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REQUIREMENTS AND ASSESSMENT OF INTEROPERABILITY CONSTITUENTS: OVERHEAD CONTACT LINE OF THE "ENERGY" SUBSYSTEM AND THE PANTOGRAPH AND CONTACT STRIPS OF "LOCOMOTIVES AND PASSENGER ROLLING STOCK" SUBSYSTEM ACCORDING TO EC TSI

Introduction

Under Article 288 of the Lisbon Treaty, legal acts stated within the EU are the following: directives (adopted by the European Parliament), decisions and regulations (adopted by the European Commission) and opinions or recommendations. The directives, decisions and regulations are binding for the recipients, unlike the opinions or recommendations. To understand the EU directives and decisions properly – and to be able to discuss them – it is necessary to learn some new terms used in these documents. According to the documents [1, 2]:

1. "New Approach Directives" – state a rule that a product can be marketed in the whole EU, i.e. it is possible to sell a locomotive to any country within the EU and to operate it on railways anywhere in Europe only if it is compliant with the essential requirements of the proper directives;
2. "Essential requirements" means all the conditions set out in Annex III which must be met by a rail system, subsystems, and interoperability constituents, including interfaces [1];
3. "Subsystem" – should be considered as an effect of division of a railway system. A subsystem may be structural or functional;
4. "Interoperability" – is defined as "the ability of a rail system to allow the safe and uninterrupted movement of trains which accomplish the required levels of performance for these lines. This ability depends on all the regulatory, technical and operational conditions which must be met in order to satisfy the essential requirements.";
5. "Interoperability constituent" – An interoperability constituent means any elementary component, group of components, sub-assembly or complete assembly of equipment that is incorporated or intended to be incorporated into a subsystem upon which the interoperability of the rail system depends directly or indirectly and includes both tangible objects and intangible ones such as software.
6. "Technical specification for interoperability" (TSI) – means a specification adopted in accordance with this Directive by which each subsystem or part subsystem is covered in order to meet the essential requirements and ensure the interoperability of the rail system [1];
7. "Notified bodies" – means the bodies which are responsible for assessing the conformity or suitability for use of the interoperability constituents or for appraising the 'EC' procedure for verification of the subsystems [1]. I.e. the Railway Institute is a notified body, registered as number NB 1467;
8. "Upgrading" – means any major modification work on a subsystem or part subsystem which improves the overall performance of the subsystem [1];
9. "Open points" – in a case that some technical aspects – related to the essential requirements – cannot be defined by the TSI they are called "open points" [1].

The aim of the Directive [1] is to obtain the interoperability of the railway system within EU territory covering the terms of the Directive. Those terms concern the process of design, construction, authorisation for placing in service, upgrade, renewal, operation and maintenance of a part of the system. Moreover, they concern professional qualifications, health and safety requirements for personnel responsible for the operation and maintenance.

Decision 2011/274/EU concerns the „Energy" subsystem for conventional railway lines. A conventional line is a railway line with operational speed is up to 200 km/h. On the other hand, the Decision 2008/284/EU concerns the „Energy" subsystem for high-speed railway lines. A high-speed line is a railway line with operational speed exceeding 200 km/h, although speeds exceeding 320 km/h are not covered by any specific requirements, but considered as an „open point". Both 2011/274/EU and 2008/284/EU decisions concern 1435 mm gauge railways only. However, European Commission Regulation No 1301/2014 [13] concerns both the conventional and the high-speed railways with all following track gauges 1435, 1520, 1524, 1600 and 1668 mm and therefore supersedes the 2008/284/EU and 2011/274/EU Decisions for new projects.

“Energy” subsystem

According to Decision [2] and Regulation [13] the „Energy” subsystem contains of a substation, section cabin, separation section (placed between two phases of the same AC power supply system or between two different power supply systems), overhead contact line (a facility transmitting the energy to the electric vehicles on the line via pantographs, containing manual or remote-operated isolators for electrical re-sectioning operations on particular tracks) and a return circuit (any conductors intended to carry the traction current from the vehicle back to the substation).

Moreover, the „Energy” subsystem includes any trainborne equipment of the Energy Measuring System (EMS) and the ground-based Compiled Energy Billing Data System (CEBD).

The „Energy” subsystem interfaces with other subsystems i.e. pantograph interfaces with the „Rolling stock” subsystem, while the structure gauge is considered to be an interface with the „Infrastructure” subsystem. ERTMS interfaces with the „Control-command and signalling” subsystem. Two parameters: current draw of a train and separation sections (for both phase and system separation) interface with „Traffic operation and management” subsystem.

For the „Energy” subsystem, the overhead contact line is the only interoperability constituent.

Parameters to be verified during the assessment of “overhead contact line” IC of “Energy” subsystem

Verification of the „Energy” subsystem should be performed according to the following parameters:

4.1. Voltage and frequency

4.2. Parameters relating to supply system performance

4.3. Current capacity, d.c. systems, trains at standstill,

4.4. Regenerative braking

4.5. Electrical protection coordination arrangements

4.6. Harmonics and dynamic effects for AC systems

4.7. Geometry of the overhead contact line

4.8. Pantograph gauge

4.9. Mean contact force

4.10. Dynamic behaviour and quality of current collection

4.11. Pantograph spacing (for OCL designing process)

4.12. Contact wire material

4.13. Phase separation sections

4.14. System separation sections

4.15. Ground-based compiled energy billing data system

4.16. Protective provisions against electric shock

4.17. Operating rules

4.18. Maintenance rules

4.19. Professional competences of staff

4.20. Personal protective safety provisions

4.21. Registration arm uplift clearance.

In the case of verification of the „Energy” subsystem the evaluation should be performed in two phases, that is in the ‘design review’ phase and in the ‘assembled, before putting into service’ phase. During the ‘design review’ phase the points 4.1 to 4.14 and 4.16 to 4.17 should be assessed, whereas during the ‘assembled, before putting into service’ phase the points to be assessed are 4.5, 4.10 and 4.16. In the case that the overhead contact line had been already assessed as an interoperability constituent at the ‘overall design’ phase it is not necessary to perform the tests once again during the „Energy” subsystem verification process.

In the case of „overhead contact wire” interoperability constituent assessment the choice of parameters is different. During the ‘design review’ phase the points 4.3, 4.7, 4.9, 4.10, 4.11, 4.12, 4.21 should be assessed, whereas during the ‘assembled, before putting into service’ phase the points to be assessed are 4.3, 4.10, and 4.21.

Ad. 4.1 Voltage and frequency

Regulation [13] states that it is necessary to use one of the following power supply systems:

1) an a.c. system, 25 kV 50 Hz or 15 kV 16,7 Hz;

2) a d.c. system, 3 kV or 1,5 kV.

Voltage and frequency limits should comply with EN 50163:2004, par. 4., as quoted in Table 1

The following requirements shall be fulfilled:

a) the duration of voltages between Umin1 and Umin2 shall not exceed 2 min;

b) the duration of voltages between Umax1 and Umax2 shall not exceed 5 min;

c) the voltage of the busbar at the substation at no load condition shall be less than or equal to Umax1.

Table 1

Nominal voltages and their permissible limits in values and duration

Electrification system	Lowest non-permanent voltage U_{min2}	Lowest permanent voltage U_{min1}	Nominal voltage U_n	Highest permanent voltage U_{max1}	Highest non-permanent voltage U_{max2}
	V	V	V	V	V
d.c. (mean values)	1 000 2 000	1 000 2 000	1 500 3 000	1 800 3 600	1 950 3 900
a.c. (r.m.s. values)	11 000 17 500	12 000 19 000	15 000 25 000	17 250 27 500	18 000 29 000

For d.c. substations it is acceptable to have this voltage at no load condition less than or equal to Umax2, knowing that when a train is present, the voltage at this train's pantograph (s) shall be in accordance with Table 1 and its requirements;

d) under normal operating conditions, voltages shall lie within the range Umin1 ≤ U ≤ Umax2;

Ad. 4.2 Parameters relating to supply system performance

System performance on a given route section is usually assessed on the basis of the three following parameters: a) maximum train current b) power factor of trains c) mean useful voltage.

The maximum permitted continuous current for contact and messenger wires can be calculated using the formula (1) already published in the paper [12]:

$$I_d = \sqrt{\frac{kAS\Delta\vartheta_d}{\rho_\vartheta}} \tag{1}$$

where: k – heat transfer coefficient;

A – circumference of the contact/messenger wire;

S – transversal cross-section of the contact/messenger wire;

$\Delta\vartheta_d$ – permissible temperature increase;

ρ_ϑ – resistivity of the contact/messenger wire at maximum permissible temperature.

According to the train timetable on a given power supply section the current drawn by the trains heats the contact wire resulting in the temperature increase process. As long as there are no trains on the section the contact wire cools down to ambient temperature. In that case the maximum permitted current I_p for the wire can be calculated using the formula (2).

$$I_p = I_d \sqrt{\frac{1-e^{\frac{-t_p}{\alpha_p T}}}{1-e^{\frac{-t_p}{T}}}} \tag{2}$$

where: $\alpha_p = (t_p/(t_p + t_b))$, t_p – presence duration of the current, t_b – absence duration of the current.

The mean useful voltage on a pantograph can be calculated using the formula (3) originally given in EN 50388:2012

$$U_{\acute{s}rednie\ u\dot{z}yteczne} = \frac{\sum_{i=1}^{n} \frac{1}{T_i} \int_0^{T_i} Up_i \times |Ip_i| \times dt}{\sum_{i=1}^{n} \frac{1}{T_i} \int_0^{T_i} |Ip_i| \times dt} \tag{3}$$

where: Ti –interval of integration for a train number i;

n – total number of trains taken into account during the simulation process for d.c. system;

Upi – actual mean voltage measured on pantograph of a train number i;

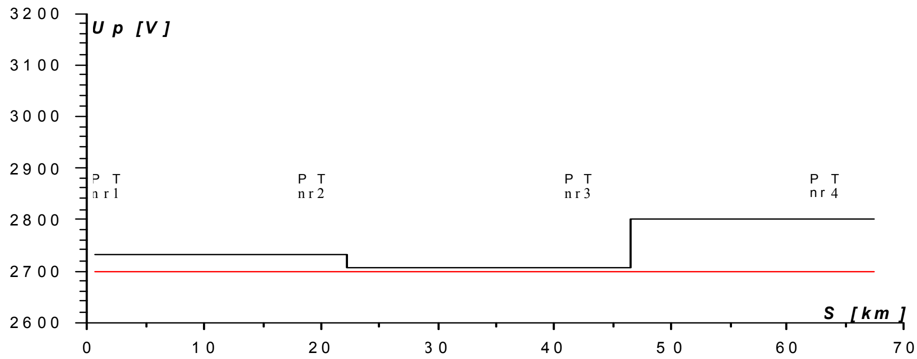
|Ipi| - modulus of actual mean train current measured on pantograph of a train number i;

The above formula shows correlation between the mean power value, calculated for reference train/trains during their travel through the section, and the corresponding mean current value.

To perform calculations according to formula (3) an overhead contact line designer should know or assume the following data: overhead contact line cross-section, line speed, power and weight for each type of train, maximum train current and its characteristics, train timetable for the line (headway), track horizontal and vertical profile, substation and section cabin location, type and number of rectifiers, short-circuit power at transformer/switching station measured on medium-voltage side, transmission line voltage, number of transmission lines.

Simulation results have to prove that in case of 3 kV D.C. system the calculated mean useful voltage is higher than 2800 V (for line speeds >200 km/h) and 2700 V (for line speeds ≤ 200 km/h). If the simulation result is positive it is necessary to check if pantograph voltage for any train is never lower than U min1 (2000 V in that case).

Maximum current should be 2500 A for conventional rail system and 3200 A for high-speed rail system.



Pic. 1. An example of mean useful voltage distribution along a section

Ad 4.3 Current capacity, D.C. systems, trains at standstill

According to the TSI it is required that – in case of the 3 kV d.c. system – every pantograph should be able to draw a current of 200 A. During this test the static contact force should be kept at Fst=90 N according to EN 50367:2012, Table 4 [11]. The maximum temperature at contact point should not exceed the limits given in EN 50119:2009, 5.1.2. [7]. After 30 minutes of heating those limit values are 120 °C for pure copper and 150 °C for copper silver alloy.

Ad 4.4 Regenerative braking

According to the TSI for the „Energy" subsystem, both d.c. and a.c. electrification systems should be designed to permit the use of regenerative braking and enable a train to exchange power at least with other trains. However, more effective use of the braking energy is possible if substations are equipped with energy storage devices. If not, the energy transmitted by braking locomotives and EMUs to the overhead contact line can be recuperated only by other electric trains that are working on the same power supply section.

Ad 4.5 Electrical protection coordination arrangements

The principle of the proper electrical protection coordination arrangements is the following. A traction vehicle, overhead contact wire, electrical circuits of a substation (on the 3 kV side) are protected against short-circuiting by high-speed circuit-breakers. On the ground side, they are installed on the supply end of feeder cables in each substation. Aboard a traction vehicle they are installed just behind its pantographs. Those areas are therefore protected against short-circuit negative effects. Once a short-circuit occurs aboard the train, the current will exceed the circuit-breaker threshold value. Preferred circuit-breaker to break this current is the trainborne one in order to avoid an unnecessary triggering of the substation one. The assessment criterion usually taken into account is the delay time for the substation circuit-breaker. This time should be 20 to 60 ms for 3 kV d.c. and 80 ms for 25 kV 50 Hz respectively.

Ad 4.6 Harmonics and dynamic effects for AC systems

This paragraph is about a.c. electrification systems. To obtain compatibility of power supply systems harmonics values should be kept below the limits given in EN 50833:2012, 10.4.

Ad 4.7 Geometry of the overhead contact line

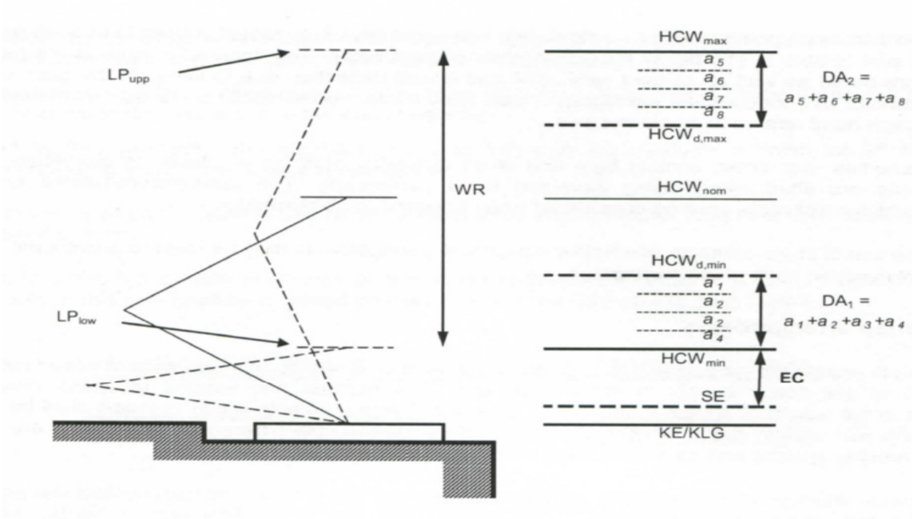
Nominal contact wire height HCW_{nom} values (Fig. 2) as well as minimum and maximum permitted contact wire height values for 1435 mm and 1520/1524 gauges, for both speeds ranges <250 km/h and 250-320 km/h, are shown in Table 2.

The contact wire can be installed higher than indicated, i.e. on level crossings, yards, etc. In that case the design contact wire height $HCW_{d,max}$ should not be greater than 6,20 m. Therefore, including installation tolerances and contact wire uplift, maximum contact wire height (HCW_{max}) should not be greater than 6,50 m.

The assessment on the design phase is performed by confirming that the minimum, nominal and maximum contact wire heights are proper.

Table 2

Description	Track gauge 1435		Track gauge 1520 and 1524
	v≥250 km/h	v<250 km/h	
	mm	mm	mm
Nominal contact wire height	5080 to 5300	5000 to 5750	6000 to 6300
Minimum contact wire height	5080	EN 50119:2009, 5.10.4	5550
Maximum contact wire height	5300	6200 or 6500 see description below	6800



Pic. 2. Relationship between the contact wire height and the pantograph position (KE/KLG – kinematic loading gauge, EC - electrical clearance, other symbols described in EN 50119:2009 [7], 5.10.4)

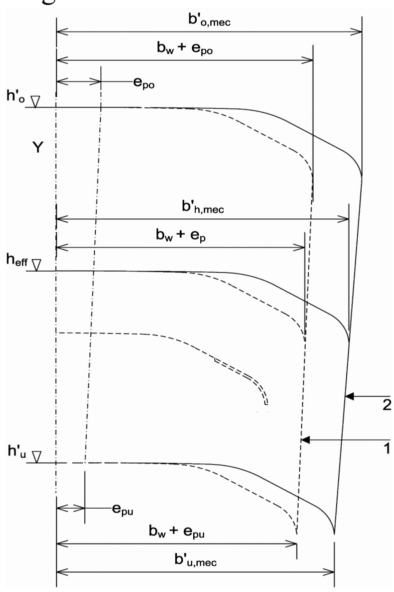
Permitted variation in contact wire height due to local conditions depends on line speed. Maximum gradient and maximum changes of gradient values are given in EN 50119:2009, 5.10.3.

Maximum permitted horizontal deflection of contact wire caused by crosswind is equal 0,55 m for 1950 mm pantograph head, measured from track centre. The deflection caused by crosswind is determining maximum span length on both tangent and curved track. The assessment on the design phase is performed by finding the longest design span on tangent track and checking if the lateral crosswind deflection is not exceeding the limit value.

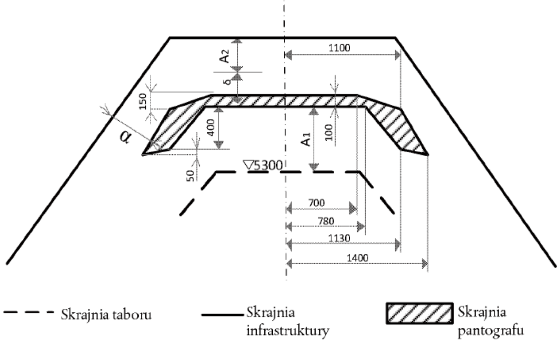
Ad 4.8 Pantograph gauge

According to the *TSI*, any part of the „*Energy*" subsystem shall not enter the kinematic pantograph gauge envelope, except for the contact wire and steady arm.

The calculation method for the pantograph gauge envelope for 1435 mm gauge railways is described in the Regulation [13], Annex D. Assuming that: lateral pantograph sway on lower height $h'_u \leq 5{,}0$ m is equal e_{pu}=0,110 m; on upper height $h'_o = 6{,}5$ m is equal $e_{po} = 0{,}170$ m respectively; half of collector head width b_u = 0,975 m (i.e. for Poland); and regarding permitted electrical clearances it is therefore possible to calculate the pantograph gauge envelope and then to compare it with structure gauge in a given country. For 1520/1524 mm railways static pantograph gauge is shown on Fig. 4.



Pic. 3. Determination of the kinematic pantograph gauge



Pic. 4. Static pantograph gauge for the track gauge 1520/1524 mm

Ad 4.9 Mean contact force

The contact force applied on the wire is a sum of static, dynamic and aerodynamic force. To calculate value of the mean contact force F_m the static force as indicated in EN 50367:2012, table 6 should be adopted. The mean contact force for the 3 kV d.c. system should be kept within following limits (4):

$$90\ N \le F_m \le 0{,}00097 \cdot vI\ +\ 110\ N \tag{4}$$

where: v – train speed in km/h, F_m – mean contact force in N.

The aerodynamic force F_{ae} depends on the design of a given pantograph. An example of the $F_{ae}+F_{st}$ value depending on speed is shown in Fig. 5.

In case of a.c. electrification systems, for train speeds up to 200 km/h the maximum contact force can be calculated using the formula (5) and for speeds between 200 and 320 km/h using the formula (6).

$$F_{m,max} \le 0{,}00047 \cdot vI\ +\ 90\ N \tag{5}$$

$$F_{m,max} \le 0{,}00097 \cdot vI\ +\ 70\ N \tag{6}$$

Ad 4.10 Dynamic behaviour and quality of current collection

The dynamic behaviour is to be checked in two phases, that is the 'design review' phase and in 'assembled, before putting into service' phase. During the 'design review' phase it is to verify the dynamic behaviour using simulation and during the 'assembled' phase by measuring the contact wire uplift at a support and by assessing the quality of current collection from the overhead contact wire. Assessment of the quality can be performed using two methods: by checking mean contact force F_m and standard deviation σ_{max} or by calculating percentage of arcing between collector head and contact wire.

The verification of the dynamic behaviour in the 'design review' phase is to be done by performing proper calculations according to assumed mathematical model of the pantograph and the overhead contact wire. Some mathematical models are described in paper [15]. The adopted method has to be validated using the algorithm given in EN 50318:2002 [10].

An example of simulation result, presenting calculated force against time, is shown in Fig. 6. However, verification of the dynamic behaviour in the 'assembled, before putting into service' phase is to be performed by measuring actual values of the contact force and then by calculating the mean contact force F_m and standard deviation σ_{max}. Accuracy of the measurement is defined by EN 50317:2012 [9]. The assessment result is deemed to be positive if the maximum contact force is lower or equal to the sum of $F_m + 3\sigma_{max}$. In the case of so-called 'stiff points' the contact force can be higher up to 350 N.

Ad 4.11 Pantograph spacing (for OCL designing process)

The pantograph spacing is to be assessed according to the Regulation [13] on basis of contact wire uplift with at least two adjacent operating pantographs. Spacing values are indicated in paragraph 4.2.1. of the this Regulation. Minimum distance between pantographs depends on line speed. Assessment is performed on the 'design review' phase. During the assessment contact wire uplift at a support should be simulated, resulting in an uplift over time waveform. Afterwards, two waveforms should be summed using the superposition method, described in paper [16]. Eventually, on the basis of the resultant waveform the given overhead contact line should be assigned to one of the following groups 'A', 'B', or 'C', defined in the Regulation.

Ad 4.12 Contact wire material

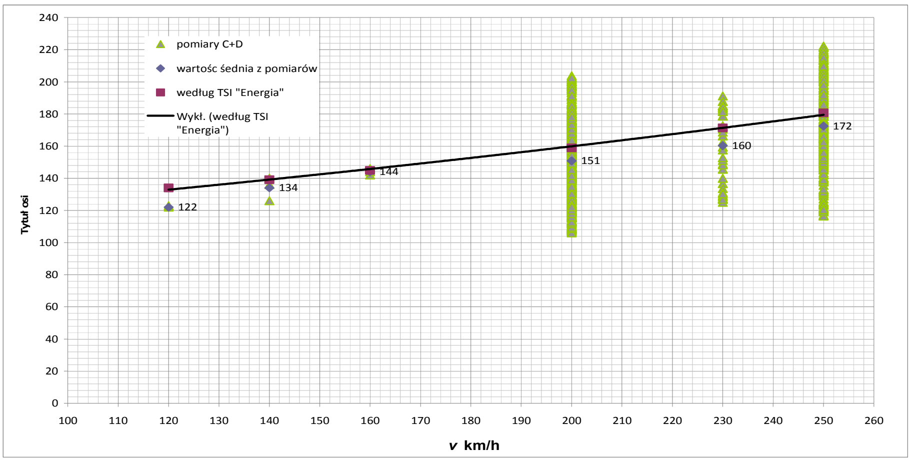
The contact wire material should be compliant to the requirements described in EN 50149:2012, 4.2, 4.3 and 4.6 to 4.8. Assessment is to be performed on the 'design review' phase. Essential requirements are: the dimensions, chemical composition and mechanical properties of the contact wire.

Ad 4.13 Phase separation sections

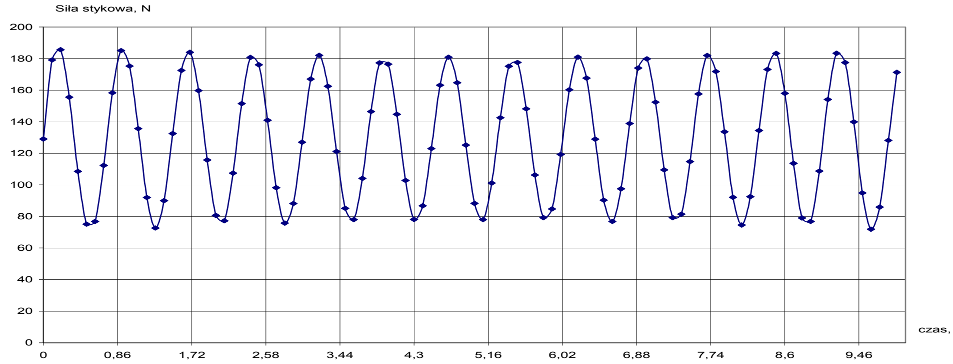
This clause is for a.c. systems only. In order to avoid short-circuiting of two consecutive phases during train transition from one to another, an OCL designer should apply one of the preventive solutions presented in EN 50367:2012, A.1.

Ad 4.14 System separation sections

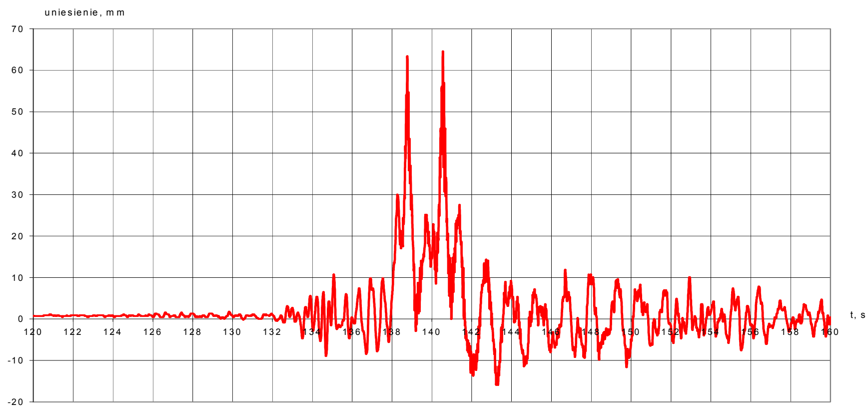
Design of the system separation section has to allow for train passing from one system to another without short-circuiting them. There are two methods to do so: with pantographs raised and with pantographs lowered.



Pic. 5. An example of F_{ae} depending on speed for a given pantograph



Pic. 6. An example of F_m over time waveform obtained during a simulation



Pic. 7. Contact wire uplift against time for two pantographs

Ad 4.15 Ground-based compiled energy billing data system

The ground-based compiled energy billing data system (CEBD) should collect train energy consumption data from a trainborne energy measuring system (EMS) and store for billing purposes. The TSI does not define any requirements for the system nor for data transmitting protocol.

Ad 4.16 Protective provisions against electric shock

For a d.c. electrification system the ‘design review’ assessment is performed by checking the kind of provisions against electric shock and earth faults of OCL. The provision can be a system using group bonding of supporting structures with individual groundings or a system using individual bonding of supporting structures. It is to be checked if the return circuit contains transversal jumper bondings between rails and tracks where needed. Moreover, it is to be checked if the bonding jumpers cross-sections and electrical clearances are sufficient, according to EN 50122-1:2011, 5.2.1, 5.3.1 i 5.3.2 and 6.1 i 6.2. Eventually, it is to be confirmed that touch voltages values are not exceeding the limits given in par. 9.2.2.1 i 9.2.2.2 of this standard (for a.c. systems) and in par. 9.3.2.1 i 9.3.2.2. (for d.c. systems, respectively).

Ad 4.17 Operating rules

Before placing a subsystem in operation it is obligatory to prepare complete technical documentation containing maintenance rules for the overhead contact line and the „*Energy*" subsystem in order to make sure that all TSI requirements will have to be under control during the whole life cycle of the subsystem.

Ad 4.21 Registration arm uplift clearance

According to the TSI the contact wire uplift at a support should not exceed a half of static distance between the contact wire and the registration arm. Calculations or measurements should be performed using mean contact force of the pantograph, as defined in formula (5), and maximum line speed. Conformity assessment of the clearance in the 'design review' phase should be performed using a validated simulation method compliant to EN 50318:2002 [10].

At first, contact force should be calculated according to paragraph Ad. 4.10. Knowing the value of overhead contact wire elasticity at a support ($e_{słup}$) it is possible to calculate the maximum uplift at a support, using the simple formula (6).

$$y_{słup} = F_m \cdot e_{słup} \qquad (7)$$

The calculation method should be validated during in situ dynamic tests. Moreover, the overhead contact line should be assessed in 'assembled, before putting into service' phase by performing proper measurements during dynamic tests.

Summary

In order to obtain an EU Certificate it is necessary to develop the design of renewal, upgrade or construction of „overhead contact line" IC (or „*Energy*" subsystem) and then to perform verification tests according to the TSI requirements. Conformity assessment process is to be performed by a specialized notified body who therefore will issue the EU Certificate valid throughout European Union. This certificate is required for the settlement of European funds granted for realization of the investment.

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The introduction to this article gives the definitions of general terms used in the European Union Directives and Decisions. Subsequently, those interoperability constituents and subsystems which can be assessed by the Electric Power Division of the Railway Institute will be discussed. Those interoperability constituents are: overhead contact line, pantograph and contact strip. Issues relating to main circuit breaker assessment – which is also performed by the Division – are not a subject of this paper. Moreover, the paper describes the process of assessing the 21 basic parameters that are subject to analysis during the assessment of overhead contact line interoperability constituents and the „Energy" subsystem. Due to the limited volume of this paper the pantograph and the contact strip interoperability constituents – which are a part of the 'Locomotives and passenger rolling stock' subsystem – have only been described briefly.

Keywords: interoperability, infrastructure, overhead contact line, locomotive, TSI requirements.

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ВИМОГИ ТА ОЦІНКА ІНТЕРОПЕРАБЕЛЬНОСТІ ІНФРАСТРУКТУРИ: КОНТАКТНІ МЕРЕЖІ ПІДСИСТЕМИ «ЕНЕРГЕТИКА» ПРИ ВЗАЄМОДІЇ ЗІ СТРУМОПРИЙМАЧАМИ І КОНТАКТНИМИ НАКЛАДКАМИ ПІДСИСТЕМИ «ЛОКОМОТИВИ ТА ПАСАЖИРСЬКИЙ РУХОМИЙ СКЛАД» ВІДПОВІДНО ДО ВИМОГ ЄС TSI

У вступі статті наведено визначення загальних термінів, використовуваних в Рішеннях і Директивах Європейського Союзу. Згодом, мова піде про ці складові взаємодії та підсистеми, які можуть бути оцінені Відділом з електроенергії Залізничного Інституту. Цими складовими взаємодії є: контактна мережа, пантограф і його полоз. Питання, що стосуються основних оцінок автоматичного вимикача, які також вирішуються Відділом – не є предметом даної статті. Більш того, у статті описується процес оцінки 21 основного параметра, що підлягає аналізу при оцінці контактної мережі, складові інтероперабельності та підсистеми «Енергія». Через обмежений обсяг даної статті взаємодія складових пантографа і його полоза, які є частиною локомотивів і підсистеми «Пасажирського рухомого складу» описані коротко.

Ключові слова: інтероперабельність, інфраструктура, контактна мережа, локомотив, вимоги TSI.

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ТРЕБОВАНИЯ И ОЦЕНКА ИНТЕРОПЕРАБЕЛЬНОСТИ ИНФРАСТРУКТУРЫ: КОНТАКТНЫЕ СЕТИ ПОДСИСТЕМЫ «ЭНЕРГЕТИКА» ПРИ ВЗАИМОДЕЙСТВИИ С ТОКОПРИЕМНИКАМИ И КОНТАКТНЫМИ НАКЛАДКАМИ ПОДСИСТЕМЫ «ЛОКОМОТИВЫ И ПАССАЖИРСКИЙ ПОДВИЖНОЙ СОСТАВ» СОГЛАСНО ТРЕБОВАНИЙ ЕС TSI

Во введении статьи приведены определения общих терминов, используемых в Решениях и Директивах Европейского Союза. Впоследствии, речь пойдет о этих составляющих взаимодействия и подсистемах, которые могут быть оценены Отделом по электроэнергии Железнодорожного Института. Этими составляющими взаимодействия являются: контактная сеть, пантограф и его полоз. Вопросы, касающиеся основных оценок автоматического выключателя, которые также решаются Отделом – не являются предметом данной статьи. Более того, в статье описывается процесс оценки 21 основного параметра, подлежащего анализу при оценке контактной сети, составляющие интероперабельности и подсистемы «Энергия». Из-за ограниченного объема данной статьи взаимодействие составляющих пантографа и его полоза, которые являются частью локомотивов и подсистемы «Пассажирского подвижного состава» описаны кратко.

Ключевые слова: интероперабельность, инфраструктура, контактная сеть, локомотив, требования TSI.

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