

TECHNICAL AND ORGANIZATIONAL AND LEGAL CONDITIONS RELATING TO THE POWER SUPPLY OF A RAILWAY VEHICLE EQUIPPED WITH AUTOMATIC TRAIN CONTROL SYSTEM

Marianna Jacyna
Jacek Kukulski, Piotr Gołębiowski

Warsaw University of Technology
Faculty of Transport
Koszykowa Street 75, 00-662 Warsaw, Poland
tel. +48 22 2347311, fax: +48 22 2341579
e-mail: maja@wt.pw.edu.pl, jkukul@wt.pw.edu.pl, pgolebiowski@wt.pw.edu.pl

Sławomir Jasiński, Wawrzyniec Wychowański

Rail-Mil Computers sp. z o.o. sp. k.
Kosmatki Street 82, 03-982 Warsaw, Poland
tel. +48 22 2099450, fax: +48 22 2099455
e-mail: slawomir.jasinski@rail-mil.eu, wawrzyniec.wychowanski@rail-mil.eu

Abstract

Railway transport is considered the most environmentally friendly. However, taking into account all factors, (including point pollution associated with the production of energy necessary for the movement of electric traction vehicles); this position is attractive, but a little less. Therefore, it is necessary to ensure that the amount of energy produced for railway transport is sufficient, but the lowest as possible. Creating new systems whose components for correct operation require a supply of electricity, they should be designed in such a way as to consume as little energy but meeting a series of standards. The aim of the article is to review selected requirements for the power supply of a railway vehicle equipped with automatic train control devices and identification of energy demand in the scope of supplying the rmCBTC on-board system, which is being developed by Rail-Mil Computers Company from Warsaw and the Faculty of Transport of the Warsaw University of Technology. The article presents an analysis of formal and legal requirements in the field of traction vehicles. Reference was made to the list of the Office of Rail Transport and the standards not included in it – PN-EN 50155, PN-EN 61000-6 and PN-EN 50125-2. Energy requirements in the field of traction vehicles equipped with an automatic train control system have been identified – e.g. voltage range of the on-board system, permissible decays, voltage dips, disturbances and environmental requirements. The energy requirements for the rmCBTC on-board system were also identified.

Keywords: *railway transport, automatic train control system, electricity, rmCBTC, power requirements*

1. Introduction

Railway transport is considered as the most environmentally friendly [5], [13]. On the one hand, it should be noted that in the case of this mode of transport [15], pollution of the natural environment is mainly related to the [19], [23], [24] emission of noise, vibrations [52] and pollution [18] from locomotives [14] (diesel and steam) as well as occupancy of the area [27]. On the other hand, it should be taken into account that it is necessary to generate an adequate amount of electricity for electric vehicles [16]. It involves the need to carry out the process of burning fuel at the power plant. As a result of this process, harmful compounds are released, which negatively influence [20] the condition of the environment near the place of production. Therefore, it is necessary to ensure that the amount of energy [43] produced for railway transport is sufficient, but the lowest as possible [7], [44].

Electric energy for the needs of railway transport [48], in particular for traction purposes, is produced in the power plant by a generator. Then [21], [22] this energy is transferred through high voltage power lines to the electromagnetic station. Then, through high or medium voltage power lines, energy is sent to the traction substations, from where it is transported to the catenaries and then to the vehicle via the pantograph [17]. There are four systems of railway traction power supply in Europe: 1.5 kV DC (e.g. the Netherlands and France) and 3 kV DC (e.g. Poland, Spain ...) and also 15 kV AC – 16 2/3 Hz (e.g. Germany, Austria ...) and 25 kV AC – 50 Hz (e.g. Bulgaria, Italy ...) [47]. Fig. 1 shows traction power systems in Europe.

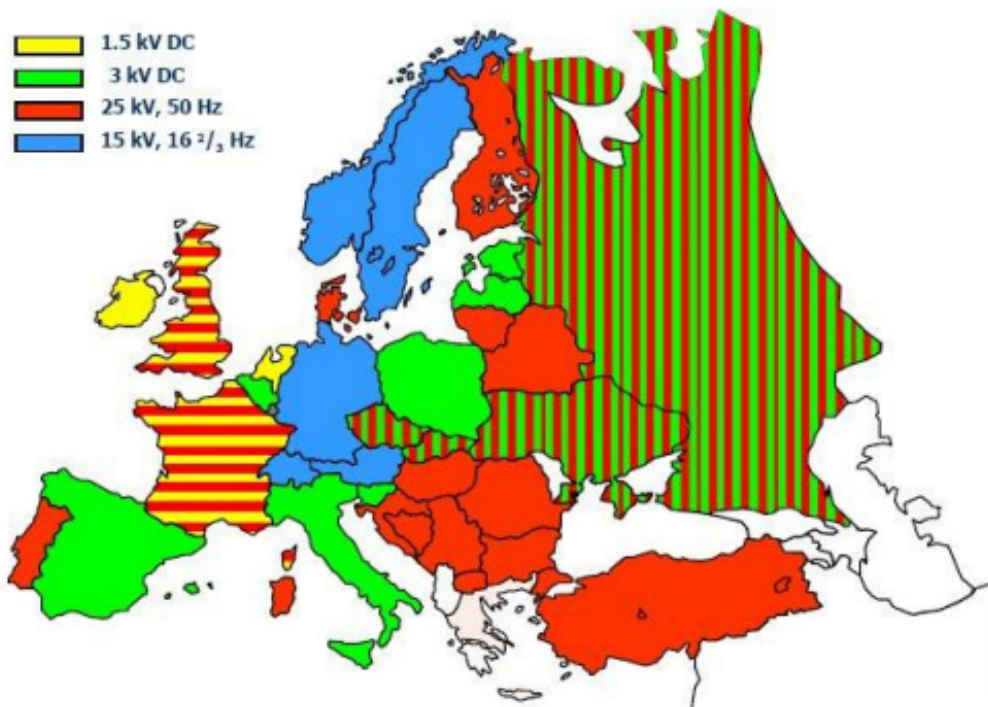


Fig. 1. Traction power system on railway lines in Europe [8]

Systems differ in the scope of parameter processing in a traction substation. With DC power, the voltage is lowered and rectified, while at AC power supply, the voltage is only lowered.

Creating new systems, whose components for correct operation require a supply of electricity, should take care of two things. The first is to ensure safety for life and health of people associated with the use of these elements [2], [6]. The second is to provide an appropriate portion of electricity so that the components work properly on the one hand, but on the other hand that the amount of consumption is as small as possible [26], [44]. It should be noted that not all devices need 3 kV DC for work. It is reduced accordingly using voltage converters. Desired quantities are determined by standards that must be met first of all by the producers of a given component [25] (for the component to work using the voltage specified in the standards), and then the system manufacturer who has to provide the appropriate voltage to work, which will be in accordance with the standards.

In Poland, development of a system for automatic train control system of CBTC class [1], [3], [4], [12], has been undertaken. It is called rmCBTC and is being prepared as part of a project carried out by Rail-Mil Computers Company from Warsaw and the Faculty of Transport of the Warsaw University of Technology co-financed by the National Centre for Research and Development from the European Regional Development Fund (Intelligent Development Operational Program). Therefore, it is necessary to analyse the requirements for supplying the railway vehicle with regard to the size of energy demand.

The aim of the article is to review selected requirements for the power supply of a railway vehicle equipped with automatic train control devices and identification of energy demand in the scope of supplying the rmCBTC on-board system. The article presents an analysis of formal and legal

requirements in the field of traction vehicles. Reference was made to the list of the Office of Rail Transport on the relevant national technical specifications and standardization documents, the use of which allows the essential requirements regarding the interoperability of the rail system to be met and the standards not included in it – PN-EN 50155 [33], PN-EN 61000-6 [38], [39], [40], [41], [42] and PN-EN 50125-2 [32]. Energy requirements in the field of traction vehicles equipped with an automatic train control system have been identified – e.g. voltage range of the on-board system, permissible decays, voltage dips, disturbances and environmental requirements. The energy requirements for the rmCBTC on-board system were also identified.

2. Analysis of formal and legal requirements in the field of traction vehicles power supply

2.1. Requirements imposed by the Office of Rail Transport [9]

List of the Office of Rail Transport [9], was analysed, which is a list of relevant national technical specifications and standardization documents. The application of these acts makes it possible to meet the essential requirements regarding the interoperability of the railway system. Legal acts and standards contained therein include compatibility of a railway vehicle with the Polish railway network, including compliance of technical and operational characteristics of the vehicle with infrastructure and permanent installations.

Accepted solutions according to national requirements qualified as listed in the list were taken into account:

- requirements for electrical installations on board the railway vehicle,
- EMC – electromagnetic compatibility (maximum electromagnetic fields / induced voltage),
- electromagnetic interference.

2.2. Description of requirements included in normative acts

2.2.1. PN-EN 50155 Standard [33]

This European Standard applies to all electronic equipment intended for control, regulation, protection, diagnostics, power supply etc. mounted in rail vehicles. In this European Standard, electronic equipment has been defined as equipment mainly consisting of semiconductor devices and identified connected components. The standard contains performance requirements, design requirements, documentation, and testing of electronic equipment as well as basic hardware and software requirements necessary to ensure compatibility and reliability of equipment.

Specific requirements relate to the practices necessary to ensure certain levels of functional safety and will be set in accordance with relevant railway safety standards.

2.2.2. Standards of the PN-EN 61000-6 series

- **PN-EN 61000-6-1** [38] – The EMC [28] immunity requirements contained in this part apply to electrical and electronic equipment intended for use in residential, commercial and light industrial environments, both indoors and outdoors. Examples: houses, apartments, shops, supermarkets, business premises, banks, cinemas, public bars, dance halls, gas stations, entertainment and sport centres, laboratories, service centres.
- **PN-EN 61000-6-2** [39] – requirements within the scope of resistance to various disturbing phenomena of a continuous or transient nature, conducted or radiated, and electrostatic discharges to which electronic and electric devices intended for work in industrial environments should be resistant and for which there are no appropriate product standards or product group standards. The listed requirements apply to the industrial environment inside and outside the premises. The industrial surroundings are considered as rooms characterized by one or more of the following features: the devices operating here are industrial, scientific and medical devices; large inductive or capacitive loads are switched; the currents and the magnetic fields that

accompany them are large. The formulated resistance requirements include a frequency range from 0 Hz to 400 GHz and testing at other frequencies is not provided.

- **PN-EN 61000-6-3** [40] – the requirements apply to emissions in the frequency range from 0 Hz to 400 GHz and tests at other frequencies are not anticipated. The requirements apply to apparatus and devices intended for direct connection to a low voltage public network or own DC source that is an interface between the device and the public low voltage network. The standard also applies to devices powered by batteries or from a private network and a non-industrial low voltage distribution network.
- **PN-EN 61000-6-4** [41] – emission requirements have been included, referring to all electrical and electronic devices operating in an industrial environment for which there are no specific standards, i.e. product standards or product groups. These devices cannot be operated in a residential, commercial and light industrial environment. The standard refers to devices and apparatus intended to be connected to the power grid supplied from high or medium voltage transformers, intended for supplying power generating installations or similar, and intended for operation in the vicinity of industrial locations, as indicated below. The standard also applies to devices powered by batteries and intended for work in industrial locations.
- **PN-EN 61000-6-7** [42] – intended for use by suppliers when requesting resistance to electromagnetic disturbances in devices that are intended for safety-related systems.

2.2.3. PN-EN 50125-2 Standard [32]

The standard presents the environmental conditions for electrical stationary devices. The influence of the environment on electric stationary devices for power supply and traction equipment of significant importance for rail operation in conditions: in the open air, in enclosed areas, in tunnels and in enclosures located in the above-mentioned areas was determined.

When evaluating stationary electric devices, environmental factors such as: altitude, temperature, humidity, air movement, rain, snow, hail, ice, sand, solar radiation, storms, pollution, vibrations, shocks and electromagnetic compatibility are also taken into account.

3. Characteristics of energy supply requirements for traction vehicles equipped with an automatic train control system

3.1. General comments

Types of available voltages on subway vehicles depend on the type of vehicle and the requirements contained in the specification of the Purchaser. The basic power system for on-board subway trains includes a 3x400 V AC circuit and a 110 V DC circuit. Depending on the inverters and needs, we can have other voltages, e.g. 24 V DC, 230 V AC.

On the Siemens Inspiro train, the on-board auxiliary power system is powered by two auxiliary converters in both rolling wagons [10]. The primary circuit of the auxiliary drives is connected directly to the main circuit at 750 V DC. Each auxiliary converter includes a three-phase inverter and a DC / DC converter (battery charger). In order to operate the elements under 24 V DC, local DC / DC converters are installed in each wagon. They draw power from the 110 V DC circuit. The Inspiro on-board supply system includes 4 auxiliary circuits [10]:

- circuit 3x400 V AC,
- circuit 230 V AC,
- circuit 110 V DC,
- circuit 24 V DC.

On the Alstom Metropolis 98B train, one static converter is installed in each end car. The device uses IGBT transistors and consists of a single-phase inverter, transformer and diode rectifier as well as an output filter. The auxiliary converter is supplied from the third rail with direct current with a voltage in the range of 500-1000 V and has two outputs – direct current 110 V and three-phase

alternating current 400 V 50 Hz. The 110 V direct current is powered by charging the battery, fans of passenger compartments, emergency lighting of passenger compartments, external lighting of the train, passenger door drive motors, electronic control devices, passenger-driver communications equipment, radio telephone, train protection devices and other cabin devices the driver. It is used to power control and control systems of all vehicle systems. Alternating current with a voltage of 400 V and frequency of 50 Hz is powered by compressors, heaters and fans of driver's cabs, brake resistors fans, ONIX box fans [11].

3.2. Range of supply voltages of the on-board system

According to the PN-EN 50155 standard [33], electronic devices powered by accumulators without a voltage stabilizing device should work satisfactorily for all values of the supply voltage in the range specified below (measured at the input terminals of the device):

- minimal voltage – $0.7 U_n$,
- nominal voltage – U_n ,
- rated nominal voltage – $1.15 U_n$,
- maximal voltage – $1.25 U_n$,
- voltage fluctuations in the range between $0.6 U_n$ and $1.4 U_n$ should not exceed 0.1 s and between $1.25 U_n$ and $1.4 U_n - 1$ s.
- In the case of power from a static converter, the fluctuations of the supply voltage can be equal:
 - minimal voltage – $0.9 U_n$,
 - nominal voltage – U_n ,
 - maximal voltage – $1.1 U_n$,
 - In extreme cases when we deal with operational equipment, these values can be achieved:
 - minimal voltage – $0.7 U_n$,
 - nominal voltage – U_n ,
 - maximal voltage – $1.25 U_n$,
 - voltage fluctuations in the range between $0.7 U_n$ and $1.25 U_n$ should not exceed 1 s. and between $0.6 U_n$ and $1.4 U_n - 0.1$ s.

3.3. Description of permissible decays, dips and voltage disturbances

According to the PN-EN 61000-4-11 standard [35], recommended test levels and durations of voltage dips and short breaks are shown in Tab. 1.

Tab. 1. Recommended test levels and durations of voltage dips and short breaks [35]

Test level $\%U_T$	Voltage dips and short breaks $\%$ reduction of U_T	Duration (in network periods)
0	100	0.5*
40	60	1
70	30	5
		10
		25
		50
		x
* For a duration of 0.5 period, the test should be performed with positive and negative polarity, i.e. starting at 0° and 180° respectively.		
COMMENTS:		
1) It is permissible to choose one or more of the above test levels and durations.		

- 2) If the EUT equipment is tested at 100% voltage dips, there is generally no need to perform the test at different levels for the same duration. However, in some cases (regarding protection systems or electromechanical devices) this is not true. In the technical requirements of the product or recommendations of product standardization committees, indications should be given regarding the applicability of this comment.
- 3) "x" means the duration that can be given in the product's technical requirements. Energy distributors in Europe have measured voltage dips and short breaks for periods ranging from 1/2 period to 3,000 periods, but durations of less than 50 periods are most common.
- 4) Each duration is allowed for each test level.

Tab. 2 shows recommended test levels and durations of voltage changes.

Tab. 2. Recommended test levels and durations of voltage changes [35]

Voltage test level	Time of voltage reduction	Duration of low voltage state	Time of voltage rise
40% U_T	2s ± 20%	1s ± 20%	2s ± 20%
0% U_T	2s ± 20%	1s ± 20%	2s ± 20%
	x	x	x
x – set of durations can be given in the technical requirements of the product			

Tab. 3 shows the immunity of an AC input (including devices with a separate AC inverter).

Tab. 3. Immunity of an AC input [45]

No.	Environmental phenomenon	Specification of the test	Units	Basic standard	Comments	Evaluation criterion
1	Voltage dips	>95	% reduction duration	PN-EN 61000-4-11 [34]	See 1)	B
		0.5	% reduction duration			C
2	Voltage breaks	>95 250	% reduction duration	PN-EN 61000-4-4 [36]	See 1)	C
3	Shock loads	1.2/50 (8/20) line to line 2 ground line (ground)	Tr/Th μs / kV (peak value) kV (peak value)	PN-EN 61000-4-5 [37]	See 2)	B
4	Fast transitional states	1.0 5/505	kV (peak value) Tr/Th ns / Repeat frequency in kHz	PN-EN 61000-4-4 [36]		B

- 1) The changes are to appear when the voltage is 0.
- 2) If the manufacturer specifies protective measures that are impractical to simulate during the test, then the applied test signal level should be reduced to 0.5 kV and 1 kV.

The following evaluation criteria are recommended:

- **A:** Normal operation within the limits set by the product manufacturer, test client, or purchaser of the product.
- **B:** Momentary loss of function or deterioration of performance, which disappears after the end

of the disturbance and after which the test device returns to normal operation without operator intervention.

- **C:** Momentary loss of function or deterioration of performance, which requires operator intervention (e.g. reset / system reset).
- **D:** Loss of function or degradation of performance, which cannot be removed due to damage to the device or program, or loss of data.

3.4. Environmental requirements

The climate zone adopted for Polish conditions is T2 with a temperature range from -40°C to 35°C (standard [29]). However, often in the specifications these conditions are modified due to working conditions, as is the case with metro vehicles. Environmental requirements for devices used in rolling stock as well as signalling and telecommunication equipment are defined in EN 50125-1 [31]. Requirements for environmental conditions are presented in tab. 4.

Tab. 4. Requirements for environmental conditions [45]

No.	Environmental conditions	Outside the vehicle	Inside the vehicle
1	Altitude	to 1000 m	to 1000 m
2	Air temperature Temperature in tunnel Ambient temperature on the surface (up to 10 minutes)	-40°C - 35°C $+5^{\circ}\text{C}$ - 30°C (values adopted for the operated rolling stock) -35°C - 40°C (values adopted for the operated rolling stock)	-40°C - 45°C
3	Air humidity	to 80% when 25°C	
4	Rain	According to point 4.6 of the PN-EN 50125-1 standard [31] (6 mm / min.)	
5	Snow, ice and hail	According to point 4.7 and 4.8 of the PN-EN 50125-1 standard [31]	
6	Sunlight	According to point 4.9 of the PN-EN 50125-1 standard [31]	
7	Resistance to pollution	According to point 4.11 of the PN-EN 50125-1 standard [31]	
8	Resistance to vibrations and shock loads	According to point 4.12 of the PN-EN 50125-1 standard [31]	
9	Resistance to electromagnetic interference	According to PN-EN 50121-3 standard [30] <u>Stationary tests:</u> 10kHz-150kHz – 25-50 dB $\mu\text{A}/\text{m}$ 150kHz-30MHz – 5-55 dB $\mu\text{A}/\text{m}$ 30MHz-1GHz – 50-60 dB $\mu\text{A}/\text{m}$ <u>Movement tests:</u> 10kHz-150kHz – 25-50 dB $\mu\text{A}/\text{m}$ 150kHz-30MHz – 5-55 dB $\mu\text{A}/\text{m}$ 30MHz-1GHz – 50-75 dB $\mu\text{A}/\text{m}$	

4. Characteristics of technical and functional requirements in the field of energy supply of the rmCBTC on-board system

4.1. Assumptions about system components

The structure of on-board devices of the rmCBTC system consists of the components shown in Fig. 2 [46].

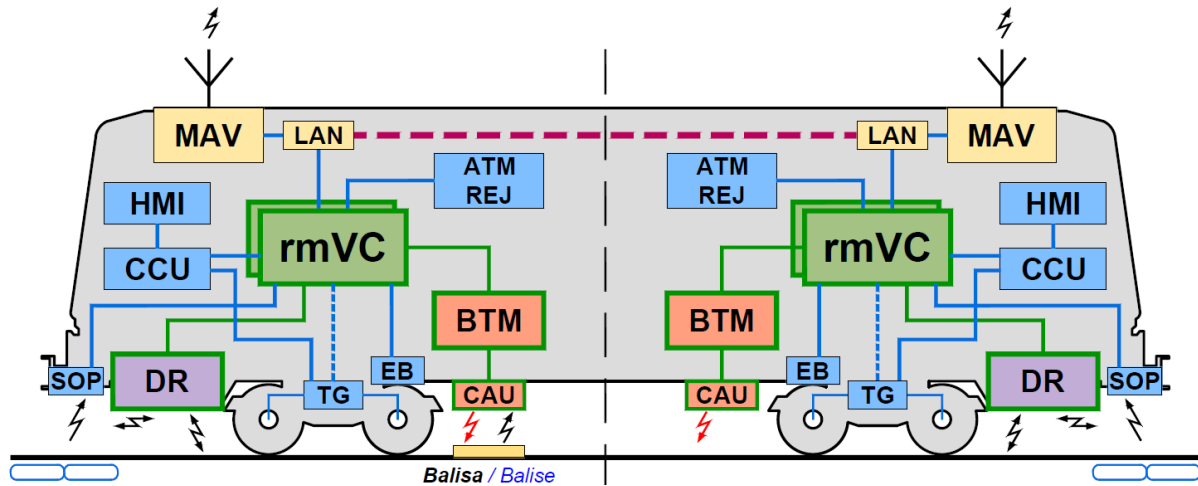


Fig. 2. Structure of on-board devices of the rmCBTC system [source: own work]

The components of the rmCBTC system presented in Fig. 2 are:

- rmVC – Vital Computer,
- BTM – Balise Transmission Module,
- CAU – Cell Antenna Unit,
- DR – Doppler Radar,
- MAV – Wi-Fi antenna for two-way, continuous communication of vehicle with the centre,
- LAN – wired network for communication and data transmission between on-board interlocking computers and MAVs,
- SOP – device cooperating with the automatic speed limitation system,
- HMI – Human Machine Interface,
- ATM REJ – recorder of rolling stock operational parameters,
- CCU – Central Control Unit,
- TG – bearing temperature sensor,
- EB – braking sensor.

It should be noted that not all components require installation on the vehicle (some are already installed). They will only have to be adapted to work with other components of the rmCBTC system. It is necessary to build rmVC, BTM, CAU, DR, WI-FI, LAN and HMI. Technical and functional requirements regarding their power supply are presented in the next section.

4.2. Technical and functional requirements for powering system components

The analysis of the requirements for powering on-board devices in railway vehicles was aimed at defining the requirements for the newly built rmCBTC system and its subassemblies. The construction of sub-assemblies that meet the requirements of the standards will enable proper and safe operation of these devices in the final development.

Assuming that the system will be powered by 110 V DC, the following requirements are specified:

- battery power supply:
- minimal voltage – 77 V,
- nominal voltage – 110 V,
- rated nominal voltage – 127 V,
- maximal voltage – 137 V,
- voltage fluctuations in the range between 66-154 V should not exceed 0.1 s, and between 137-154 V – 1 s,
- in the case of power from a static converter, the fluctuations of the supply voltage can be equal:
- minimal voltage – 99 V,

- nominal voltage – 110 V,
- maximal voltage – 121 V,
- in extreme cases when we deal with operational equipment, these values can be achieved:
- minimal voltage – 77 V,
- nominal voltage – 110 V,
- maximal voltage – 137 V,
- voltage fluctuations in the range between 77-137 V should not exceed 1 s, and between 66-154 V – 0.1 s.

The nominal output power that can be used by the on-board system receivers will depend on the converter used on the vehicle.

Requirements for environmental conditions are presented in Tab. 5.

Tab. 5. Requirements for environmental conditions for the rmCBTC on-board system

No.	Environmental conditions	Outside the vehicle	Inside the vehicle
1	Altitude	to 1000 m	to 1000 m
2	Air temperature Temperature in tunnel Ambient temperature on the surface (up to 10 minutes)	-40°C-35 °C +5°C-30°C (values adopted for the operated rolling stock) -35°C-40°C (values adopted for the operated rolling stock)	-40°C-45°C
3	Air humidity	to 80% when 25°C	
4	Resistance to pollution	According to point 4.11 of the PN-EN 50125-1 standard [31]	
5	Resistance to vibrations and shock loads	According to point 4.12 of the PN-EN 50125-1 standard [31]	
6	Resistance to electromagnetic interference	According to PN-EN 50121-3 standard [30] <u>Stationary tests:</u> 10kHz-150kHz – 25-50 dBμA/m 150kHz-30MHz – 5-55 dBμA/m 30MHz-1GHz – 50-60 dBμA/m <u>Movement tests:</u> 10kHz-150kHz – 25-50 dBμA/m 150kHz-30MHz – 5-55 dBμA/m 30MHz-1GHz – 50-75 dBμA/m	

5. Summary and conclusions

The article presents an overview of selected requirements for powering railway vehicle equipped with automatic train control devices, and identification of energy demand in the scope of supplying the rmCBTC on-board system. The rmCBTC automatic train control system is the first in Poland CBTC class system. It uses a combination of two-way wireless data transmission and components of the interoperable ETCS rail system, increasing the level of efficiency and safety in the agglomeration of rail transport. It should be noted that the most important element of the CBTC class system is data transmission [49] using wireless Wi-Fi network [50] (802.11 standard [51]) and this distinguishes it from other automatic train control systems. The rmCBTC system is being prepared as part of a project implemented by Rail-Mil Computers Company from Warsaw and the Faculty of Transport of the Warsaw University of Technology co-financed by the National Centre for Research and Development from the European Regional Development Fund (Intelligent Development Operational Program). Finally, the prototype of the system is to be built in the Warsaw

Metro on the first four stations of the first line and on the Alstom Metropolis 98B vehicle.

The rmCBTC system components need electricity for proper operation. Designing detailed solutions, one should strive to ensure that energy consumption is on the one hand adequate, but on the other hand, the smallest as possible. It will allow limiting the negative impact on the environment associated with the production of electricity for traction purposes in the place of its production. The article presents an analysis of formal and legal requirements in the field of traction vehicles. Reference was made to the list of the Office of Rail Transport to ensure that the rmCBTC system meets the essential requirements for the interoperability of the rail system. In connection with this, the system will be able to be used for various types of agglomeration railways – not just metro. In addition, an analysis of the standards not included in the list of the Office of Rail Transport – standard PN-EN 50155 [33], PN-EN 61000-6 [38], [39], [40], [41], [42] and PN-EN 50125-2 [32] was made. Energy requirements in the field of traction vehicles equipped with an automatic driving system have been identified – e.g. voltage range of the on-board system, permissible decays, voltage dips, disturbances and environmental requirements. On the basis of energy requirements for traction vehicles equipped with an automatic train control system, recommendations for energy in the scope of supplying the rmCBTC on-board system were made.

This article is co-financed by the European Union under the European Regional Development Fund from the project POIR.01.01.01-00-0276/17



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Manuscript received 10 July 2018; approved for printing 25 October 2018

