fundamental frequency 50 Hz or 60 Hz. In case of neutral, only one set of amplitude and frequency is recommended.

The static tolerances for the train line voltages are given at the far end of the train line (at load side). The voltage drop along the line has to be taken into consideration, that is why the voltage tolerances are tighter at auxiliary converter side with only –5 %. Figure 2 shows the different voltage tolerances at different locations on the train line with –5 % near the auxiliary converter outputs and –10 % at the end of the train line. If a transformer is used between the train line and specific loads, an additional voltage drop is considered (the tolerance becomes -14 %).

Table 2 – Voltage amplitude

Parameter	Name	Unit	Description	Value
Nominal line-to-line voltage	$U_{1\text{-L-L}}$	V	r.m.s. line-to-line voltage at the fundamental frequency F_1 In accordance with IEC 60038:2009, Table 1	400 V at 50 Hz or 480 V at 60 Hz
Nominal line-to-neutral voltage	$U_{1\text{-L-N}}$	V	r.m.s. line-to-neutral voltage at the fundamental frequency F_1 in case of 3 AC+N system	230 V at 50 Hz
Static voltage tolerance at train line level	% $U_{\text{L-L}}$ % $U_{\text{L-N}}$	%	Variations of the r.m.s. line-to-line or line-to-neutral voltage at any location of the train line limited at 200 m	+ 10 % /- 10 % See Figure 2
Static voltage tolerance at load terminals	% U_{Load}	%	Variations of the r.m.s. line-to-line or line-to-neutral voltage at load terminals supplied by a transformer In accordance with IEC 60038:2009, Table 1, and to EN 50160:2007, 4.3	+ 10 % / - 14 % See Figure 2
NOTE Values are given in steady state and normal conditions (no overload).				

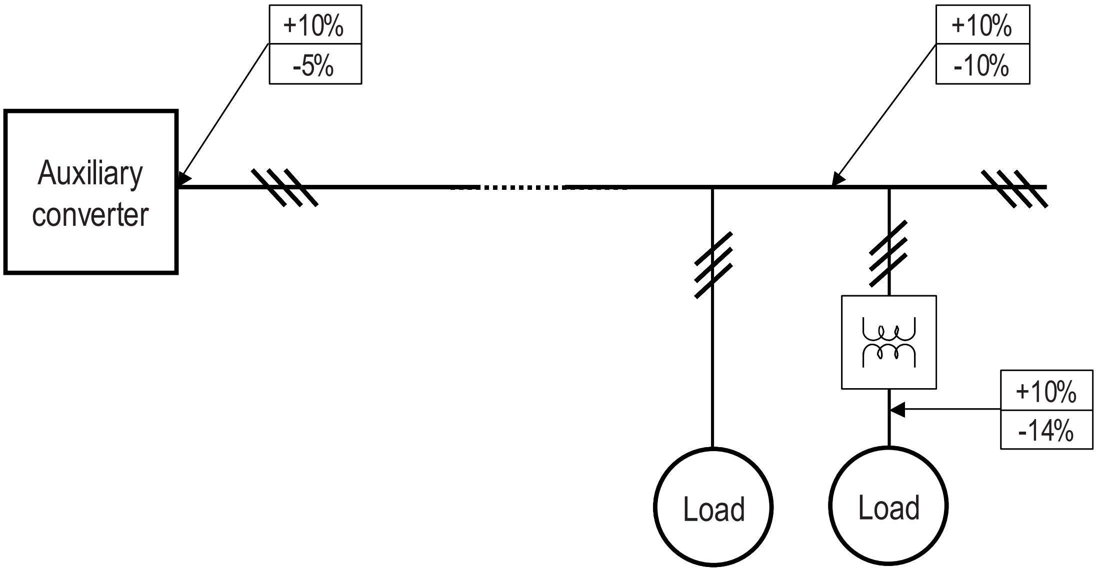

Figure 2 — Static voltage tolerances along the train line

4.4 Voltage harmonics

The train line voltages are not pure sinusoidal waveforms, voltage harmonics due to the switching of the auxiliary converters or non linear loads are present in the line. Table 3 gives the TDR (Total Distortion Ratio) acceptable in steady state conditions without overload when sine filters are installed at the auxiliary converter outputs.

Table 3 — Voltage harmonics

Parameter	Name	Unit	Description	Value
Total Distortion Ratio with linear loads (TDR)	TDR_{Lin}	%	Total line-to-line or line-to-neutral voltage harmonic components with a linear load up to 100 % of the rated apparent output power of the auxiliary converter	≤ 8 %
Total Distortion Ratio with non-linear loads	TDR_{NLin}	%	Total line-to-line or line-to-neutral voltage harmonic components with a non-linear load up to 10 % of the rated output apparent power of the auxiliary converter in normal conditions (no overload) Non linear load is supposed here to be a three-phase diode bridge rectifier with a very large choke at DC side which produces a quasi-square waveform current in the three-phase train line.	≤ 10 %

4.5 Voltage unbalance

Due to single phase loads connected to the train line and the inevitable impedance of the network, the three-phase voltage amplitudes can be unbalanced. The consequence could be additional losses in the three-phase asynchronous motors. Table 4 gives the current and voltage unbalance limits. The train integrator shall try to balance the single phase load power between the three wires. Voltage unbalance is generally calculated over a period of time in accordance with IEC and EN standards.

Table 4 — Current and voltage unbalances

Parameter	Name	Unit	Description	Value
Phase current unbalance	$(I_1\text{-}I_2)/I_N$ $(I_2\text{-}I_3)/I_N$ $(I_3\text{-}I_1)/I_N$	%	Difference of any two-phase currents divided by the rating current (I_N) of the auxiliary converter	≤ 10 %
Voltage unbalance (r.m.s.)	U_2/U_1	%	10 min average of the ratio of the r.m.s. values of the negative phase sequence U_2 over the positive phase sequence U_1 In accordance with EN 61000-2-2:2002, 4.6, EN 50160:2007, 5.10, EN 60034-26:2006, Clause 4, and to EN 60146-2	≤ 2 %
Voltage unbalance (peak)	U_2/U_1	%	Instantaneous ratio value of the r.m.s. values of the negative phase sequence U_2 over the positive phase sequence U_1	≤ 5 %
NOTE Values are given in steady state and normal conditions (no overload).				

4.6 Train line voltage amplitude and rate of rise

The semi-conductor switching of the auxiliary converters can entail fast variations on the train line wires. The maximum voltage amplitude and rate of rise (dU/dt) on the different lines are given by Table 5. Depending on the auxiliary system architecture and on the three-phase filter installed at the outputs of the auxiliary converters, different values can be achieved: see Annex A.

The dU/dt is generally defined by the voltage variation (ΔU) between 10 % and 90 % of the signal during the rise (or fall) time. Figure 3 shows a typical voltage waveform (thin line) with high frequency noise. To measure the proper dU/dt it is advised to slightly smooth the signal (bold line).

Table 5 — Train line voltage amplitude and rate of rise- dU/dt

Parameter	Name	Unit	Description	Value
Variation of line-to-line voltage	dU_{L-L}/dt	V/µs	Variations (rise time or fall time) of the line-to-line voltages with sine filter	≤ 10 V/µs
Variation of line-to-neutral voltage	dU_{L-N}/dt	V/µs	Variations (rise time or fall time) of any line-to-neutral voltage with sine filter	≤ 10 V/µs
Variation of the line-to-earth voltage	dU_{L-E}/dt	V/µs	Variations (rise time or fall time) of any line-to-earth voltage when an auxiliary power converter system architecture with only a dU/dt filter is used This dU/dt has to be taken in consideration during the motor design to avoid any Electrical Discharge Machining (EDM) phenomenon which could reduce the bearing lifetime.	≤ 500 V/µs See Figure 3
Variation of the star point-to-earth voltage	dU_{O-E}/dt	V/µs	Variations (rise time or fall time) of star point voltage or common mode voltage when an auxiliary power converter system architecture with only a dU/dt filter is used This dU/dt has to be taken in consideration during the 3 AC motor design to avoid any Electrical Discharge Machining (EDM) phenomenon which could reduce the bearing lifetime.	≤ 500 V/µs See Figure 3
Maximum line-to-earth voltage	U_{L-E}	V	The maximum peak voltage applied between any phase line and earth when an auxiliary power converter system architecture with only a dU/dt filter is used. In accordance with IEC/TS 60034-17:2006, Clause 9, Figure 7 (1 350 V)	1 350 V_{max}
Star point displacement	U_{0-E}	V	The maximum peak voltage applied between the star point of three-phase loads and earth when an auxiliary power converter system architecture with only a dU/dt filter is used. Generally this voltage may reach the peak voltage delivered by the auxiliary converter, that is the DC link voltage added with the switching overshoot.	1000V peak

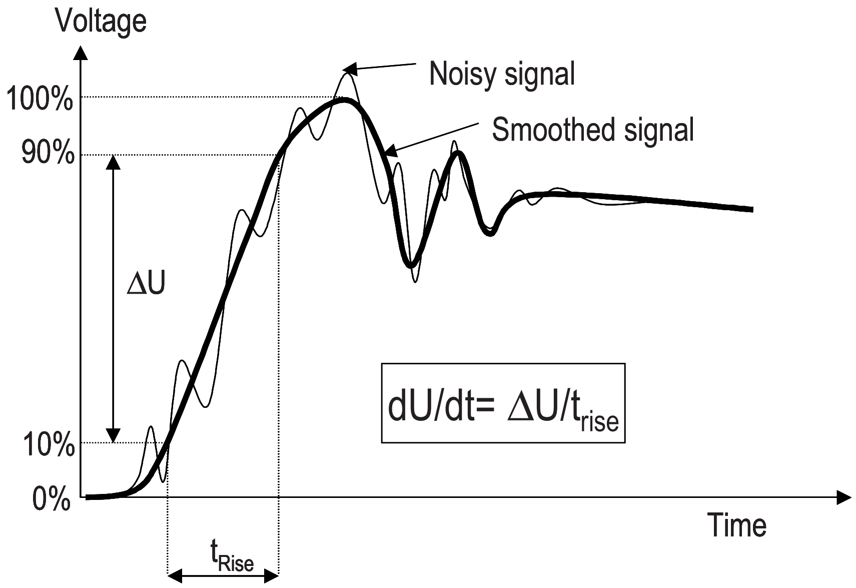

Figure 3 — Voltage rise time- dU/dt definition

4.7 Transient overvoltage

Due to the impedance of the train line network transient over-voltages may occur on the wires when overcurrents are cut-off sharply by switches, circuit breakers or fuses. Table 6 gives a range of possible overvoltages encountered.

Table 6 — Transient overvoltage

Parameter	Name	Unit	Description	Value
Transient overvoltages line-to-earth or line-to-line	OV_{L-E} OV_{L-L}	V	Transient over-voltages of some µs up to some ms may occur between any phase line and earth due to operation of switches or fuses when a fault occurs. (In accordance with EN 50160:2007, 4.9)	2 500 V to 6 000 V

4.8 Dynamic characteristics – Voltage dips – Supply interruption

For certain loads it is important to know the way the three-phase voltages rise at starting of the auxiliary converters, Table 7 and Table 8 describe the train line voltages build up (voltage and frequency versus time).

Table 7 -— 3-AC voltage start-up

Parameter	Name	Unit	Description	Value
Train line voltage start-up time Ramp-up from 0 to U_{nominal}	T_{start}	s	Time of the three-phase output voltages to reach the nominal value when the auxiliary converter starts NOTE T_{start} can be very short when the train line is supplied from an external source (shore supply) by means of a 3 AC contactor.	0 s to 5 s max. See Figure 4

Figure 4 shows a chronogram of voltages across the loads directly connected to the train line. When the auxiliary converter starts up, the voltages ($U_{1L\text{-}L}$) across the load terminals ramp-up while the fundamental frequency F1 is instantaneously established at its nominal value (50 Hz or 60 Hz). The ramp up time will not exceed 5 s. These loads do not benefit from a constant flux at starting.

NOTE If the loads are connected to the train line via an electromechanical device (switch, contactor…) they have to withstand a voltage step when the switchgear will close.

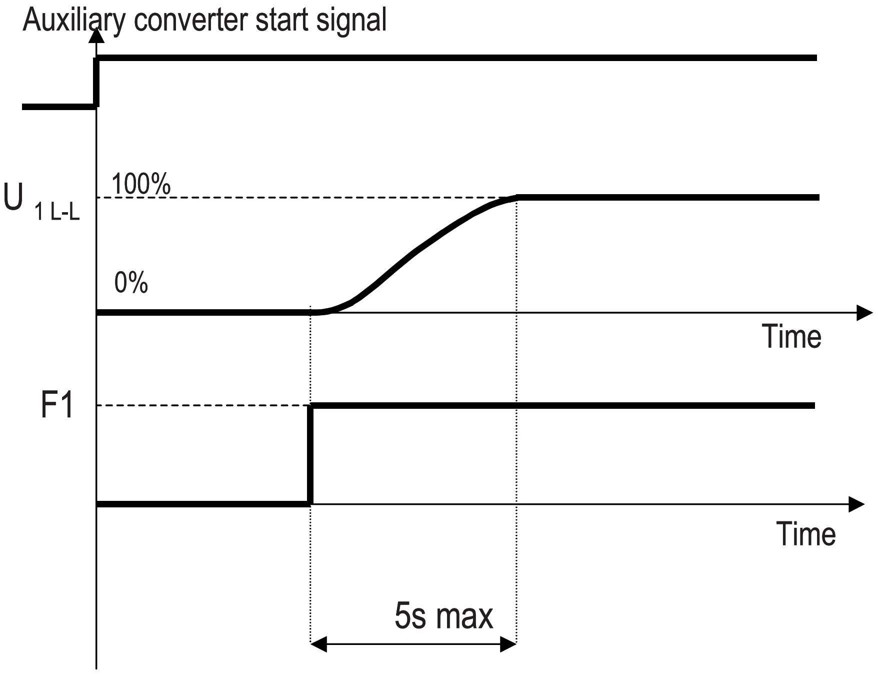

Figure 4 — Train line voltage start-up

The train line power is limited. Consequently, any power variation creates a voltage fluctation which must be limited. Table 8 gives the maximum voltage fluctuation versus time for 100 % load variation of the rated power. This power step is theoritical. In normal operation, the power variation is much lower. This step amplitude value has been selected to simplify the type test conditions of the auxiliary converter.

Table 8 — Voltage fluctuations

Parameter	Name	Unit	Description	Value
Frequency variation		-	The frequency is maintained constant at its nominal value F_1, in any operation mode (namely start-up, normal or overload conditions).	Constant
Output voltage fluctations due to load variations	$U_{L\text{-}L}/U_{1L\text{-}L}$	p.u.	Output voltage fluctations compared to the nominal value due to a load step changing from 100 % to 0 % or 0 % to 100 % of the rated output apparent power of the auxiliary converter Reference to EN 60077-1:2002, 8.2.1.4.	0,7 to 1,25 of $U_{1L\text{-}L}$ during 1 s 0,6 to 1,4 of $U_{1L\text{-}L}$ during 0,1 s See Figure 5

Figure 5 shows the positive and negative fluctuations versus time with a load step of 0-100 % and 100-0 %, referring to the rated power. After 1 s the variations have to be within plus or minus 10 % which corresponds to the static tolerances.

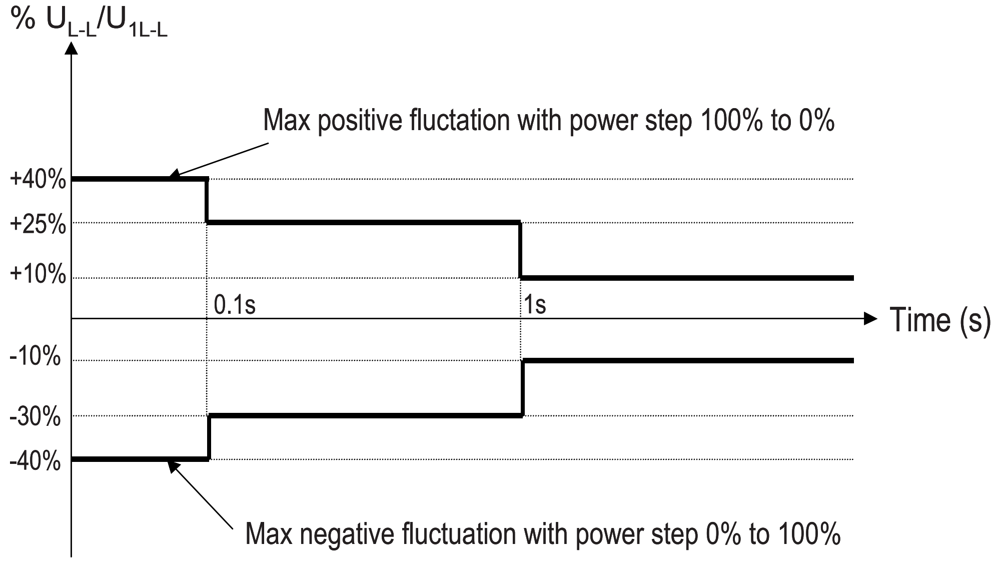

Figure 5 — Voltage fluctuation tolerances

In case of overload the auxiliary converter has to be protected. After maximum 5 s overload, the converter stops and will attempt to restart a certain number of times. The number of restarts has to be determined at the system level by the train integrator taking into account the specific constraints of both sides: auxiliary converters and loads. Table 9 gives the different conditions which can lead to switch off and restart of the train line power. The load suppliers will have to design and protect their product accordingly.

Table 9 — Overload and interruptions

Parameter	Name	Unit	Description	Value
Maximum overload time before converter shut down	T_{CL}	s	If the r.m.s. phase current delivered by an auxiliary converter exceeds a certain level of current (I_{CL}) during more than 5 s the converter will be stopped. Several attempts to restart can take place. After a specified number of attempts the converter is definitively locked out. The number of restarts will be defined case by case by a common agreement between the train system integrator and the load supplier. On the consumer side, every load having a limited number of restarts should be protected by its own control (e.g. air conditioning compressor within an HVAC unit) or by the train load management system (TCMS). When the r.m.s. phase current exceeds 100 % of the rated current the 3 AC phase voltages may be reduced. In that case the variation of the voltages remains within the dynamic tolerances, not the static tolerances.	5 s See Figure 6
Three-phase line voltage interruptions		n/h	Power shut down on 25 kV - 50 Hz catenary lines due to the neutral section crossing	10/h

Different levels of output current of the auxiliary converter versus time are shown by Figure 6. Three levels of current are considered with different actions:

I_N (grey shaded area): r.m.s nominal current; normal and steady state conditions; the voltages remain within the static tolerances (Table 2).

$I_N<I< I_{CL}$ (hatched area): the converter operates in overload mode ; e.g. when an auxiliary motor is starting ; after elapsed time (T_{CL}) the converter is shut down ; in this mode the voltages may go outside of the static tolerances (Table 2) but shall remain within the dynamic tolerances (Table 8).

I_{CL}: r.m.s. current limitation; e.g. if the converter starts while there is a short circuit on the train line ; the converter reduces its output voltages as low as required to limit its output current at I_{CL} ; after a time T_{CL}, the converter is shut down; the voltages may be lower than the minimum dynamic tolerances.

I_{OC}: overcurrent (instantaneous peak current) level; e.g. short-circuit on the train line; if exceeded by the current of any phase, the converter is immediately shut down.

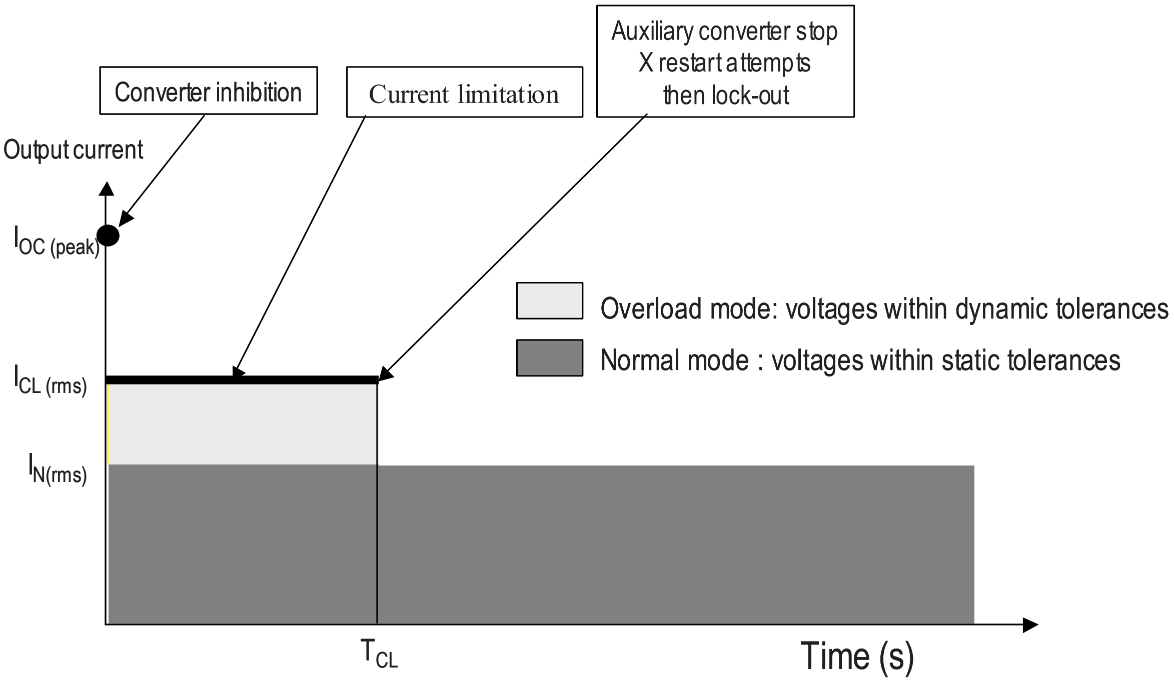

Figure 6 – Current limitation

4.9 Train line additional data (informative)

Table 10 provides some extra data (informative) regarding the output voltages when the train line supply architecture is used with only dU/dt filters without galvanic isolation.

Table 10 — Informative data about 3-AC voltages

Parameter	Name	Unit	Description	Value
Main frequency of the star point-to-earth voltage (informative)	F_{SW}	Hz	The main harmonic frequency seen by the star point-to-earth voltage of the three-phase loads is F_{SW}, i.e. the switching frequency of the auxiliary converter.	F_{SW}
Main frequencies of the line-to-earth voltage (informative)		Hz	The main frequency seen by any line-to-earth voltage is $F_{SW} \pm 2{*}F_1$, i.e. the switching frequency of the auxiliary converter ± twice the fundamental frequency.	$F_{SW} \pm 2{*}F_1$

5 Shore supply

5.1 General

In normal operation the 3 AC train line is supplied by the on board auxiliary converter system delivering a voltage quality as mentioned in Clause 5.

For train maintenance activities in depots and workshops the 3 AC train line can be supplied from an external source.

In that case all the onboard auxiliary converters are first de-energized and disconnected from the 3 AC train line which is then supplied by the shore supply. The shore supply interfaces shall be compliant with EN 50546.

5.2 Shore supply voltage characteristics

In most of the cases the shore supply source is connected to the 3 AC industrial grid via a 3 AC transformer to adjust the output voltage at 400 V - 50 Hz.

The voltage quality in that case is fully defined by EN 50160.

However the shore supply source impedance will have to be determined to maintain the static voltage tolerances of the 3 AC train line within + 10 % and - 10 % as defined in 4.3 for the specified auxiliary power.

Generally the required auxiliary power during the maintenance operations is reduced compared to the onboard 3 AC train line nominal auxiliary power in normal operation.

The TDR (Total Distortion Ratio) of the shore supply will be maintained below 10 % by use of an appropriate filter if necessary.

5.3 Shore supply general features

For protection aspect and according to UIC 554-1 the 3 AC 400 V - 50 Hz from the shore supply shall be floating and isolated from the industrial power grid. This way to proceed avoids any ground circulating current if the on board 3 AC train line is not floating (e.g. neutral connected to ground).

The 3 AC 400 V - 50 Hz from the shore supply will be connected to the train line by means of a 3 AC contactor. Consequently the AC loads permanently connected to the train line have to be able to withstand the voltage step with no ramp up without causing any disorder on board as an overcurrent.

NOTE A monitoring and protection system should ensure that the 3 AC train line cannot be energized at the same time by the onboard auxiliary converter system and the shore supply.

Annex A
(informative)

Train line supply architectures

A.1 General-Train line supply classes

Different three-phase train line supply architectures can be realized depending on the train specific architecture, refer to CLC/TS 50534 and CLC/TS 50535 for information.

Most of the three-phase train line characteristics are not linked with the supply architecture however some of them depend directly on the chosen architecture namely TDR, dU/dt, line-to-earth and star point-to-earth voltages.

Galvanic isolation is preferred but not compulsory. However, without galvanic isolation, the train line supply architecture must be compliant with EN 50153 “Recommendations for the protective provisions relating to electrical hazards”.

According to the state-of-the-art several train line supply architectures have to be considered .Three different classes of train lines can be distinguished. Table 11 summarizes the three train line supply classes with their respective characteristics.

Table 11 — Train line supply classes

	Class 1	Class 2	Class 3
Galvanic isolation	Yes	No	No
Sine filter	Yes	Yes	No
dU/dt filter	No	No	Yes
TDR (U_{L-L} , U_{L-N})	≤ 8% or ≤ 10%	≤ 8% or ≤ 10%	>>10%
dU/dt (U_{L-L} , U_{L-N})	≤ 10V/µs	≤ 10V/µs	≤ 500V/µs
dU/dt (U_{L-E} , U_{O-E})	≤ 10V/µs	≤ 500V/µs	≤ 500V/µs
U_{O-E}	$0V_{mean}$, $<100V_{peak}$	$\leq 400V_{mean}$, $<1000V_{peak}$	$\leq 400V_{mean}$, $<1000V_{peak}$
U_{L-E}	$0V_{mean}$, $<450V_{peak}$	$\leq 400V_{mean}$, $<1350V_{peak}$	$\leq 400V_{mean}$, $<1350V_{peak}$

The following subclauses A.2, A.3 and A.4 describe some examples of architectures for Classes 1, 2 and 3.

A.2 Class 1 - Galvanic isolation at auxiliary converter output side and sine filter

Class 1 example. The galvanic isolation is ensured by a 3–phase output transformer. A low TDR is achieved by using a sine filter (upper part of Figure A.1). The star point of the 3-phase secondary windings of the transformer can be connected to the ground. The line-to-earth voltages are nearly sinusoidal and the common mode voltage at 3 AC load star point is close to zero.

If, by common agreement between the operator and the train integrator, it is preferred to have the 3-phase train line floating (insulated from ground) the neutral point may be connected to earth via a small capacitor C_N (lower part of Figure A.1). Again the line-to-earth voltages are nearly sinusoidal, the neutral and common mode potential at 3 AC load star point are close to earth.

These architectures provide a 3-AC train line voltage quality minimising the stress on the AC loads: low TDR, very little voltage overshoot and dU/dt at any line or common mode voltage. However, a low frequency transformer is necessary, the weight of which can be a drawback for applications where the axle load limit is very tight.

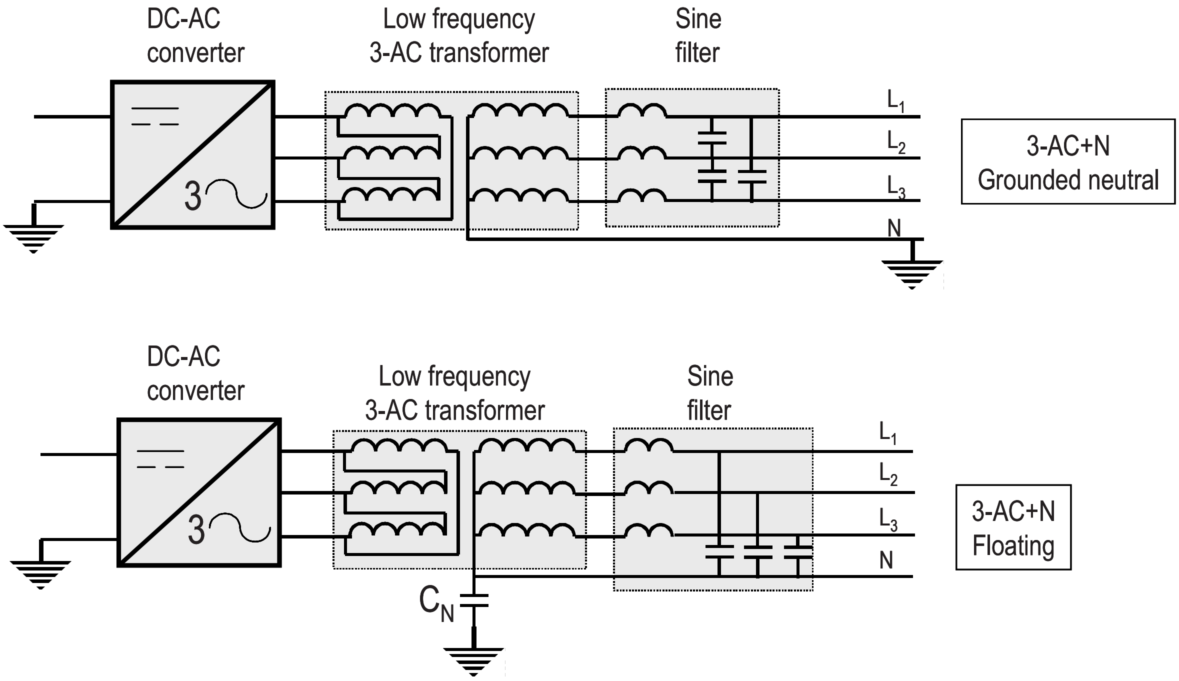

Figure A.1 — Train line supply architecture with galvanic isolation at auxiliary converter output side

A.3 Class 1 - Galvanic isolation at auxiliary converter input side and sine filter

Class 1 example. The galvanic isolation can be obtained at the input side of the auxiliary converter by means of a high frequency transformer to save weight and volume (upper part of Figure A.2), or directly from a winding of the main traction transformer for AC catenary line supply (lower part of Figure A.2).

Several possibilities are offered depending if the train line is a 3 wire system or a 3 wire + neutral system and if single phase loads have to be connected between lines and neutral. Here again, both architectures provide a 3-AC train line voltage quality minimising the stress on the AC loads as the line-to-earth voltages are nearly sinusoidal and the 3 AC load star point is close to earth: low TDR, very little voltage overshoot and dU/dt at any line or common mode voltage.

In Figure A.2 upper part, the capacitors of the sine filter are star connected to earth, this solution is efficient for a 3 wires network. If single phase loads have to be used between any line and neutral the scheme of Figure A.2 lower part is preferable to minimise voltage unbalance and static tolerances: neutral inductance L_N connected to the medium point of the DC bus capacitors.

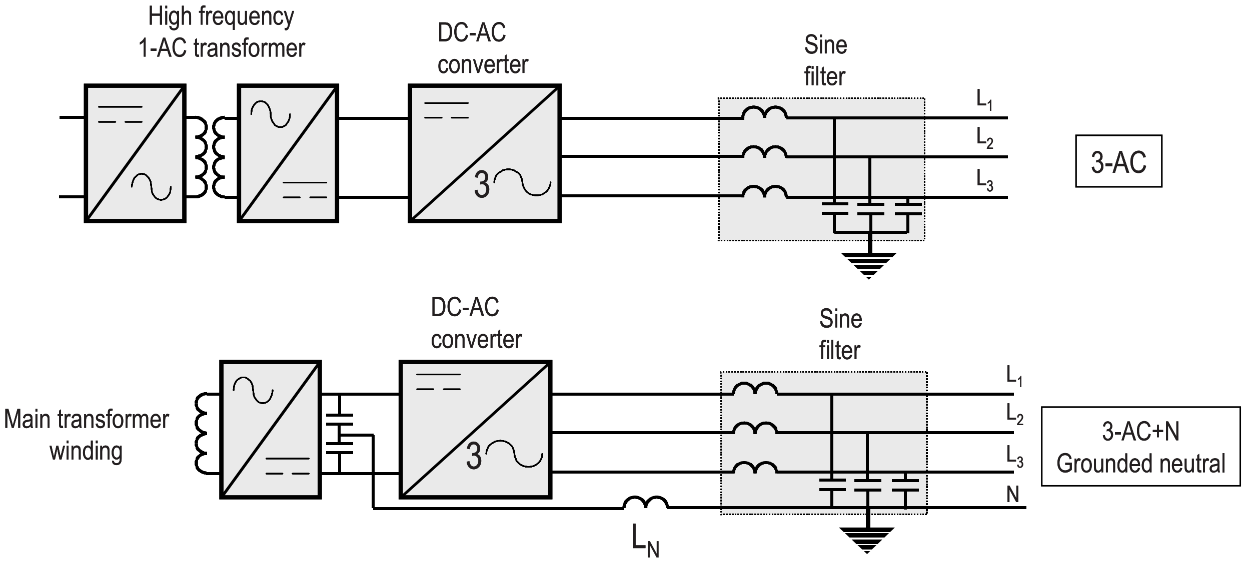

Figure A.2 — Train line supply architecture with galvanic isolation at auxiliary converter input side

A.4 Class 2 and Class 3 - Train line supply without galvanic isolation

The use of galvanic isolation and sine filter is not always feasible for weight and volume aspect in certain railway applications.

Class 2 example: Figure A.3 (upper part) shows an example without galvanic isolation but fitted with a sine filter at the three-phase output of the auxiliary converter. With this type of architecture the line-to-line and line-to-neutral voltages present a low TDR and are quasi-sinusoidal. However, the line-to-earth and the star point to earth voltage of the three-phase loads have an average value of half the DC input voltage and present large swings with high dU/dt. This constraint has to be taken into consideration for the motor design. Here again a neutral inductance L_N between neutral and medium point of the DC input is needed to reduce unbalance and static tolerances if single loads exceed a certain amount of the rated power and to limit homopolar currents.

Class 3 example: Figure A.3 (lower part) shows an example which minimizes weight and volume: no galvanic isolation and only a dU/dt filter at the auxiliary converter output. In that case the dU/dt is limited at 250V/µs at auxiliary converter side and can reach 500V/µs maximum at the end of a long train line (worst case). The dU/dt filter has to be adapted to the train line impedance.

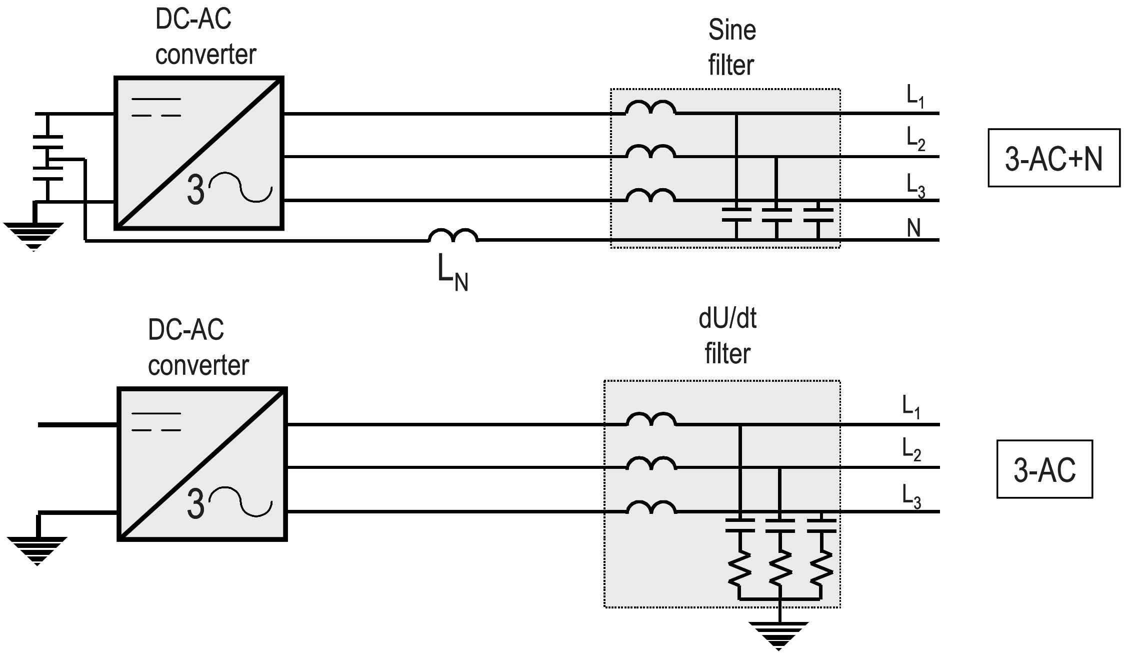

Figure A.3 — Train line supply architecture without galvanic isolation

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3) Under development.

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