TECHNICAL STANDARDS

DETAILED TECHNICAL CONDITIONS FOR THE CONSTRUCTION OF THE RAILWAY INFRASTRUCTURE OF THE SOLIDARITY TRANSPORT HUB – DESIGN GUIDELINES

VOLUME II.1

OVERHEAD CATENARY SYSTEM AND TRACTION POWER SUPPLY

2 x 25 KV 50 HZ AC

Version 1.3.0, closed on 05.08.2021

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The list of volumes constituting the detailed technical conditions for the construction of the railway infrastructure of the Solidarity Transport Hub:

Volume A	Introduction to the STH railway standards
Volume I.1	Railway track – layout geometry
Volume I.2	Railway – design of civil structures
Volume I.3	Railway track – drainage of track layout
Volume I.4	Railway track – gauge
Volume I.5	Railway track – geotechnical investigations and design
Volume II.1	**2 x 25 kV 50 Hz AC overhead catenary system and traction power supply** Defines the principles of designing, construction and acceptance of power supply and overhead catenary systems of 2 x 25 kV power supply systems
Volume II.2	3 kV DC overhead catenary system and traction power supply
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Volume XI	Electromagnetic compatibility (EMC)
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Volume XIII	Technical support facilities
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Volume XV	Survey control
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Volume XVIII	Security, protection and cybersecurity integrity requirements

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Revisions of the document “Detailed technical conditions for the construction of railway infrastructure of the Solidarity Transport Hub; Volume II.1; 2 x 25 kV 50 Hz AC overhead catenary system and traction power supply”:

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1. Introduction

This volume II.1 of the Technical Standards – Design Guidelines is one of 30 volumes containing a description of detailed technical conditions for the construction of railway lines up to a speed of Vmax ≤ 350 km/h.

1.1. Technical scope

These guidelines apply to all categories of railway lines. The guidelines define the principles of designing, construction and acceptance of power supply and overhead catenary systems of 2 x 25 kV power supply systems. These guidelines contain technical requirements related to general parameters for the 2 x 25 kV power supply system, basic parameters of traction substations and autotransformers, design parameters of the 25 kV overhead catenary system, as well as electric shock protection and safety requirements. Compliance with the guidelines enables reliable operation of a 2 x 25 kV power supply system.

1.2. Links to other volumes

The links between this Standards volume and other volumes are presented in Table 1.

Table 1.

Volume No	Volume title	Relation content
Volume I.1	Railway track – Layout geometry	Requirements for geometrical parameters on the horizontal plane
Volume II.2	3 kV DC overhead catenary system and traction power supply	Requirements concerning the method of isolating the overhead catenary system at stations and junction signal boxes
Volume III.2	Tunnels	Requirements for overhead catenary system and traction power supply in a tunnel
Volume IV	Non-OCL power engineering solutions	Requirements for power supply systems for non-traction consumers
Volume VI.1	Control command and signalling – basic equipment	Requirements for information signs at the boundaries of system separation sections; requirements for semaphore locations in system and phase separation section areas
Volume VIII.2	Technical buildings	Requirements for the location of traction substations
Volume X	Conflicts with external networks	Requirements concerning proximity for networks and systems not related to railway traffic
Volume XI	Electromagnetic compatibility (EMC)	Requirements concerning the resistance of the control command and signalling circuits to disturbances generated by power lines at proximities or crossings with railway lines

1.3. Definitions of terms used

1) Basic parameter

Legal, technical or operational conditions essential for interoperability, as defined in the relevant TSIs

[as defined in the EU Railway Interoperability Directive[1]

2) Infrastructure manager

An entity responsible for managing the railway infrastructure, its operation, maintenance, renewal or participation in the development of the infrastructure, and in the case of construction of new infrastructure, an entity that commenced its construction as the investor

[as defined in the Railway Transport Act[2]*]*

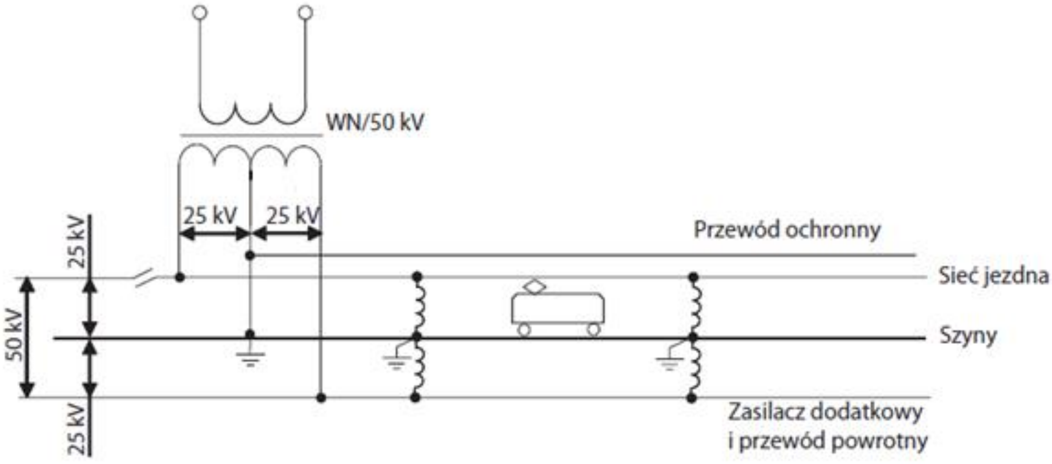
3) **Power supply system** includes the following parameters:

• supply source type (AC),

• voltage value,

• supply voltage frequency (AC).

4) **Power supply system** – a diagram of the main current circuit of the power supply circuit, specifying its basic equipment and the system of overhead catenary, supply and return lines.
5) **Short-circuit current** [Iss] – expected current determined as a result of a short-circuit caused by damage or incorrect connection in the electric circuit
6) **High voltage** – 110, 220, 400 kV voltage
7) **2 x 25 kV 50 Hz traction power supply system** – a power supply system in which the transformers installed in traction substations have two secondary windings with 25 kV 50 Hz voltage, the common central terminal of which is earthed and connected to the busbars and the return conductor. The end of one winding is connected to the contact line and the end of the other one – to the additional supply line. Between the substations, there are autotransformers located at a distance from a few to a dozen kilometres from each other. They are connected between the contact line and the additional supply line. As a result, the voltage between the overhead catenary system and the rails is 25 kV and the power transmission from a substation to autotransformers is between 35.4 and 50 kV, depending on the transformer solution – the angle of shift of output voltages relative to each other. Figure 1.1 shows the 2 x 25 kV power supply system (with single-phase transformers). The 2 x 25 kV 50 Hz system consists of sections of lines or tracks on which the contact line is supplied from an autotransformer or substation, but it is not equipped with a positive feeder.



PL	EN
Przewód ochronny	protective conductor
Sieć jezdna	contact line
Szyny	rails
Zasilacz dodatkowy i przewód powrotny	auxiliary feeder and return cable

Figure 1.1 – Diagram of 2 x 25 kV 50 Hz electric traction power supply system

8) **Single-phase traction transformer** – a traction transformer with one primary winding and one secondary winding the middle tap of which is connected to the busbar. 2 x 27.5 kV secondary voltage shifted to each other by 180°.

9) **V-V traction transformer** – a traction transformer whose primary winding is three-phase and the secondary winding forms an incomplete triangle. 2 x 27.5 kV secondary voltage shifted to each other by 120°.

10) **"D" traction transformer** – a traction transformer with a star-delta connection system with an output neutral point of the primary winding and one earthed top of the secondary winding delta. 2 x 27.5 kV secondary voltage shifted to each other by 120°.

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2. Essential, basic and general requirements for the STH railway infrastructure

The below-mentioned essential requirements for the railway system (general) and subsystems under Directive 797/2016 and the basic requirements under the Construction Law and the Act on construction products, as well as the general requirements supplementing them, defined in the context of the role of the railway lines in the Polish transport system, constitute the basis for verification of the completeness of detailed technical conditions for the construction of railway lines. Therefore, each volume in chapter 2 contains the links between the detailed technical conditions and these essential requirements for railway lines in the form of tables (with reference to the below-mentioned numbering).
Table 2 defines the link between the detailed technical conditions and the essential, basic and general requirements for railway lines.

Table 2.

sub-chapter of this volume defining detailed technical conditions	essential requirements (Railway Interoperability Directive)						basic requirements	general requirements for the STH railway infrastructure			
	1.1. security	1.2. reliability and accessibility	1.3. health	1.4. environmental protection	1.5. technical compliance	1.6. accessibility	2.1. mechanical resistance and stability 2.2. safety in case of fire 2.3. hygiene, health and the environment 2.4. safety and accessibility in use 2.5. protection against noise 2.6. energy economy and heat retention 2.7. sustainable use of natural resources	3.1. focus on the needs of economy	3.2. orientation towards the needs of passengers	3.3. orientation towards the needs of carriers	3.4. compatibility with the railway infrastructure connected with the STH railway infrastructure
3.1	1.1.1, 1.1.7				1.53		2.4.1, 2.6.1				
3.2	1.1.1, 1.1.3, 1.1.7				1.5.3		2.4.1, 2.6.1				
3.2.1					1.5.3						
3.2.2					1.5.3						
3.3	1.1.1, 1.1.3, 1.1.7			1.4.3	1.5.3		2.4.1, 2.6.1				
3.3.1	1.1.1, 1.1.7			1.4.3			2.4.1, 2.6.1				
3.3.2	1.1.3			1.4.3	1.5.3		2.4.1, 2.6.1				
3.3.2.1	1.1.3				1.5.3		2.4.1				
3.3.2.2	1.1.3				1.5.3		2.4.1				
3.3.2.3	1.1.3				1.5.3		2.4.1				
3.3.2.4	1.1.3			1.4.3	1.5.3		2.4.1, 2.6.1				
3.3.2.5	1.1.3			1.4.3	1.5.3		2.4.1, 2.6.1				
3.3.2.6	1.1.3			1.4.3	1.5.1		2.4.1, 2.6.1				
3.3.2.7	1.1.3			1.4.3	1.5.1		2.4.1, 2.6.1				
3.3.2.8	1.1.3				1.5.1						
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3.3.3.4	1.1.1., 1.1.7										
3.3.3.5	1.1.1, 1.1.7										

3.3.3.6	1.1.1, 1.1.7										
3.4	1.1.1, 1.1.3, 1.1.7			1.4.2	1.53		2.1.1, 2.4.1				
3.4.1	1.1.1, 1.1.3, 1.1.7			1.4.2	1.5.3		2.1.1, 2.4.1				
3.4.1.1	1.1.1, 1.1.7				1.5.3		2.1.1., 2.4.1				
3.4.1.2					1.5.3						
3.4.1.3					1.5.3						
3.4.1.4					1.5.3						
3.4.1.5	1.1.1, 1.1.7						2.4.1				
3.4.1.6					1.5.3		2.1.1				
3.4.1.7	1.1.3, 1.1.7			1.4.2	1.5.3		2.1.1				
3.4.2	1.1.1,1.1.7				1.5.3						3.4.1
3.4.2.1	1.1.1, 1.1.7				1.5.3						
3.4.2.2	1.1.1, 1.1.7				1.5.3		2.1.1				3.4.1
3.4.2.3	1.1.7										
3.4.3					1.5.3						
3.4.4	1.1.1, 1.1.7				1.5.1		2.4.1				
3.4.5	1.1.1, 1.1.5, 1.1.7						2.4.1				
3.4.5.1	1.1.1, 1.1.7						2.4.1				
3.4.5.2	1.1.1, 1.1.5						2.4.1				
3.4.5.3	1.1.1						2.4.1				
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3.4.10					1.5.3						
3.4.10.1					1.5.3						
3.4.10.2					1.5.3		2.1.1, 2.4.1				

Cybersecurity

Technical solutions which collect, store, process, make available or transmit data ensuring the compliance with essential safety requirements (requirements from 1.1.1. to 1.1.11. specified in Volume A of the STH Railway Standards) and general requirements for the STH railway infrastructure concerning security (requirements 1.1.12. and 1.1.13 specified in Volume A of the STH Railway Standards) should be designed taking into account cybersecurity, i.e. “security of network and information systems”, defined in the Directive concerning measures for a high common level of security of network and information systems across the Union, as follows:

> “security of network and information systems” means the ability of network and information systems to resist, at a given level of confidence, any action that compromises the availability, authenticity, integrity or confidentiality of stored or transmitted or processed data or the related services offered by, or accessible via, those network and information systems;
>
> *[as defined in Article 4 of Directive 2016/1148]*

Cybersecurity includes two types of threats resulting from unauthorised access to the systems/equipment/networks that collect, store, process, make available or transmit data:

1) physical security threats

   It is necessary to secure systems/equipment/networks against direct access which could enable causing (intentionally or unintentionally) threats to functional safety.

2) IT security threats

   It is necessary to secure systems/equipment/networks against logical access via IT systems/equipment/networks, which could enable causing (intentionally or unintentionally) threats to functional safety.

Cybersecurity defined this way applies both to information systems used for rail transport purposes and to operational systems used for rail transport purposes, but the STH railway standards do not include requirements for information systems, e.g. timetabling systems.

Physical security threats and IT security threats for operational systems for which requirements are defined in the STH railway standards should be addressed by railway operators as part of the risk assessment and by design engineers/manufacturers/contractors as part of threat control. Additionally, it is required for the applied protections to be documented and verified in accordance with the requirements included in Volume XVIII of the STH railway standards.

Cybersecurity within the scope of this volume of the STH railway standards

Currently, in the area covered by this volume of standards, there are no networks and information systems whose security could be endangered. However, it is possible that such networks and information systems or technical solutions that collect, store, process, make available or transmit data may arise. For example, a system of sensors may be used that, through wired or wireless networks, public or non-public networks or directly, will connect to, for instance, an infrastructure manager's system. Then, they should be protected against physical security and IT security threats in a manner compliant with the requirements of the Information Safety Management System (ISMS) implemented by the STH company.

At the same time, it should be kept in mind that the ISMS will be subject to changes because maintaining the required level of cybersecurity is not possible by meeting requirements of the standards once since cybersecurity is a process rather than a state. In order to minimise the number and size of cyber threats, the requirements (obligations) included in the Act of 5 July 2018 on the national cybersecurity system in Chapter 3 for operators of key services, in Chapter 5 for public entities should be continuously observed in operational processes and only digital service providers fulfilling the obligations described in Chapter 4 of that Act should be used.

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3. Detailed technical conditions for construction of the STH railway infrastructure

3.1. Formal arrangements

1) The power supply system of the railway line in accordance with [3] should be designed so as to enable achievement of full performance parameters for normal and emergency conditions, taking into account:
a) railway line speed,
b) minimum succession of trains,
c) maximum current consumed by a train,
d) train power factor,
e) timetable and scheduled maintenance,
f) required mean usable voltage, according to a given line category.
2) The existing technical solutions concerning the power supply circuits of the 2 x 25 kV AC electric traction system, which may be used in operation, have a different design of the transformers used and the level of asymmetry introduced at the points of connection to the power system. The circuit solution must be selected on the basis of an analysis of its impact on voltage asymmetry introduced to the power system.
3) The requirements of this volume also apply to railway tunnels compliant with Volume III.2

3.2. General requirements for the 2 x 25 kV AC power supply system

1) On newly constructed railway lines, a 2 x 25 kV 50 Hz AC traction power supply system should be used.
2) Exceptions are allowed:
   a) for high-speed rail sections at railway junctions with the existing DC traction power supply system. At such sections, it is possible to use the DC traction power supply system with an appropriate feasibility study with a limit of travel speed to 250 km/h;
   b) for the front sections (terminals, depots, technical back-up facilities, etc.), it is possible to use the 25 kV AC traction power supply system – power supply of the overhead catenary system from a substation or an autotransformer substation without the use of any additional feeder;
   c) at sections of lines reaching the system separation section, supply of the overhead catenary system with 25 kV voltage from a substation or an autotransformer substation without the use of any additional feeder is used;
   d) other.
3) If a railway line includes sections equipped with DC and AC traction power supply systems, technical and economic calculations should take into account the need to connect DC and AC sections at current type change points and to use double-system electric rolling stock.
4) The external power supply system of the electrified railway system must supply power to traction substations from the power system so that any damage to one of the substations (main sections) of the power system or feeder does not result in switching off a traction substation. For this purpose, traction substations should, in principle, feature double-sided power supply from the distribution network or through two radial lines from different busbars of one substation of the power system with at least two power sources.
5) The selection of voltage supplying traction substations (110 kV, 220 kV or 400 kV) should be made on the basis of an analysis of the power supply system structure (possible variant solutions) and an expert opinion on the impact of the designed 2 x 25 kV electric traction power supply system on the national power system at the point of connection to the power system. The technical conditions to be met by equipment, systems and networks connected to the distribution network are specified in the Distribution Network Code (DNC) of the relevant Distribution System Operator (DSO). In the case of connection to the transmission network, the connected network should meet the conditions specified in the Transmission Network Code (TNC) [4].

6) The selection of a high voltage value supplying traction substations of railway infrastructure (110 kV, 220 kV or 400 kV) should be made on the basis of the results of traction and electrical calculations, provided that the traction is reliably supplied, the assumed timetable can be followed, and that the investment expenditures for the construction of traction equipment and the costs of connection to the distribution network can be incurred. A feasibility study should be prepared for each power supply section.
7) When selecting the methods of connecting traction substations to the power system network and equipment of traction substations, asymmetry and distortion of voltages in three-phase external power networks should be minimised. The quality of electricity should meet the provisions of Chapter 10 of the Regulation of the Ministry of Economy of 4 May 2007 on detailed conditions for the operation of the power system, No. 623 [5].
8) Traction substations must be supplied from two independent sources of electricity. In justified cases, it is allowed to supply a substation with two lines from one main power supply point (main power supply point), but from different HV sections.
9) A return line is planned for the return network of the railway traction power supply system, laid along the traction network poles and connected to the tracks.
10) The traction power supply system of the railway infrastructure must ensure the possibility of using regenerative braking by electric rolling stock.
11) The railway traction power supply system must ensure the possibility of electric melting of ice or preventive heating of overhead catenary system wires of the main station tracks and open lines.
12) When designing the equipment for the power supply system of the traction railway infrastructure, the following basic parameters should be specified:
    a) distances between adjacent traction substations,
    b) location of autotransformer stations,
    c) power, number and type of transformers in traction substations,
    d) rated current of switching gear and switching devices,
    e) power output and number of autotransformers in zones between substations,
    f) types and power of traction substation equipment ensuring an increase in the quality of electricity in the power supply system and the overhead catenary system,
    g) type, cross-section and number of overhead catenary system wires, supply and return line conductors and cables.
13) The selection of the main parameters is made in accordance with traction and electrical calculation results relative to the predefined traffic distribution of trains with the smallest distance between trains. The main parameters are selected taking into account the recuperation mode.
14) Traction and electrical calculations should take into account the timetable which generates the highest loads for the power supply system including recuperation, as well as instantaneous voltage values on the pantographs of electric rolling stock in accordance with EN 50388:2012 [6].
15) In the Detailed Design and possibly in the As-built Design of the overhead catenary system, apart from descriptions of the calculations specified above, the designed overhead catenary system and the railway infrastructure relevant for the project should be marked on 1:500 scale survey maps.
16) As output data for traction and electrical calculations, the following items are assumed: railway plan and longitudinal profile; traction and energy characteristics of electric rolling stock; train masses, the smallest distance between trains moving by; number of trains per hour of the maximum traffic level.
17) For selected parameters of the traction power supply system, the minimum permissible train sequence and the highest train speeds in emergency operation modes should be specified for normal operating conditions:
    a) one transformer in the substation is out of operation,
    b) one autotransformer is out of operation,
    c) one traction substation is out of operation.
18) In the place of a parallel route of 2 x 25 kV AC and 3 kV DC electric traction systems, at distances

smaller than 50 m between them, there is an interaction zone. In such cases, the requirements of EN 50122-3:2010 [7] must be met.

19) The parameters of the traction power supply system and its elements should ensure the implementation of the assumed timetable in case one line supplying the substation or one transformer in the traction substation is switched off.
20) Detailed EMC requirements for the 2 x 25 kV power supply system are included in Volume XI Electromagnetic compatibility (EMC).
21) The source of harmonics is a traction vehicle. An example of voltage spectrum for traction vehicles equipped with modern four-quadrant converters is presented in Fig. 3.1.

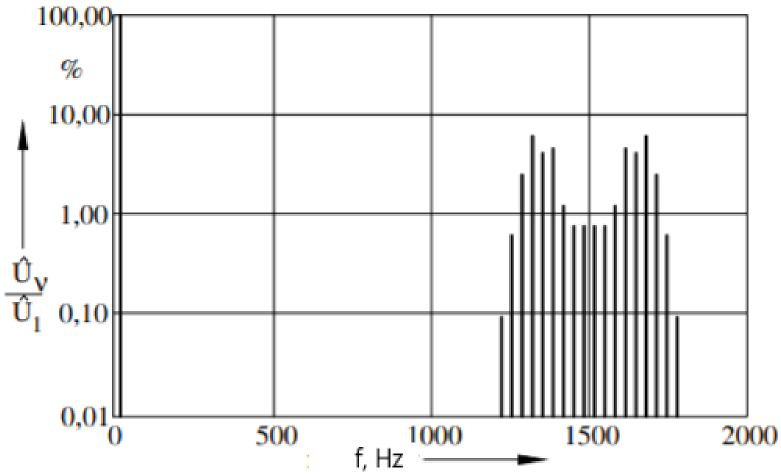

Figure 3.1 Voltage spectrum of traction vehicles equipped with four-quadrant converters[1]

3.2.1. Operating and short-circuit currents

1) The parameters referred to in point **Błąd! Nie można odnaleźć źródła odwołania.** are used to size instrumentation and do not replace the timetable when performing the simulation.
2) The maximum current consumed by the train on lines P1, M1 should be assumed at 1,500 A in accordance with Table 4 and Table F1 PN-EN 50388 [6] .
3) The maximum current consumed by the train on lines P2, M2 should be assumed at 600 A in accordance with Table 4 and Table F1 PN-EN 50388 [6].
4) The maximum current consumed by the train on lines P3, P4, M3 should be assumed at 500 A in accordance with Table 4 and Table F1 PN-EN 50388 [6].
5) The main circuits of all power supply equipment and overhead catenary system equipment should be characterised by resistance to a short-circuit current flow of 15 kA, in accordance with PN-EN 50388 [6].
6) Each device of the 2 x 25 kV power supply system must be designed to a strength value being equal to or higher than the maximum short-circuit current calculated or specified for the respective location.

3.2.2. Voltage in the overhead catenary system

1) The value of voltage in the overhead catenary system, its variations and frequency should be in accordance with the requirements of EN 50163 [8].
2) Regardless of the operating condition of the traction power supply system, taking into account harmonics, resonances and other disturbances, the voltage in the overhead catenary system must not exceed 29,000 V and 50 kV of the instantaneous peak value.

[1]The provided literature example was sourced from the monograph *by F. Kiessling, R. Puschmann, A. Schmieder, and E. Schneider. 2018. Contact Lines for Electric Railways: Planning, Design, Implementation, Maintenance, 3rd Edition. Wiley.*

3) During the design process, it should be checked whether, in accordance with the requirements of PN-EN 50163:2004, clause 4 [8], the lowest non-permanent voltage is not lower than 17,500 V, the lowest permanent voltage is not lower than 19,000 V, the highest permanent voltage does not exceed 27,500 V, and the highest non-permanent voltage does not exceed 29,000 kV. In addition, it should be determined whether, taking into account harmonics, resonances and other disturbances, the voltage in the overhead catenary system does not exceed 29,000 V and 50 kV of the instantaneous peak value.
4) The value of the mean usable voltage at the pantograph should be in accordance with EN50388:2012 [6]:
   a) 22500 V – on railway lines P1, M1,
   b) 22000 V – on railway lines P2, M2, P3, P4, M3.
5) As specified in clause 4.2 of EN 50388:2012 [6] for the 25 kV 50 Hz AC power supply system, the permissible frequency limits are as follows:
   a) for systems with synchronous connection to the interconnected system:
      – 50 Hz ± 1% (i.e. 49.5 Hz to 50.5 Hz) for 99.5% of the year,
      – 50 Hz + 4%/- 6% (i.e. 47 Hz to 52 Hz) for 100% of the time.
   b) for systems with non-synchronous connection to the interconnected system (e.g. power supply systems on certain islands):
      – 50 Hz ±2% (i.e. 49 Hz to 51 Hz) for 95 % of the week,
      – 50 Hz ± 15% (i.e. 42.5 Hz to 57.5 Hz) for 100% of the time.
6) In accordance with the TSI relating to the “Energy” subsystem, point 4.2.6 [3], traction power supply systems should allow the use of regenerative braking by electric rolling stock.

3.3. Traction substations, autotransformer substations in the 2 x 25 kV AC system

3.3.1. Location of the traction substation and autotransformer stations

1) Traction substations and autotransformer substations should be located at distances ensuring supply of the power required by vehicles and the required mean usable voltage level at the pantograph.
2) The location of traction substations, autotransformer substations should be selected so as to enable access of tractors with a low-bed trailer or to enable an access road to be routed with the required parameters. The requirements concerning the location of traction substation buildings are included in point 3.7 of Volume VIII.2 Technical buildings.
3) The distance between the last autotransformer and the system separation section should not exceed half of the distance between autotransformer stations.
4) The area for the designed substation, autotransformer station should enable installation of all necessary equipment and instrumentation, construction of the traction substation building and access roads. The size and topography of the area for the substation or autotransformer station must not hinder the replacement of equipment during operation of the autotransformer substation or station. The substation area should enable construction of an earthing system between the building and the substation fence, meeting the requirements of EN 50122-1:2011 [9].
5) Traction substations, autotransformer substations and access roads are recommended to be located in railway areas, on lands with a possibly low agricultural class.

3.3.2. Requirements and basic parameters of instrumentation and equipment

3.3.2.1. Traction substation supply and feeders

1) Traction substations should be supplied by HV lines with a voltage of 220 kV AC or 400 kV AC.
2) In justified cases, it is allowed to supply traction substations with HV lines with a voltage of 110 kV AC.
3) Regardless of the supply voltage value, the requirements concerning boundary values of voltage asymmetry coefficients in the power system should be met [5].
4) Each substations should have two connections: main and backup. They should be routed directly from two different main power supply point switching-stations or from separate sections of the main power supply point switching-station.
5) The feeders of 400, 220 or 110 kV AC substations should be connected to the utility power system in main power supply points, distribution power supply points or to the line (tie-in).
6) Traction substations may be connected to HV lines by means of static converters ensuring perfectly balanced 3-phase HV load, even when connected to the 110 kV HV network with a low short-circuit power value.
7) For power supply of traction substations with static converters, no phase separation zones between the feeder sections are required.
8) The electricity supplier may accept the return of electricity regenerated during regenerative braking. Consumed and regenerated energy must be recorded accurately and separately.

3.3.2.2. HV AC switchgear

1) The HV switchgear should be designed with air insulation.
2) The HV switchgear in H5 configuration contains the following main components:
   a) circuit breakers,
   b) disconnector switches,
   c) current/voltage transformers,
   d) surge arresters.
3) The HV switchgear should have a single busbar system and should be equipped with transformer bays, feeder bays and a coupler with circuit breakers. Detailed solutions must result from the Technical Conditions for Connection and the Connection Agreement concluded with a territorially competent distribution system operator. These documents should also specify the operational limits between the distribution system operator and the energy consumer, requirements for the protection instrumentation, remote control system and basic data (power and short-circuit currents at feeder points) necessary for calculations of the power supply system.
4) All drives and control circuits should be adapted to supply with 220 V DC voltage for unification with the existing solutions.
5) The disconnector switches should be overhead, three-pole, double-column, single-break units with one or two sets of earth blades. The insulation should be made of brown porcelain or composite.
6) Current transformers, voltage transformers and current and voltage transformers (combined) should be made as outdoor, standing, single-phase transformers with porcelain or composite casing. The casing should be hermetic, explosion-proof, preventing the rupture of the instrument transformer during an internal short circuit by a controlled discharge of the insulating medium and its decomposition products in a direction safe for the personnel.
7) The recommended technical data of HV switchgears are presented in Table 3.

Table 3 Recommended parameter values of HV switchgears

Parameter	Recommended rated voltage values		
	110 kV	220 kV	400 kV
Highest (permanent) voltage for equipment, kV	170	362	420
Standard impulse withstand voltage, kV	750	1175	1425
Ambient temperature, °C	-20 ... +40		

3.3.2.3. **2 x 27.5 kV AC switchgear**

1) The 2 x 27.5 kV gas or air insulated switchgear distributes traction power to the respective sections. In order to supply the 2 x 27.5 kV autotransformer, the switchgear must be equipped with a section system of 2 x 27.5 kV busbars. Each busbar section should be fed by one of two HV / 2 x 27.5 kV transformers.
2) In case of failure of one transformer, it is necessary to secure the possibility of remote resectioning of the switchgear so as to enable feeding of all outgoing feeders from one transformer.
3) Each traction substation should be equipped with separate outgoing feeders to supply associated sections equipped with circuit breakers and disconnector switches. Individual feeders should be interlocked accordingly, taking into account possible circuit configurations, in order to ensure safety of personnel and equipment.
4) Recommended basic electrical characteristics of 2 x 27.5 kV switchgears:
   a) Frequency (fr): 50 Hz
   b) Number of phases: 2
   c) Rated voltage (Un): 27.5 kV (RMS value)
   d) Lightning impulse test voltage:
      – to earth and line-to-line: 170 kV
      – along the isolating distance: 200 kV
   e) Power-frequency test voltage
      – to earth, line-to-line and along an open 80 kV switch
      – along the 90 kV isolating distance
   f) Rated supply voltage of auxiliary circuits: 220 V DC
   g) Rated continuous current for P1, M1 railway lines
      – of feeder bay: 1700 A
      – by-pass buses: 1300 A
   h) Rated continuous current for P2, M2 railway lines
      – of feeder bay: 700 A
      – by-pass buses: 450 A
   i) Rated continuous current for P3, P4, M3 railway lines
      – of feeder bay: 630 A
      – by-pass buses: 400 A
   j) Peak withstand current: 63 kA
   k) Rated short-time withstand current: 25 kA / 1 s

3.3.2.4. **Traction transformers**

1) In 2 x 25 kV power supply systems, the basic transformer connection system is a system with single-phase transformers.
2) Other connection systems of traction transformers in power supply systems are allowed.
   2 x 25 kV:
   a) three-phase transformers in delta configuration,

b) three-phase transformers in V-V configuration.
3) Transformers of the same type should be installed in one substation.
4) In order to select the connection system, the level of asymmetry which is introduced into the power system at the high voltage level at the point of connection to the power system should be analysed.
5) Oil-immersed traction transformers must be ONAN cooled and equipped with an on-load voltage control system. The transformers must be designed in accordance with IEC 60076:2011 [10].
6) In order to achieve high reliability of the traction power supply system, all traction substations must be equipped with at least two traction transformers.
7) Each traction transformer should transfer the total load for normal operating conditions in the assigned power section as well as in emergency shutdown mode of one substation. The rated power of the transformers must be determined at the stage of feasibility study based on transport operation.
8) The transformers must meet the overload capacity requirements in accordance with PN-EN 50329:2010, taking into account the expected traffic [11].
9) Oil-immersed traction transformers must be installed outdoors near the HV switching station.
10) The transformers should be protected against overvoltages by surge arresters, coordinated and sized in accordance with the overall insulation coordination study.
11) The recommended technical data of single-phase traction transformers are presented in Table 4.

Table 4 Recommended parameter values for single-phase traction transformers

Technical data of transformers	**Recommended parameter values**			
Rated upper voltage, KV	110[2], 220, 400			
Rated power, MVA	16**Błąd! Nie zdefiniowano zakładki.**	25	40	63
LV side voltage, kV	2x27.5			
Short-circuit voltage, %	≤10			

3.3.2.5. **Traction autotransformers**

1) Oil-filled traction autotransformers should be ONAN cooled and designed in accordance with IEC 60076 [10].
2) Autotransformers should be able to withstand short-circuits in accordance with the requirements of EN 60076-5 [12].
3) The recommended technical data of traction autotransformers are presented in Table 5.

Table 5 Recommended parameter values for traction autotransformers

Technical data of autotransformers	**Recommended parameter values**	
Rated upper voltage, KV	55[3], 47.3[4]	
Rated power, MVA	10	15
Short-circuit voltage, %	≤1	≤1
Maximum load losses, kW	18	21

[2] For P3, P4, M3 railway lines
[3] For single-phase transformers
[4] For three-phase transformers in Vv and Yd configuration

Maximum no-load losses, kW	8	10

3.3.2.6. **Compensating, symmetrising and damping equipment**

1) The main place of installation of compensating, symmetrising and damping equipment is the 2 x 27.5 kV switchgear of traction substations.
2) It is allowed to use symmetrising equipment (active, passive) in cases when the asymmetry factor exceeds the boundary value. It is recommended to install symmetrising equipment in the transformer bays of traction substations on the 27.5 kV side.
3) It is recommended to install reactive power compensating equipment in 2 x 27.5 kV switchgear of traction substations.
4) It is recommended to install damping equipment at locations on the power sections selected on the basis of calculations or at the ends of power supply sections.

3.3.2.7. **Power supply of auxiliary circuits and non-traction receivers**

1) The auxiliary power supply system of the traction substation and autotransformer substation includes the following equipment:
   a) two auxiliary MV/LV transformers,
   b) 230 V AC switchgear,
   c) 220 V DC switchgear,
   d) maintenance-free battery bank,
   e) 230 V AC installation switchgear,
   f) inverter (optional).
2) To supply auxiliary circuits in traction substations and autotransformer substations, the single-phase auxiliary transformers installed in the 2 x 27.5 kV switchgear bays should be used.
3) Recommended technical parameters of auxiliary transformers:
   a) Rated power: 250 kVA and 100 kVA,
   b) Rated HV side voltage: 27.5 kV,
   c) Primary voltage control: ±2.5%, ±5%,
   d) Rated secondary voltage: 240 V,
   e) Rated frequency: 50 Hz,
   f) Short-circuit voltage (at 120 °C): 6% (tolerance ± 7,5%).

2) The 230 V switchgear should be designed as a wall-mounted cabinet. The connections between the transformers and the switchgear should be made as cable connections. The switchgear should be equipped with an automatic transfer switch (automatic loss-of-voltage tripping). After shutdown of the automatic transfer switch (automatic loss-of-voltage tripping system), parallel operation of the auxiliary transformers should be possible, provided that the conditions of parallel operation of these transformers are met. If uninterrupted power supply of selected AC circuits (from the inverter) is necessary, these circuits should be separated.
3) The 220 V DC switchgear should interoperate with a maintenance-free battery bank. The following circuits are supplied from this switchgear:
   a) drives of HV and MV AC and DC circuit breakers (separate circuits for each switchgear),
   b) automation, protections and control (separate circuits for each switchgear),
   c) signalling (common for the entire substation),
   d) safety lighting,
   e) locking,
   f) inverter (if applicable).
4) The battery bank rectifier should be fed from the AC switchgear and connected to the battery in the buffer system.

5) The rectifier connection system should enable periodic charging of batteries bypassing the DC switchgear.
6) Individual auxiliary circuits should be protected with appropriate interference and overvoltage filters while maintaining appropriate grading of this protection.
7) It is allowed to supply all circuits not directly related to the substation technology from the 230 V AC installation switchgear. These include, among others: lighting, heating, sockets, ventilation, hydrophore, etc.
8) The requirements concerning power supply systems for non-traction receivers are presented in Volume IV Non-OCL power engineering solutions.

3.3.2.8. Feeders

1) The feeders are to be designed as cable lines with minimum impedance per 1 km. In justified cases, it is allowed to use feeders designed as overhead lines.
2) The cross-section of cable feeders is selected on the basis of the 30-minute RMS current value, but not less than 185 mm^2.
3) For construction of railway feeders, cables with an aluminium live wire with a rated insulation voltage of at least 25 kV, with insulation, sheath and polyvinyl shield, with an armour between the sheath and the shield should be used. In justified cases, it is allowed to use cables with a copper live wire. It is never allowed to use a ferromagnetic armour in cables with unbalanced magnetic field. It is allowed to use other types of cables, provided that the protective conductor of these cables is able to withstand short-circuit currents which may occur in case of damage to the feeder cable.
4) Indoor terminations of feeder cables should be made with indoor terminations that enable the armour to be routed to the earthing. On the side of the contact line, outdoor terminations should be used.
5) It is recommended to use straight-through joints made of synthetic or thermosetting resins with a minimum insulation voltage of 30 kV, which must comply with the requirements of EN 60137.
6) The return/screen wire of the 25 kV traction cable should be divided into insulated sections and each section should be earthed. The design engineer should check how long the connected sections of the shielding conductor/screen may be so that the induced voltage does not exceed the permissible values specified in EN 50122.
7) The technical design should include an analysis of induced voltages at the unearthed end of the cable. If the permissible values of touch voltages are exceeded, the design should provide for indirect earthing of the cable along the cable route.
8) The design should specify the required value of indirect earthing resistance of the cable.
9) Such points should be marked on site and provided with a test connector for measuring indirect earthing resistance of the cable.

3.3.3. Local automation and protection devices

3.3.3.1. General requirements

1) Local automation and protection systems should be provided on the basis of microcomputer digital devices in accordance with the requirements of IEC 61850.
2) One type of data transmission protocol bus should be used in all power supply facilities. If protection devices using other buses and transmission protocols are used, they must be used provided that a module converting signals from a non-standard bus to a selected standard is ensured.
3) Traction substations, autotransformer substations and sectioning points should be fully prepared for remote operation as standard.
4) The automation system of traction substations should be able to operate in the following modes:
   a) remote operation mode – equipment operation is controlled from the Central Control Room;
   b) local operation mode – equipment operation is controlled directly from the traction substation;
   c) partially local operation mode – equipment operation is controlled from the Central Control Room and selected bays of the switching station or equipment from the traction substation.

5) Control operations should be allowed only from the place specified in the selected operation mode (Central Control Room for remote operation or traction substation for local operation), except for shutdown operations for selected equipment, which should be allowed from each place, regardless of the selected operation mode.
6) The remote control system should be compatible with the control system of the adjacent power supply facility operated by another operator.
7) Automation and control equipment operating in the substation should be able to operate in the following modes (regardless of the operating mode of the traction substation):
   a) automatic operation – equipment operation is controlled via the transmission link; commands sent via the transmission link are received by controllers performing control operations of power equipment (from the computer terminal to the substation or remotely),
   b) manual operation – equipment operation is controlled by means of push-buttons or levers co-operating directly with the equipment controller (while maintaining protections),
   c) overhaul – equipment does not operate normally (main circuits disconnected); the control of electric instrumentation in this mode is used to control the correctness of their operation.
8) The controllers should be provided with displays ensuring unambiguous visualisation of the status of the controlled instruments and a menu in Polish.
9) Controller design and software should provide protection against improper or unintentional control, also in case of controller failure.
10) The controllers should have the function of event recording with the record of date and time with event-specific accuracy (10 ms on average). The controller should enable the review of events and their resetting.
11) The selection of methods of protecting the reliability of the power supply system, methods of discriminating fault clearances, methods of protection of selectivity should comply with the recommendations of EN 50633:2016 [13].

3.3.3.2. **HV switching station**

1) it is required to use digital protection terminals and station automation systems in the HV switching station. All devices should be delivered with software for configuration, data reading and for setting and configuration changes.
2) The devices should be equipped with communication interfaces for:
   a) joint operation with the control and monitoring system for communication with the Distribution Operator,
   b) joint operation with the substation operator's control and monitoring system;
   c) construction of the engineering channel,
   d) local communication with the device.
3) All station protections and automation systems should be equipped with event and disturbance recorders.
4) Primary and back-up protections using different short-circuit detection criteria should be used. These protections should operate jointly with separate current and voltage circuits. Tripping should take place in both tripping circuits.
5) The protections should include at least two setpoint banks. The selection of the setpoint bank should be possible locally and remotely.
6) One of the applied protections should function as a bay controller. Such protection should be equipped with a graphic display representing the meter states in the bay and should enable control of all meters equipped with electric drives.
7) There should be local signalling of activation of protection functions in the form of signal lights (LEDs).
8) Each protection should have its own test terminal for safe testing.
9) The protections should have an automatic supervision function and programmable logic. They should be supplied with 220 V DC voltage.
10) The HV line bays should be equipped with the following protections:

   a) primary – distance or differential. For cable or overhead lines with a length of up to 2 km, differential protection should be used,
   b) back-up – distance or earth fault, current protection for radial feeders,
   c) automatic power restarting (reclosing) implemented in the distance protection.
11) Differential and distance protections operating concurrently should communicate using appropriately selected fibre optic interfaces through separate fibre optic fibres.
12) HV bus coupler bays equipped with a circuit breaker should be equipped with overcurrent protection or, in justified cases, distance protection.
13) Depending on the needs, the HV switching-station should be equipped with an automatic transfer switch (automatic loss-of-voltage tripping). Automatic loss-of-voltage tripping should be implemented by means of a dedicated device. It should be possible to switch off the automatic transfer switch (automatic loss-of-voltage tripping).
14) The automatic loss-of-voltage tripping system should be automatically interlocked after activation of protections in the HV bays, protection of the HV busbars, HV breaker failure protection.
15) In stations in the H configuration, it is allowed to use breaker failure protection and busbar protection as a single device.
16) The breaker failure protection should be activated by all installed protections of individual bays.
17) The operation of the breaker failure protection should be based on the current and circuit-breaker criteria.
18) Busbar protection should be equipped with the function of dead zone recognition.
19) The breaker failure protection should operate in two stages:
   a) pulsing to deactivate the circuit breaker in the bay in which a retrip has occurred,
   b) pulsing to deactivate all circuit breakers of the respective section or busbar system.
20) The breaker failure protection and bus bar protection should automatically adjust the operating zones to the current configuration of the HV switching station.
21) The automatic breaker failure protection and busbar protection systems should allow for extension with another bay without the need to alter the entire system.
22) The automatic breaker failure protection and busbar protection systems should be provided with two redundant feeders, at least one of which should be fed with 220 V DC voltage.
23) It should be possible in each bay to shut down the excitation and tripping of the breaker failure protection of a given bay. Signalling from the translators should be introduced to the master system.
24) Automatic power restarting (reclosing) should be used in outdoor and outdoor/cable lines.
25) The automatic power restarting system should be three-phase, single-shot, activated by the primary and back-up protections.
26) The automatic power restarting system should lock during operational switching of the line and disconnection of the circuit-breaker drive.
27) It should be possible to locally and remotely interlock the automatic power restarting system.

3.3.3.3. **Protections of traction transformers**

1) Oil-immersed traction transformers should be equipped with the following protections:
   a) differential and overcurrent protections. Such protections protect the transformer against internal short-circuits and result in tripping.
   b) delayed overcurrent protection against external short-circuits resulting in tripping.
   c) transformer factory protections:
      – I and II stage temperature protections,
      – I and II stage gas-flow protections,
      – oil level decrease signalling,
      – safety valve tripping.

3.3.3.4. **2 x 27.5 kV switchgear**

1) it is required to use digital protection terminals and station automation systems in the HV switching station. All devices should be delivered with software for configuration, data reading and for setting and configuration changes.
2) The 2 x 27.5 kV switchgear automation system should be supplied with 220 V DC voltage. It is allowed to introduce 230 V AC voltage for the lighting of cabinets and service sockets.
3) The protections should have an automatic supervision function and programmable logic.
4) The equipment should have the following data transmission channels:
    a) primary channel,
    b) backup channel,
    c) engineer channel,
    d) additional communication interfaces (if necessary).
5) The protections should trip the circuit breaker using two independent control voltages.
6) The protections should have at least two setpoint banks. The selection of the setpoint bank should be possible locally and remotely.
7) The bay protection device should act as a bay controller, be equipped with a graphic display mapping the switch states in the bay and enable control of all switches equipped with electric drives.
8) The devices should locally signal the activation of protection functions on protection panels.
9) In order to ensure effectiveness and selectivity of protection activation, the protection devices of the 2 x 27.5 kV switchgear should provide automatic protection of the busbars and breaker failure protection. Synchronisation of the busbar protection and the breaker failure protection should be performed by all installed protections of individual bays except for bays in which the protection is only a receiver of this signal. The automatic busbar protection and breaker failure protection systems should enable individual shutdown for individual protections.
10) The feeder bay should be equipped with the following protection and automatic control devices:
    a) short-circuit protection,
    b) independent overcurrent protection, min. 3 stages,
    c) earth-fault protection with directional function,
    d) undervoltage and overvoltage protection,
    e) frequency protection,
    f) inputs of the breaker failure protection, busbar protection and automatic loss-of-voltage tripping (automatic transfer switch).
11) The outgoing line bay should include the following protection and automation solutions:
    a) short-circuit protection,
    b) independent overcurrent protection, min. 3 stages,
    c) non-directional earth-fault overcurrent protections, min. 2 stages,
    d) directional earth-fault overcurrent protection,
    e) earth admittance protections with directional function,
    f) automatic power restarting (reclosing) for overhead and overhead and cable lines, activated by any protection device,
    g) automation solutions for accelerating protection activation when the line experiences a short circuit,
    h) automation solutions for breaker failure protection, busbar protection and automatic loss-of-voltage tripping (automatic transfer switch).
12) All protection devices trip the respective circuit breaker.
13) The bay of the auxiliary transformer should have the following protection and automation solutions:
    a) independent two-stage overcurrent protection (I and II stage),
    b) differential protection,
    c) transformer factory protections,
    d) automation system of the breaker failure protection and busbar protections.
14) Activation of the circuit-breaker in the bay should take place in case of activation of the following protections:
    a) overcurrent protection,
    b) 2nd stage transformer factory protection.

15) The activation of other protections mentioned in point 13 should trigger signalling.
16) The bus coupler bay should include the automation system of breaker failure protection and busbar protections as well as protections tripping the circuit breaker:
    a) short-circuit protection;
    b) independent overcurrent protection, min. 2 stages,
    c) earth-fault overcurrent protection (in a network earthed using a resistor),
17) The 2 x 27.5 kV switchgear should be equipped with voltage measurement with undervoltage and overvoltage protections.
18) The 2 x 27.5 kV switchgear should be equipped with an automatic transfer switch unit (automatic loss-of-voltage tripping system).
19) The automatic transfer switch unit should include:
    a) voltage measurement system with adjustable overvoltage and undervoltage stages and time settings,
    b) automation system with a possibility of selecting the backup type,
    c) external signalling system with a possibility of generating alarm states,
    d) internal signalling and automatic supervision system with a possibility of monitoring switch states and internal damage to the controller,
    e) event recording system,
    f) remote and local control and signalling system.
20) Activation of short-circuit and overcurrent protections in feeder bays, incoming transformer bays, bus coupler bays and activation of some protections in the auxiliary bays should interlock the automatic loss-of-voltage tripping.
21) The automatic loss-of-voltage tripping should enable remote and local interlocking and unlocking as well as should have the possibility of local (manual) shutdown.
22) It is recommended that the 2 x 27.5 kV switchgear, with air insulation, be equipped with arc protection, operating with light and voltage criteria.
23) Arc protection should activate tripping of feeder bay circuit breakers and bus coupler bays.
24) Arc protection devices should detect an arc fault within less than 10 ms and switch it off within up to 50 ms.
25) A typical protection system of the overhead catenary system should have the following protections:
    a) three-stage (I, II, III) distance protection,
    b) delayed and instantaneous overcurrent protection,
    c) overload protection,
    d) overvoltage and undervoltage protection,
    e) system for detecting the location of fault in the overhead catenary system,
    f) system preventing mistaken activation of the circuit breaker.
26) Distance protections mentioned in point 25 should be able to ensure remote control of the setpoint to adjust the changes necessary in the case of isolating the substation (track) from the system to be maintained or due to a malfunction.
27) The selectivity of protections in the 2 x 25 kV power supply system should be maintained in such a manner that during a failure only the section of the network where the failure has occurred is switched off.

3.3.3.5. Protection of autotransformers

1) Oil-immersed autotransformers should be equipped with the following protection systems:
    a) differential protection against internal short-circuits in the autotransformer resulting in tripping,
    b) delayed overcurrent protection against external short-circuits resulting in tripping,
    c) autotransformer factory protection (Buchholz relay),
    d) overload protection resulting in signalling.

3.3.3.6. Protections of 25 kV bays of capacitor banks

1) The MV bays of the capacitor banks should have the following protections:
   a) overcurrent protection against external short-circuits resulting in tripping of the bank,
   b) protection against internal short-circuit resulting in tripping of the bank.

3.4. 2 x 25 kV AC overhead catenary system

3.4.1. **Contact line parameters**

3.4.1.1. **General recommendations**

1) On railway lines, when designing supporting structures, the infrastructure gauge determined on the basis of the kinematic outline given in EN 15273-2:2013 (first column of Annex A.3.12) [14], as described in the TSI "Rolling stock" – locomotives and passenger rolling stock subsystem of the rail system in the European Union" – Commission Regulation (EU) No 1302/2014 [15] and/or the kinematic parameters and structure gauge GC should be taken into account.
2) In all cases, deflection of supporting structures should be taken into account at the highest characteristic load also with wind load.
3) The provisions on the distance of the supporting structures from the centre line of the nearest track should also apply to the outages of these structures and to all auxiliary structures and accessories mounted on the supporting structures.
4) The performance parameters to be met by contact lines are as follows:
   a) maximum line speed,
   b) minimum succession of trains,
   c) train power consumption at the collection point,
   d) maximum current consumed by a train,
   e) average effective voltage,
   f) timetable and scheduled maintenance.
5) When calculating the overhead catenary system, the maximum driving speed should be assumed as follows:
   a) 350 km/h for P1, M1 railway lines,
   b) 250 km/h for P2, M2 railway lines,
   c) 200 km/h for the P3, P4, M3 railway line.
6) For the purpose of calculations, the design curve radius included in Volume I.1 Railway track – Layout geometry should be assumed.
7) The calculations should take into account the minimum permissible horizontal curve radius of the track equal to 600 m for railway lines from P1 to P4 and M1 to M3 and the maximum permissible horizontal curve radius of 20,000 m.
8) The following characteristic temperatures should be adopted during calculations:
   a) minimum temperature: -30°C,
   b) rime ice temperature: -30°C,
   c) normal temperature: +10°C,
   d) temperature at wind: +10°C,
   e) maximum temperature: +40°C,
   f) the following operating stress values should be used:
      – for contact wires at least 200 MPa,
      – for messenger wires 150 MPa.
9) Detailed requirements concerning exposures for networks and systems not related to railway traffic are provided in Volume X Conflicts with external networks.

10) An example of overhead catenary system impedance5 is:
    a) for the type Re250 overhead catenary system (contact wire AC-120 – CuAg, messenger wire - BzII 70 mm^2, rails UIC 60, feeder cable 243-AL1, return-earthing cable 243-AL1) - 0.079 + j0.227 = 0.247 ∠ 71° Ω/km for a single-track line, 0.044 + j0.138 = 0.145 ∠ 72° Ω/km for a double-track line,
    b) for the type Re330 overhead catenary system (contact wire AC-120 – CuMg, messenger wire - BzII 120 mm ^{2}, rails UIC 60, feeder cable 243-AL1, return-earthing cable 243-AL1) - 0.077 + + j0.223 = 0.236 ∠ 71° Ω/km for a single-track line, 0.043 + j0.136 = 0.143 ∠72° Ω/km for a double-track line.
11) The 25 kV power cable lines used for traction power supply should be routed along the railway line along the area at the disposal of the railway infrastructure manager, in the space between the acoustic baffle and the fencing at a distance of at least 1.5 m from the acoustic baffle foundations.
12) The location of individual cable lines, including also 25 kV and 15 kV cables, is specified in Volume IV Non-OCL power engineering solutions.
13) The minimum depth of laying 25 kV cables outside the stations should be 0.8 m and 1.2 m within the station, measured as the distance between the ground level and the coating of the upper outer edge of the casing pipe.
14) At crossings or exposures of the constructed 25 kV cable lines with other structures or on-site obstacles, the cables should be laid in casing pipes. If cables are laid in casing pipes, double-walled DVK 160/red corrugated pipes intended for open excavations should be used.
15) Cables on poles should be laid in rigid casing pipes resistant to UV radiation.
16) The cable laying method should be compliant with the N-SEP-004.
17) In the case of crossings with tracks, the following distance should be maintained, resulting from the structure gauge below the rail head of the railway line:
    a) at least 1.5 m from the upper crown of the rail,
    b) at least 0.5 m from the bottom of the drainage ditch,
    c) at least 0.8 m from the bottom pipe of the technical duct and the bottom of the cable duct used for routing low voltage power cables and communication cables.
18) Cables laid under the tracks should be placed in rigid casing pipes.
19) The cable must not be located in the outline of the structure gauge below the rail head (description in Volume I.4 Railway track – Gauge), i.e. at a distance of less than 2.2 m from the track centre line and at a depth of less than 1.5 m from the rail head.
20) Design and construction of 25 kV cable lines should be carried out on the basis of technical solutions and materials commonly used in power engineering, having relevant certificates and technical approvals, approved for use in the construction industry.
21) Cables should be marked during laying. The following information should be placed by the contractor on the outer coating of the protective pipe or directly on the cable at intervals not exceeding 1 m:
    a) cable type,
    b) rated voltage,
    c) designation of the line owner (CPK Sp. z o.o.),
    d) linear length cable marker,
    e) power supply location.
22) The cable route should be marked.
23) The 25 kV power cable lines used for traction power supply, routed in accordance with the guidelines specified above, eliminate the hazards resulting from the adverse impact of electromagnetic fields on telecommunication and communication cables.
24) For a justified deviation from cable routing specified in point 3.4.1.1, the following rules should be observed:

[5] The provided literature examples from Table 5.9 were sourced from the monograph by *F. Kiessling., R. Puschmann, A. Schmieder, and E. Schneider. 2018. Contact Lines for Electric Railways: Planning, Design, Implementation, Maintenance, 3rd Edition. Wiley.*

a) the 25 kV cable power lines used to supply traction equipment must not, at any point, be in contact with low voltage power lines and communication lines,
b) at exposure locations, communication cables should be placed in a two-section metal-earthed casing pipe, with at least 1 m of distance to be maintained,
c) maximum length of exposure must not exceed 10 m,
d) at the crossings of 25 kV power lines with communication cables, communication cables should be placed in a two-section metal-earthed casing pipe, with at least 0.5 m distance to be maintained,
e) any exposure and crossing not adhering the specified distances requires an analysis of the electromagnetic impact on communication cables.

3.4.1.2. Mechanical wave propagation velocity

1) The mechanical wave propagation velocity should be selected so that the maximum travel speed on a given line does not exceed 70% of the wave propagation velocity.

3.4.1.3. Contact line geometry

1) For the 2 x 25 kV power supply system, the overhead catenary system should be designed for a pantograph with a head length of 1600 mm.
2) In accordance with the requirements of point 4.2.9.1 of the TSI “Energy” [3] and point 5.1 of PN-EN 50367:2012 [16], the rated height of the contact line for driving speeds exceeding 250 km/h should be between 5080 and 5300 mm.
3) If, due to local conditions, e.g. bridges, it is necessary to change the contact wire height, the design values of the gradient and change of the gradient should not exceed the values specified in point 5.10.2 of PN-EN 50119:2009 [17].
4) Contact wire stagger should amount to:
   a) along a straight line ± 200 mm,
   b) on bends with a radius of R < 4000 m, the contact wire should be routed in the middle of the span tangentially to the track centre line, the stagger should be increased in the suspension area, and should not exceed 360 mm.
5) Basically, the full contact wire stagger cycle should be completed within two directly following spans, the stagger between the messenger wire and the contact wire should be the same and in the same direction.
6) The maximum lateral deviation of the contact wire relative to the track centre line in crosswind is 400 mm for a 1600 mm long pantograph and 550 mm for a 1950 mm long pantograph. The values should be adjusted taking into account the movement of the pantograph and track tolerances according to Appendix D.1.4 of TSI “Energy”.
7) Wind loads should be calculated in accordance with the requirements specified in point 4.3 of PN-E-50341-2-22:2016 [18] for the height < 300 m. The resistance factor of the overhead catenary system should be calculated according to the rules given in point 6.2.4 of EN 50119:2009 [17], taking into account the impact of hangers and hanger brackets.
8) The largest span on a straight line is determined from the wind-out condition. The maximum deviation of the contact wire from the track centre line given in the TSI “Energy” [3] – point 4.2.9.2 should not be exceeded as long as the proper dynamic joint operation of the contact line with current collectors is ensured.

3.4.1.4. Distance of the contact line from earthed structures

1) In the most unfavourable design atmospheric and dynamic conditions, the distance between the components of a contact line or a live current collector and earthed structures should amount to at least 150 mm, unless otherwise specified below.
2) The distance of the overhead catenary system or its live parts from parts of the visual signalling equipment and from parts of the external lighting equipment supplied by a cable should be at least:
   a) 1500 mm from the semaphore signal and from the edge of the luminaire. With reference to lighting equipment, this distance should be measured in the horizontal plane,

b) 1500 mm from the edge of the light signal luminaire and other visual signalling elements.

3) These distances should be maintained in all operating positions of the elements of signalling devices and external lighting at the most unfavourable design weather conditions.
4) The distances between the contact line or its live parts and the areas intended for human presence are specified in PN-EN 50122-1:2011 [9] – point 5.1.2.
5) The distances referred to in point 3.4.1.5 4) may be reduced provided that barriers meeting the requirements specified in PN-EN 50122-1:2011 [9] – point 5.1.3. are used.

3.4.1.5. **Pantograph static contact force**

1) For 25 kV systems, the static contact force is defined in point 7.2 of EN 50367 [16] and is exerted by the pantograph on the contact wire. The overhead catenary system should be designed for a static contact force of 60 to 90 N in accordance with point 7.2 of PN-EN 50367:2012 [16].

3.4.1.6. **Wires and contact line component materials**

1) The overhead catenary system should be constructed in accordance with the requirements specified in point 4.2 of the TSI “Energy” [3] and points 5 and 6 of PN-EN 50119:2009 [17] – points: 5 and 6 and UIC 799-1 [19]
2) It is recommended to use compensated simple catenary equipment consisting of one messenger wire and one contact wire.
3) It is recommended to use the following structural heights:
   a) 1.80 to 1.6 m for networks of open lines and main straight tracks of stations,
   b) 1.30 m for station siding track networks.
4) For the (upper) overhead catenary system of the 25 kV power supply system in the pantograph area, in accordance with point 4.2.10 of the TSI “Energy”[3], no part of the energy sub-system should enter the mechanical kinematic pantograph gauge (GC) except for the contact wire and steady arm. A description of the procedure for calculating the mechanical gauge is given in Appendix D to the TSI “Energy”. The pantograph gauge is maintained if the mechanical and electrical gauge is maintained at the same time.
5) For the 2 x 25 kV power supply system, the minimum insulation clearances should be used between the overhead catenary system components energised at 25 kV and the earthed components in accordance with point 5.1.3 of PN-EN 50119:2009 [17], amounting to 270 mm in static conditions and 150 mm in dynamic conditions.
6) For the 2 x 25 kV power supply system, the minimum insulation clearances should be used between the overhead catenary system components energised at 25 kV with different phases (phase-to-phase voltage) in accordance with point 5.1.4 of PN-EN 50119:2009 [17], amounting to 540 mm in static conditions and 300 mm in dynamic conditions.
7) The contact wire should meet the requirements of PN-EN 50149:2012 [20] – tables 1, 3, 4 and 5. Materials approved for use in contact wires are copper and copper alloys. It is recommended to use materials marked in the above-mentioned standard with the following symbols: Cu-ETP CuAg0,10, CuMg0,2; CuMg0,5; CuMg0,7.
8) The recommended contact wire cross-section should be 120 mm^2 to 150 mm^2.
9) For travel speeds of 250 km/h and above, it is not allowed to profile the height of the contact wire. For lower speeds, the permissible inclination values of the contact wire are specified in PN-EN 50119:2009 [17] – point 5.10.3.
10) Stresses in the maximum wire wear condition must not exceed the permissible values in accordance with PN-EN 50119:2009 [17] – point 5.3.1. Calculations should be made assuming the maximum local wear of the contact wire of 30%.
11) The messenger wire should be made of copper or a copper alloy with a cross-section of 50 mm^2 or 70 mm^2 and meet the requirements of PN-E-90081:1974 [21].
12) Recommended contact wire cross-section – from 70 mm^2 to 150 mm^2.

13) Permanent forces should be taken into account, i.e. weight of the wire and accessories of the contact line, tension of the wires.
14) Momentary loads should also be taken into account, i.e. weight of rime ice, wind pressure, current collector contact force, loads during line installation, loads during the breaking of wires.
15) The rime ice loads of the contact line wires should be determined in accordance with point 4.5 of PN-E-50341-2-22:2016 [18].
16) Failure to take into account catastrophic rime ice. The weight of rime ice on hangers and overhead contact line accessories should not be taken into account.
17) In overhead contract lines of the 2 x 25 kV power supply system, smooth-surface supporting structures made of steel or pre-tensioned concrete should be used.
18) Steel supporting structures should be hot dip galvanised in accordance with the requirements of PN-93/E-04500 [22], and then painted twice with paints of the type determined by the overhead contract line administrator. The thickness of the zinc coating should be at least 60 µm.
19) It is recommended to build foundations using the piling technique. Pile foundations should be constructed as follows:
    a) they should be driven with a suitable pile driver, which will allow them to be sunk to the planned depth without damage,
    b) when striking the top of the pile head with the hammer, it shall be ensured that the hammer and pile are concentric and that the impact is perpendicular to the top of the head,
    c) the impact velocity should be adjusted to the pile type and soil conditions.
20) It is allowed to build foundations as block and cast foundations. Foundation heads should be made of concrete of a class not lower than B-30.
21) The head of the prefabricated concrete pile foundation, which is hit during driving, should be protected with a washer ensuring reduction and uniform distribution of stresses on the top of the pile head.
22) The minimum electrical clearances between the working parts of the contact line of the 2 x 25 kV AC system connected to different phases should be compliant with PN-EN 50119:2009 [17].
23) The load-carrying and conductive accessories (connectors, holders, etc.) should be made of copper alloys using forging technology.
24) The safety factor for slipping and tearing for heavy-tensile accessories should be 1.54.
25) Requirements for supporting structures:
    a) when constructing the overhead catenary system, the primary solution is to use individual supporting structures of the contact line in the form of individual galvanised, painted, smooth-surface steel poles fastened to pile foundations with bolts. Supporting structures of a different design are allowed,
    b) in special cases, it is allowed to use cast foundations for prefabricated moulds sunk in the ground.
    c) it is allowed to use portal structures, especially at stations. The recommended structure consists of one-span portals with a span of up to 34.5 m,
    d) static calculations and designing of steel supporting structures should be performed on the basis of ZN-87/MTŻiŁ-CBP-11 and PN-B-03200 standards,
    e) static calculations and designing of reinforced concrete supporting structures should be performed on the basis of PN-B-03264:2002 and ZN-89/MŻiŁ-CBP-10 standards,
    f) when designing the height of the supporting structures, it is necessary to take into account the need to attach a group earth wire, return wire or positive feeder to them for the 2 x 25 kV power supply system,
    g) supporting structures should not be isolated from pile foundations or cast foundations. This also applies to the stays of supporting structures.
    h) the structures of the contract line of each track of a double-track route should be arranged symmetrically, opposite each other,
    i) the supporting structures of the contact line should be spaced so as to maintain the visibility of light signals.
26) Contact wire connectors should be selected taking into account the following requirements:

a) in new contact lines of open lines and main straight tracks of stations, it is not allowed to use contact wire connectors,
b) the overhead lines of positive feeders should be calculated in accordance with PN-E-50341-2-22:2016 [18]. Stresses in wires must not exceed the permissible normal stresses,
c) the cross-section of electrical connection cables of contract lines should be at least 50% of the larger of the total cross-sections (messenger wire and contact wire) of the connected contact lines,
d) earthing wires, return wires and wires of positive feeders should be fastened in the centre line on the pole top or on the opposite side of the pole in relation to the track centre line,
e) when the wire of the positive feeder crosses the messenger wire, a minimum clearance of 150 mm should be maintained under the least favourable conditions,
f) earthing wires, return wires and the wires of positive feeders should not be routed above platforms. If necessary, it is required to follow the provisions of point 3.6 of Volume X Conflicts with external networks.

27) The requirements for hangers are as follows:
a) the design should ensure permanent (non-sliding) location of the hanger in the place of installation on the messenger wire, auxiliary wire or contact wire,
b) the design of hangers should ensure conductivity. Depending on the type of line, hangers should be made of 25 mm^2 copper wire (Cu) or 10-16 mm^2 alloyed copper wire (BzII) using a contact wire with a 120 mm^2 cross-section,
c) the length of a single hanger should not be smaller than 250 mm,
d) crossings and exposure sections of contact lines with other electrical networks.

3.4.2. **Isolation of the contact line**

1) Requirements concerning numbering methods for sections, disconnector switches and power interruptors are included in point 3.4.2 of Volume II.2.

3.4.2.1. **Phase separation section**

1) Considering that traction substation transformers are connected to two HV network phases, the power sections on the left and right side of the traction substation have different phase angles and therefore must be separated by phase separation sections.
2) Phase separation sections should be designed in accordance with the requirements of point 4.2.15 the TSI “Energy” [3] in such a manner so as to ensure that trains can move from one section to an adjacent one without bridging the two phases.
3) Adequate means should be provided to allow a train that is stopped within the phase separation section to be restarted.
4) The length of the neutral sections should be selected in accordance with the rules of EN 50367:2012 [16], with the gauges in accordance with point 5 of EN 50119:2009 [17] and uplift S_0.
5) For railway lines, a long phase separation section is preferred (the length of the neutral section is at least 402 m), where all pantographs of the longest trains compliant with the TSI are within the neutral section. Requirements for such phase separation section are specified in the TSI “Energy” and in point A.1.2 of EN 50367:2012 [16]. In justified cases, it is allowed to use other phase separation section solutions as provided for in the TSI “Energy” and in EN 50367:2012.
6) The position of the stop indicator in relation to the position of the neutral section should be designed taking into account the line profile, the maximum speed, the train parameters – power, mass, acceleration, movement resistances.
7) The distance of semaphores from the phase separation section is subject to an interdisciplinary agreement, taking into account the parameters of the railway line and rolling stock at the design stage.

3.4.2.2. System separation section

1) The design of the system separation sections must comply with the requirements specified in point 4.2.16 of the TSI “Energy” [3] and should allow trains to move in one of the two methods:
   a) with pantograph raised and touching the contact wire,
   b) with pantograph lowered and not touching the contact wire.
2) The infrastructure managers of adjacent systems should agree on the method of trains traversing system separation sections.
3) The length of the neutral sections should be selected in accordance with the rules of EN 50367:2012 [16], with the gauges in accordance with point 5 of EN 50119:2009 [17] and uplift S_0.
4) If the method with raised pantographs has been selected, the following conditions must be met:
   a) the geometry of different elements of the overhead catenary system should prevent pantographs short-circuiting or bridging both power systems,
   b) provision should be made in the energy subsystem to avoid bridging of both adjacent power supply systems should the opening of the on-board circuit breaker(s) fail,
   c) variation in contact wire height along the entire separation section should fulfil requirements set in 5.10.3 of EN 50119:2009 [17].
5) The method of train traversing a system separation section with lowered pantographs should be used if the conditions of operation with pantographs raised cannot be met.
6) If the method of train passage with lowered pantographs has been selected, the separation section of the power supply systems should be designed so as to avoid the electrical connection of the two power supply systems by an unintentionally raised pantograph.
7) At the beginning and at the end of the system separation section, information signs should be established informing about the change of the power supply system (entry to the 25 kV AC zone and exit from the 25 kV AC power supply zone). Detailed conditions are specified in Volume VI.1 Control command and signalling – basic equipment.
8) The distance of semaphores from the system separation section is subject to an interdisciplinary agreement, taking into account the parameters of the railway line and rolling stock at the design stage.
9) The change of pantograph when traversing a system separation section should take place on the 3 kV DC side in accordance with the operation manuals.

3.4.2.3. Isolation at stations, junction signal boxes and tension section

1) The maximum length of the tension section should not exceed 1260 m.
2) For tension sections of a contact line tensioned on both sides, line middle anchorages should be used. The maximum length of a contact line section between the balance weight termination and middle anchorage is 630 m.
3) The lengths of contact line tension sections should be determined so that the overlap spans located near the entry and exit semaphore of a station ensure maximum visibility of these semaphores.
4) The lengths of contact line tension sections should be determined so that the location of the overlap span is possible at a distance of not less than 10 m before a passenger stop platform in accordance with the relevant direction of travel.
5) Requirements for the method of isolating an overhead catenary system at stations and junction signal boxes, etc., are included in point 3.4.2 of Volume II.2.

3.4.3. Contact line crossings

1) The overhead crossing design should ensure passage on the main (straight) track at the maximum speed for a given contact line type. When driving on turnout tracks, the speeds depend on the type of track turnout used, characterised by two parameters: crossing angle and curve radius.
2) For a driving speed exceeding 160 km/h, overhead crossings installed in open lines and main straight tracks of stations should be constructed as a spatial arrangement of messenger wires and

contact wires without mechanical connections between both lines of the contact line. These structures should ensure smooth passage of the pantograph head in all directions for which driving is planned.

3) For a travel speed of 160 km/h and less, the crossings should be designed with a crossing of contact wires and should ensure smooth passage of the current collector head in all directions for which a crossing passage is planned.

3.4.4. **Return circuit**

1) Admissible RMS values of touch voltage are specified in point 4.2.2 of PN-EN 50122-1:2011 [9].
2) The return circuit is a network of electric shock protection connections and is a source of earth return currents.
3) The running rails together with the earthing wire or return-earthing wire, intentionally earthed, constitute the traction system earth in accordance with the provisions of PN-EN 50122-1:2011 [9] – point 3.5.3.
4) All direct connections to running rails should be made up within one rail. As long as made possible by the devices used in Control Command and Signalling, it is recommended to connect up to two rail sections.
5) Locations of earthing connections and impedances of earth electrodes, earth conductors or earth and return conductors (traction system earth) should be determined on the basis of an analysis of touch and exposed voltages available in accordance with EN 50122-1:2011 [9].
6) The purpose of the earthing wire is to equalise the potential of the supporting structures and other conductive parts located in the impact zone of the contact line and current collectors. The earth conductor cross section should not be less than 120 mm² AFL. The earth conductor is rigidly fixed to the supporting structures.
7) The purpose of the earth and return conductor is to equalise the potential of the supporting structures and other conductive metallic parts located in the impact zone of the contact line and current collectors, as well as to conduct the working return current along the path to the traction substation or the nearest autotransformer (in the 2 x 25 kV system). The cross section of the earth and return conductor should range from 240 mm² to 400 mm² AFL. The earth and return conductor is fixed to metal supporting structures and must be suspended in a rigid manner using an electrically conductive terminal. The connection to rails should be made every 250 to 300 m. The distance between the connections should ensure the values of the effective touch voltages below the permissible values.
8) Making direct transverse interconnections of earthing conductors or earthing and return conductors of the return circuit and their direct connection to rail sections is allowed only in cases where the operating conditions of the control command and signalling system circuits allow it.
9) The design of the overhead catenary system should include, in addition to a diagram of the contact line, also an electrical return circuit diagram.
10) The following electrical connections are present in the return circuit:
    a) longitudinal busbar couplers,
    b) transverse inter-rail busbar couplers,
    c) transverse inter-track busbar couplers,
    d) lateral equipotential bonding between the return or earthing conductors of each of the tracks,
    e) bypass connections,
    f) rail connections to return wires or return rails and earthing wires,
    g) rail connections to exposed conductive parts (connections to the rail – earthing),
    h) connections of rails or earthing wires to earth electrodes,
    i) autotransformer connections,
    j) return cable connections.
11) Return line conductors and electrical connections conducting operating currents in normal operating conditions should have cross-sections suitable for the maximum equivalent 30-minute operating

current flow. The cross-section of the return cables should include a reserve. Moreover, the thermal strength of these conductors and earth conductors should be checked for loads with maximum short-circuit currents.

12) lateral equipotential bonding and bypass connections should be made by means of connectors with a cross-section of at least 50 mm² Cu or equivalent.
13) The equipotential bonding between the tracks and the equipotential bonding between the earth and return wires on the double track lines should be installed as cable connections so as to avoid routing the wires above the contact line.
14) The resistance values and the location of the return circuit earthing electrodes should be coordinated with the earthing-conductor voltage values. Direct connections of earth electrodes with the return circuit should be made to one rail section.

3.4.5. Electric shock protection and safety

3.4.5.1. General recommendations

1) Meeting the requirements of electric shock protection is superior to other technical and environmental requirements. For the application of safety measures and electric shock protection against contact, the requirements of the following standards should apply: PN-EN 50122-1 [9], PN-EN 50119 [17].
2) Electric shock protection in the 25 kV AC traction power supply system against contact should include one integrated system of direct earthing of running rails constituting the “traction system earth”, in accordance with the provision of point 3.5.3 of PN-EN 50122-1 [9].
3) Items and components with longitudinal dimensions (measured along the track) not exceeding 2 m and not equipped with any electrical systems present in the impact zone of the upper contact line do not need to be earthed – in accordance with the requirements of PN-EN 50122-1 [9].
4) In the 25 kV AC system, the return circuit of the overhead catenary system should be connected directly to the earthing system of the traction substation.
5) In the case of the 25 kV AC electric traction system, the continuous permissible voltage value is 60 V (limited to 25 V on the premises of halls, workshops, etc.). At the same time, it is the permissible value of the exposed voltage.
6) If the response time of protections and short-circuit current tripping allows adoption of a higher value of the permissible touch voltage, the voltage level of the voltage limiter may be increased in accordance with the recommendations of PN-EN 50122-1[9] – point 7. The above should be taken into account when designing earth electrodes and the location of their connection points to the earth conductor or the earth and return conductor, as well as connections to running rails.
7) All exposed conductive parts located in the impact zone of the overhead catenary system and current collectors should be connected directly to the traction system earth in accordance with the requirement of PN-EN 50122-1 [9] – point 5.2. Connections should be made to one rail section.
8) The basic means of protection against indirect contact in the return circuit is to earth the conductive parts located in the impact zone of the overhead catenary system and current collectors.
9) The traction system earth is a directly or indirectly earthed circuit of running rails, in accordance with the requirements of PN-EN 50122-1:2011 [9].
10) A direct connection to the traction system earth is established between all conductive parts in the impact zone of the overhead catenary system and current collectors under normal voltage-free operating conditions. Connections to the traction system earth provide protective earthing and form part of the current circuit for short-circuit currents.
11) It is permissible to connect grouped or individual connections of conductive parts and supporting structures with an earth conductor or an earthing and protective conductor with running rails directly or indirectly.
12) In exposed places, basic protection measures against direct touch should be applied to live wires of the overhead catenary system under normal operating conditions in accordance with the requirements of the standards indicated in point 3.2.5.1.

13) Each switch-off of the supply voltage to the overhead catenary system in the traction substation of the 2 x 25 kV system, regardless of the reason, should take place simultaneously through the circuit breaker of the network power supply unit and the circuit breaker of the positive feeder.
14) In exposed places (footbridges above tracks, overpasses, bridges, tunnels, shelters, etc.), basic protection measures should be applied against direct contact with the upper portion of live parts of the contact line under normal operating conditions. The basic protection measures include: insulating shields, screens, insulating inserts, partitions – in accordance with the recommendations of the PN-EN 50122-1:2011 [9] – point 5.
15) The standard mentioned above contains requirements and recommendations concerning:
    a) areas to be occupied by passengers,
    b) areas to be occupied by persons performing works,
    c) minimum contact wire height at crossings,
    d) height of the power supply cable suspension above the loading routes,
    e) distance between the upper contact line and trees,
    f) use of barriers,
    g) means of protection against climbing the structures in the vicinity of the overhead catenary system,
    h) warning signs,
    i) minimum insulation clearances.
16) In emergency conditions, the potential of the busbar against ground determines the value of touch voltages or voltages available in operating conditions. PN-EN 50122-1:2011 [9] specifies the admissible values of touch and available voltages and their durations.
17) The value of the design rail potential (PN-EN 50122-1:2011 [9] – Annex C) should be determined for the maximum values of the operating current and short-circuit current flowing in the running rail (taking into account the initial value of short-circuit current). If the design values of touch or available voltages exceed the permissible values (taking into account their duration), the measures recommended in PN-EN 50122-1:2011 [9] should be applied.
18) Additional protection measures and requirements for power supply systems, telecommunication systems and other LV systems are specified in PN-EN 50122-1:2011 [9] – point 7.
19) The positive feeder cable of overhead catenary systems should be routed in accordance with the requirements of PN-EN-50341-2-22:2016 [18].
20) Every fifth traction pole should be equipped with a point of connection of the traction earthing device. It should be marked appropriately from the side of the tracks.

3.4.5.2. Guards

1) Bridges, flyovers, pedestrian overpasses and, if necessary, other structures under which the contact line runs should be equipped with vertical guards protecting people that may be present on these structures against accidental touching of live parts of the contact line and the contact line against damage as a result of accidental touching or falling of objects onto the contact line.
2) All planes (e.g. platforms) for an unrestricted stay of persons located above the contact line (road overpasses and pedestrian overpasses, etc.) should be equipped with vertical or horizontal guards (protective nets) compliant with the requirements of PN-EN 50122-1:2011/A1:2011/A2:2016-06 – point 5.3.2 and Annex A, fig. A.2. They should be installed above each electrified track on both sides of the structure, symmetrically in the track centre line. The width of the guards must be not smaller than the width of the pantograph zone adopted in TCS (3400 mm), including the angle of the crossing of the track axis and the edge of the engineering structure. This condition applies to structures that are new and already used regardless of the owner.

3.4.5.3. Lightning protection of the contact line

1) The contact line should be protected against the effects of lightning surges by means of horn, valve or semiconductor lightning arresters.
2) When determining the arrangement of lightning surge protections along the contact line, apart from the specified zone of operation, areas with increased storm activity should be taken into account. It

is recommended to install two protections on one section of the contact line tension in normal conditions.

3.4.6. Protective measures against the impact of earth return currents

1) The 2 x 25 kV electrical traction system uses passive protection measures against the impact of earth-return currents. They are included in the provision of appropriate technical solutions are applied at the design stage.
2) The use of a 2 x 25 kV system with autotransformers limits the current flow in the rails to the section between two adjacent autotransformers or to the section between the traction substation and the nearest autotransformer.
3) It is required to connect all supporting structures of the overhead catenary system and positive feeders to the earth and return conductor or the earth conductor.

3.4.7. Pantograph spacing

1) In accordance with the requirements of point 4.2.13 of the TSI “Energy” [3], the pantograph spacing should be assessed on the basis of the contact wire uplift affected by at least two pantographs located at a distance specified in Table 4.2.13 of the TSI “Energy” [3]. Pantographs should be certified to comply with the “Rolling stock and passenger rolling stock” TSI in the trans-European conventional rail system 1302/2014 [15].
2) For the AC power supply system and the driving speed:
   a) up to 80 km/h inclusive, for subsequent types of lines of types A, B, C, the distance between pantographs is 8 m, 8 m, 8 m respectively,
   b) from 80 to 120 km/h inclusive, for subsequent types of lines of types A, B, C, the distance between pantographs is 20 m, 15 m, 15 m respectively,
   c) from 120 to 160 km/h inclusive, for subsequent types of lines of types A, B, C, the distance between pantographs is 85 m, 85 m, 35 m respectively,
   d) 160 to 250 inclusive for subsequent types of lines of types A, B, C, the distance between pantographs is 200 m, 85 m, 35 m respectively,
   e) over 250 km/h, for subsequent types of lines of types A, B, C, the distance between pantographs is 200 m, (...) respectively.
3) Contact wire suspension height according to point 4.2.9 of the TSI “Energy” [3] for speeds:
   a) equal to or higher than 250 km/h – should be between 5080 mm and 5300 mm,
   b) lower than 250 km/h should be between 5,000 mm and 5,700 mm,
   c) for speeds of 250 km/h and higher, it is not allowed to profile the level of the contact wire,
   d) as specified in point 7.2.3. of the TSI “Energy” [3], new lines adapted to speeds greater than 250 km/h should accommodate a pantograph with a head length of 1600 mm and 1950 mm,
   e) permissible changes in the contact wire profiling within the speed range of up to 250 km/h are specified in point 5.10.3. of PN-EN 50119 [17].
4) The maximum lateral deviation of the wire under action of crosswind, calculated from the track centre line, for a pantograph with a head length of 1600 mm should be in accordance with the values given in table 4.2.9.2. TSI “Energy” [3].
5) The new structures of the upper contact line should be assessed by simulation carried out in accordance with the provisions of PN-EN 50318 [23] and by measuring the test section of the new structure in accordance with PN-EN 50317 [24].

3.4.8. Overlap span design

1) Two types of overlap spans should be developed in new contact lines:
   a) isolated, with an electrical connection through a sectional power interruptor,
   b) short-circuited, with a direct electrical connection.
2) A common railtrack in the network of open lines and main straight tracks of stations should be created in a dynamic arrangement under the influence of the current collector contact force specified for the maximum driving speed.

3) In point 6.1.4.1 of the TSI “Energy” [3], for the assessment of dynamic behaviour and quality of current collection it is required to perform a simulation for the contact line. For simulation purposes, two sections should be tensioned with a common overlap span in the centre. The simulation method should be verified in accordance with the recommendations of PN-EN 50318 [23].
4) Three-span four-pole overlap spans should be used. Electrical connections in overlap spans should be located outside the area of joint operation with the current collector, in the zone between the cross suspension and the network anchoring; the railtrack should be calculated in dynamic conditions.
5) In the insulated overlap span, when calculating the maximum span, the following should be assumed:
   a) the horizontal distance between the conductors of different tension sections routed in parallel (measured between the centre lines of the nearest conductors) should be at least:
   – in the case of spans constituting an element of the electrical division of circuits with a phase difference of 0 : 270 mm in a static state, 150 mm in dynamic states (including wind pressure forces and impact of current collectors),
   – in the case of spans constituting an element of the electrical division of circuits between which a phase difference of 120° may occur: 400 mm in a static state, 230 mm in dynamic states (including wind pressure forces and impact of current collectors),
   – in the case of spans constituting an element of the electrical division of circuits between which a phase difference of 180 ° may occur: 540 mm in a static state, 300 mm in dynamic states (including wind pressure forces and impact of current collectors),
   b) the vertical distance between the conductors of different tension sections routed in parallel should, at the point of their crossing, meet the conditions specified in sub-point b) and, in the case of conductors from which the conductors crossing on top are in an insulating sheath – at least 150 mm (the distance is measured between the axes of the nearest conductors);
   c) the distance between the components of the network accessories of different tension sections (of a given circuit) belonging to different electrical circuits should meet the conditions specified in sub-point b).
6) Along the entire length of the tension section, the greatest deviation of the moving part of the cantilever from the plane passing through the centre line of the supporting structure and perpendicular to the centre line of the track should not exceed 12º within the entire design temperature variability range.
7) It is not planned to use lateral suspensions for the contact lines intended for operation with a maximum train speed of 250 km/h and above.
8) Electrical and mechanical properties of positive feeder cables for the 2 x 25 kV power supply system should meet the requirements of PN-IEC 1089:1994 [25] and PN-E-90081:1974 [21].

3.4.9. Interaction of the overhead catenary system with the pantograph

3.4.9.1. Mean contact force

1) In order to ensure proper quality of current collection without undue arcing and to reduce wear and hazards to contact strips, the mean contact force F_m exerted by the pantograph on the contact wire in a function of the train driving speed should comply with the relationship described in EN 50367 [16]:

2) The maximum force (F_{max}) on the track should be within the range of F_m plus three standard deviations σ. In other places, higher values may occur. Upper values F_{max} presented in point 5.2.5. of EN 50119:2009 [17]

3) For railway lines, the conformity assessment should be carried out in accordance with the provisions of point 6 of PN- EN 50317 [26].

3.4.9.2. Dynamic characteristics and quality of current collection

1) Definitions, values and test methods or simulations are given in PN-EN 50317 [26] and PN-EN 50318 [23].
2) The overhead catenary system must reach the values of the dynamic properties and the contact

wire uplift. The requirements for dynamic behaviour and quality of current collection are presented in Table 4.2.12 of the TSI "Energy" [3]. The uplift space of the steady arm is marked with 2 S_0, and S_0 is the calculated, simulated or measured contact wire uplift at the steady arm under normal operating conditions for one or more pantographs having a maximum force equal to the upper limit of the Fm at the maximum line speed.

3) The values of the average contact force in a function of speed for the AC power supply system are specified in point A4 [16]

4) The overhead catenary system must be designed to withstand the upper threshold limit of the contact force Fm given in Table 6 of [16].

5) The standard deviation at the maximum line speed σ_{max} [N] must not exceed 0.3 F_m, $\sigma_{max} \leq 0.3$ F_{max} .

6) The overhead catenary system must be designed so as to enable interaction of at least two pantographs with the system. The overhead catenary system must be designed so as to enable interaction of at least two pantographs with the system. The spacing between the pantograph head centre lines of pantographs operating adjacently should be in accordance with point 4.2.13 of the TSI "Energy" [3].

7) Contact wire uplift for the designed maximum line speed should be maximum S_o.

8) The geometry and interpretation profiles of 1,600 mm and 1,950 mm current-collector bow are specified in point A.2 of EN 50367:2012 [16]

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4. Reference documents

The following reference documents were used to prepare Volume II.1:

4.1. Legal documents

[1] Dyrektywa Parlamentu Europejskiego i Rady (UE) 2016/797 z dnia 11 maja 2016 r. w sprawie interoperacyjności systemu kolei w Unii Europejskiej (Dz.U.UE L 138/44 z dnia 26.05.2016). 2016.

4.2. Legal documents of the Republic of Poland

[2] Ustawa z dnia 28 marca 2003 r. o transporcie kolejowym. Dz.U.2020. Poz. 1043. 2020.

4.3. Normative documents

[3] COMMISSION REGULATION (EU) No 1301/2014 of 18 November 2014 on the technical specifications for interoperability relating to the ‘energy’ subsystem of the rail system in the Union (TSI Energy). 2014.

[4] PSE. Instrukcja Ruchu i Eksploatacji Sieci Dystrybucyjnej. 2018.

[5] Rozporządzenie Ministra Gospodarki z dnia 4 maja 2007 r. w sprawie szczegółowych warunków funkcjonowania systemu elektroenergetycznego (Dz. U. z 2007 r. Nr 93, poz. 623). 2007.

[6] EN50388:2012 Railway Applications - Power supply and rolling stock - Technical criteria for the coordination between power supply (substation) and rolling stock to achieve interoperability.

[7] EN 50122-3:2010 Railway applications. Fixed installations. Electrical safety, earthing and the return circuit. Mutual Interaction of a.c. and d.c. traction systems. CENELEC, 2010.

[8] EN 50163:2004 Railway applications – Supply voltages of traction systems. CENELEC, 2004.

[9] EN 50122-1 2011 Railway applications - Fixed installations - Electrical safety, earthing and the return circuit - Part 1: Protective provisions against electric shock. CENELEC, 2011.

[10] IEC. IEC 60076-1:2011 Power transformers - Part 1: General: IEC 60076-1:2011. 20.04.2011.

[11] PN-EN 50329:2003/A1:2010 - wersja angielska. Zastosowania kolejowe. Urządzenia stacjonarne. Transformatory trakcyjne. 2010.

[12] IEC. PN-EN 60076-5:2009 - wersja polska. Transformatory -- Część 5: Wytrzymałość zwarciowa: PN-EN 60076-5:2009. 2009.

[13] EN 50633 Railway applications - Fixed installations - Protection principles for AC and DC electric traction systems, 2016.

[14] EN 15273-2:2013+A1:2016 Railway applications. Gauges. Rolling stock gauge: CENELEC,2016.

[15] COMMISSION REGULATION (EU) No 1302/2014 of 18 November 2014 concerning a technical specification for interoperability relating to the ‘rolling stock — locomotives and passenger rolling stock’ subsystem of the rail system in the European Union.

[16] EN 50367:2012 Railway applications - Current collection systems - Technical criteria for the interaction between pantograph and overhead line. CENELEC, 2012.

[17] EN 50119:2009 Railway applications - Fixed installations - Electric traction overhead contact lines. 2009.

[18] PN-EN 50341-2-22 – Elektroenergetyczne linie napowietrzne prądu przemiennego powyżej 1 kV. Część 2-22: Zbiór normatywnych warunków krajowych. Normatywne warunki krajowe Polski: PN-EN 50341-2-22. PKN, 2016.

[19] UIC 799-1 Characteristics of direct-current overhead contact systems for lines worked at speeds of over 160 km/h and up to 250 km/h. 2000.

[20] PN-EN 50149:2012 Zastosowania kolejowe - Urządzenia stacjonarne - Trakcja elektryczna -

Profilowane przewody jezdne z miedzi i jej stopów. Wersja angielska. 2012.

[21] PN-E-90081:1974 Elektroenergetyczne przewody gołe -- Przewody miedziane,1974.

[22] PN-93/E-04500 Elektroenergetyczne stalowe konstrukcje wsporcze. Powłoki ochronne cynkowe zanurzeniowe.

[23] EN 50318. Railway applications. Current collection systems. Validation of simulation of the dynamic interaction between pantograph and overhead contact line. CENELEC, 2018.

[24] PN-EN 50317:2012 Zastosowania kolejowe -- Systemy odbioru prądu - Wymagania dotyczące walidacji wyników pomiarów oddziaływania dynamicznego pomiędzy pantografem a siecią jezdną górną.

[25] PN-IEC 1089:1994 Przewody gołe okrągłe o skręcie regularnym do linii napowietrznych. 1994.

[26] EN50317:2012 Railway applications - Current collection systems - Requirements for and validation of measurements of the dynamic interaction between pantograph and overhead contact line. CENELEC, 2012.

[27] N SEP-E-004:2014. Elektroenergetyczne i sygnalizacyjne linie kablowe. Projektowanie i budowa

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