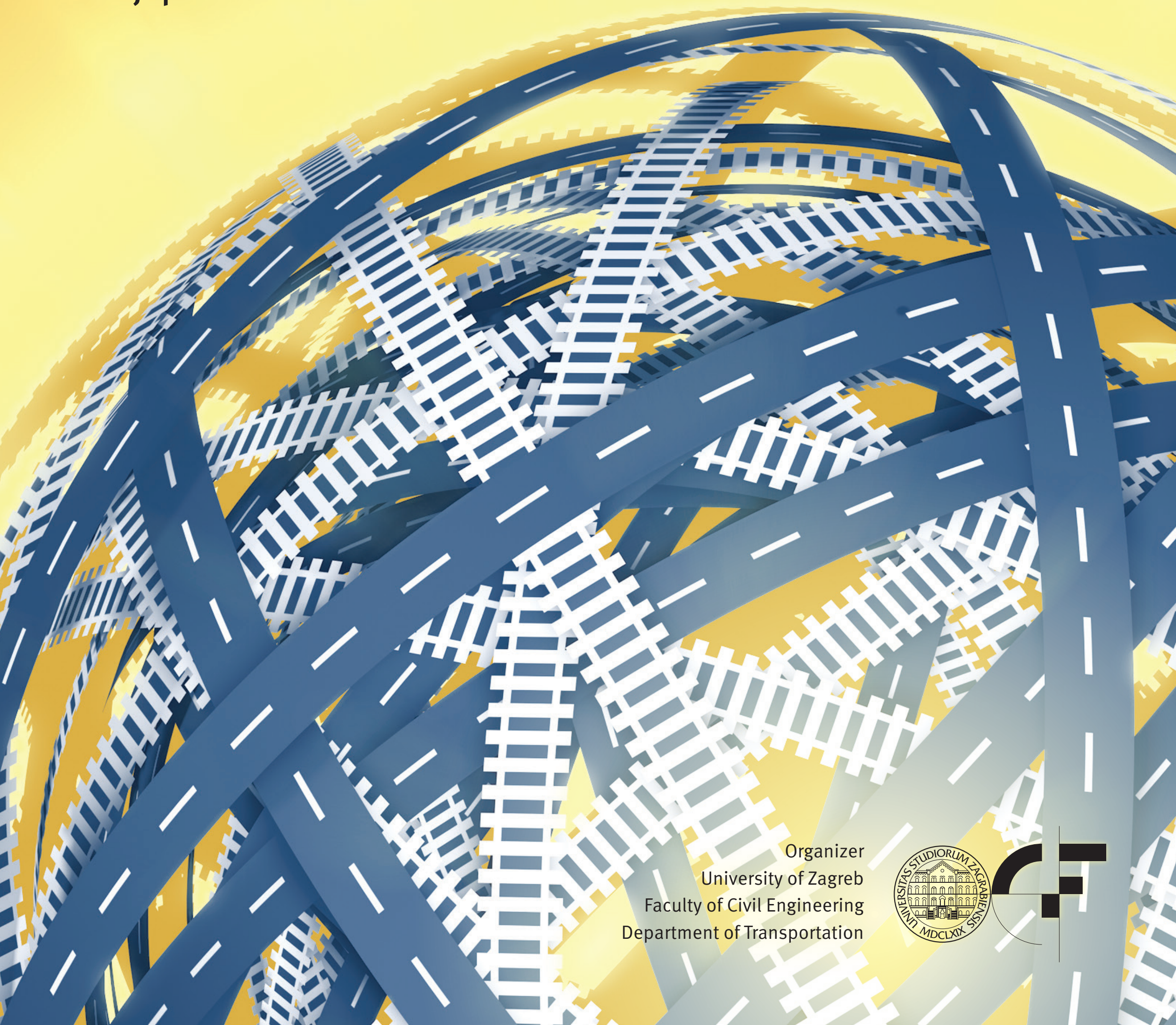
CETRA[2016]

4th International Conference on Road and Rail Infrastructure
23–25 May 2016, Šibenik, Croatia

Road and Rail Infrastructure IV

Stjepan Lakušić – EDITOR



Organizer
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Faculty of Civil Engineering
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4th International Conference on Road and Rail Infrastructure
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TITLE
Road and Rail Infrastructure IV, Proceedings of the Conference CETRA 2016

EDITED BY
Stjepan Lakušić

ISSN
1848-9850

PUBLISHED BY
Department of Transportation
Faculty of Civil Engineering
University of Zagreb
Kačićeva 26, 10000 Zagreb, Croatia

DESIGN, LAYOUT & COVER PAGE
minimum d.o.o.
Marko Uremović · Matej Korlaet

PRINTED IN ZAGREB, CROATIA BY
“Tiskara Zelina”, May 2016

COPIES
400

Zagreb, May 2016.

Proceedings of the
4th International Conference on Road and Rail Infrastructures – CETRA 2016
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Road and Rail Infrastructure IV

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PROBLEMS OF ELECTRICAL SAFETY IN DEPOTS AND WORKSHOPS FOR SERVICING ELECTRIC TRACTION VEHICLES

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Warsaw University of Technology, Faculty of Electrical Engineering, Poland

Abstract

Electric rolling stock workshops and depots are to be prepared for service of modern rolling stock, typically equipped with power electronic converters and in a case of railway vehicles with a multi-system as well. Presence of catenary, which is supplied by DC or AC voltage, and need to supply wagons by different voltages and use of typical low-voltage 230/400 V 50 Hz installations pose some obstacles due to different requirements towards electric shock protection in AC and DC systems. For DC systems in a catenary/pantograph zone bonding as a protection measure is applied and rails are not to be straight-line grounded due to a stray currents flow, while for AC catenary and in-door electric installations earthing is required. The safety of personnel during normal and emergency operation cases is a pre-requisite of any type of solution, which is to be applied in that kind of areas. So the allowed level of touch voltage is reduced both during a long-term (permanent voltage drops) and short-term (over-voltage, short-circuits) period, furthermore the presence of mix AC and DC components is to be taken into consideration acc. to the EN 50122-3 standards. The technical infrastructure spread-out in depots could cause an unexpected current flow through hidden elements as well as appearance of dangerous potential. In order to reduce possible occurrence of such cases during exploitation it is required, at a design level to undertake a detailed study of methods to assure safety. Additionally tests upon completion of the installation are to be performed as well. The paper presents safety measures implemented in a newly build depot of electric rolling stock in Poland. The paper discusses the problems of electric shock-protection coordination in depots and workshops of electric traction vehicles. Furthermore, the results of analysis of electric shock voltage under normal and different fault conditions of operation are described. A multi-track model of a return network was applied in the analysis, which allowed assessing values of maximum voltages which could appear during fault conditions. A study-case of a protection system for devices and installation requiring grounding or bonding, whilst maintaining isolation of rails from earth has been presented as well.

Keywords: tram, electric shock-protection, catenary, depots, earthing

1 Introduction

In the halls used for servicing electric rolling stock one might come across potential dangers from DC constant and AC alternating voltage. There are catenaries supplied with 600 V constant voltage for trams or with 3 kV for trains. Installation and devices with 230/400 V 50 Hz supply are also used. The DC traction supply system requires structures in a danger zone to be bonded. Both AC installations and structures inside the halls need to be earthed as well. At the same time, rails of the tracks shall be isolated from earth in order to provide protection against stray currents [2]. Technical requirements for an electric traction supply system, which is implemented by an overhead contact line and a return network, pertain to, among other things, safety of personnel and reduction of negative influence on devices and elements of infrastructure in the area of electrified transport system (short-circuits, effective touch voltages, voltage drops, EMC, stray currents).

2 Permissible line-to-ground voltages

To ensure safety of both personnel and electrical devices some restrictions are imposed on voltages and time of their occurrence in a rail return network and bonded elements in relation to the surrounding earth and the earthed parts. These restrictions ensue from the PN-EN 50122-1:2011 Standard [1]. As far as the workshops are concerned, a permissible long-term DC constant touch voltage is 60 V. Theoretically, during isolation failure, both constant and alternating voltages might appear. For such overlapping of voltages Standard [4] requires the presented below characteristics (Fig. 1) to be fulfilled. Higher voltages are permitted, however with shorter times.

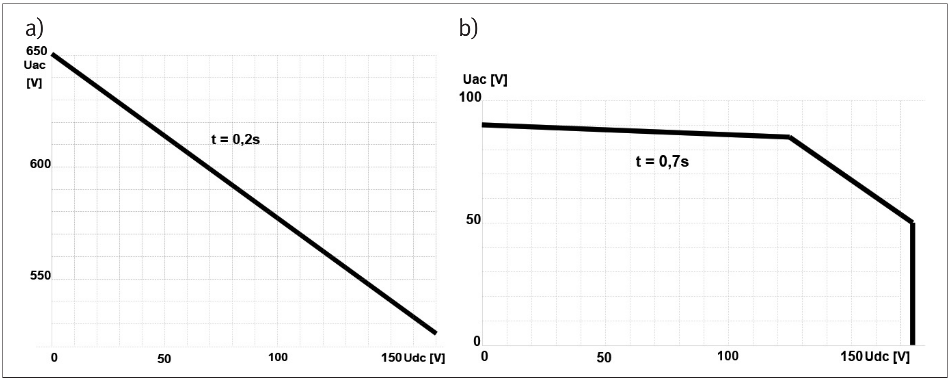

Figure 1 Example of permitted levels of AC and DC combined voltages for time a) 0.2 s and b) 0.7s [5]

Values of line-to-ground voltages depend on the values of maximum currents and resistance in circuits. In order to determine the parameters of current and voltage, it is required to develop a model of a supply system and conduct calculations [6, 7].

3 Exemplary model of a contact line for a multiple track system

In workshops of tramway traction supplied with 600 V system voltage occur higher traction currents than in railway workshops that are supplied with 3 kV system voltage. What is necessary for extensive track systems is an analysis of currents and voltages that might appear between the rails and earth, which would be conducted by means of a complex model [6, 11]. Normal and emergency (short-circuit) operation conditions are subject to analysis. Exemplary 10-track model for a tram hall is presented in Fig. 2. The model includes the parameters of a substation, traction feeders and return cables as well. Rails of the electrified tracks might be electrically connected in a permanent manner with tracks' rails in the area outside the hall. Such solution eliminates the need of using separated rectifier units for the tracks in a hall. Thus, both operational currents and short-circuit currents can flow through the tracks in the hall and outside the hall. Voltage level between the rails of electrified tracks and the earthed elements or earth is the basic criterion that is determined during the analysis. The adopted system of rails that are isolated from earth causes changes in voltage to earth, depending on the values of currents and their flow path. Due to this fact the analyses are conducted for the least favourable cases of return system emergency operation. The results of calculations pertain to voltage between the analysed track point in the hall and the negative bus of a traction substation. In the present case two operating states have been examined:

- emergency mode operation (unlikely) – when only one return cable connected to a hall's track system operates. Resistance of a hall's earth electrode is considerably larger than the resistance of a substation's earth electrode and rail-to-ground leakage resistance.
- normal mode operation – when in the area of a depot all return cables operate. Resistance of a hall's earth electrode is compliant with the project, lower than or comparable to the substation's earth electrode resistance.

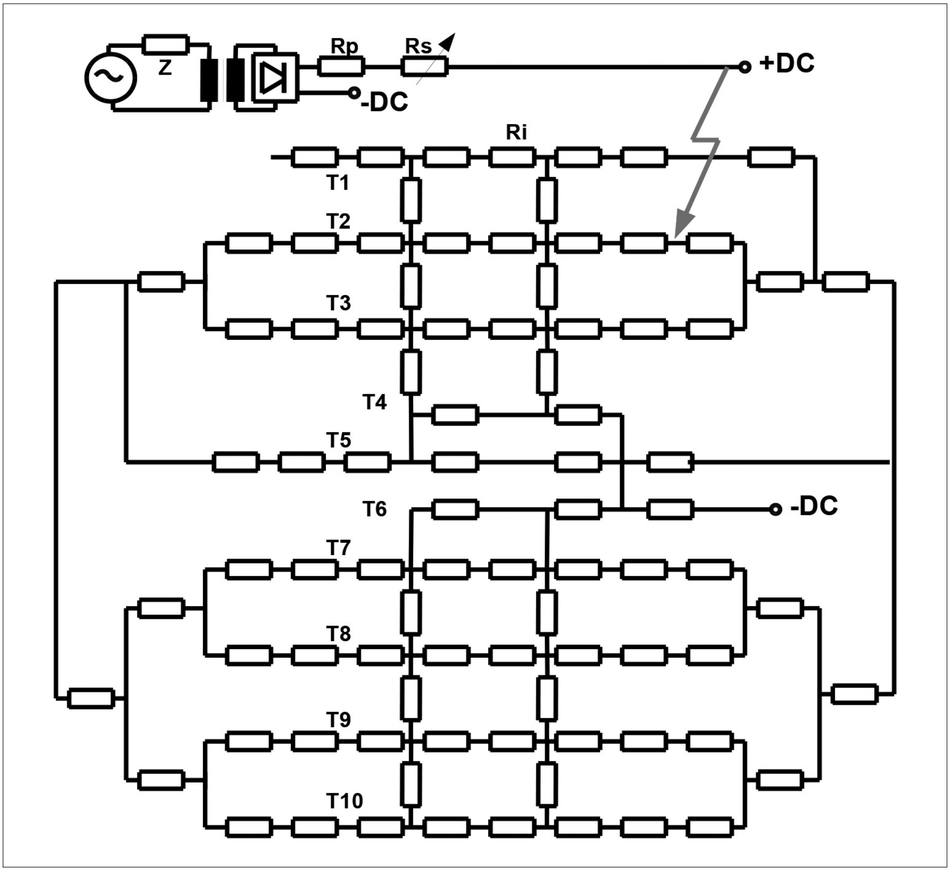

Figure 2 Diagram of the power supply system of the analysed 10-track (T) tram depot and hall

3.1 Normal operation mode (load)

In the state of load, currents flowing in all tracks, both inside and outside the hall, influence the voltage levels. Influence of tram currents (outside the hall) is limited and dispersed. For the purpose of the analysis one has assumed an extreme case, in which hall's tracks are connected to the negative buses of a traction substation only with one return cable. Impact of trams outside the halls has been omitted. However, current flowing in the analysed track is the most important element. Current consumed by one tram depends on a ride phase and tram's speed. Speed limit to several km/h and acceleration limits in the area of a depot results in current limits – current consumed by one tram shall not exceed 400 A.

During the analysis, one included a borderline case of simultaneous start-up of 2 trams and a flow of standstill currents of 4 trams, which has increased current up to 1000 A. Voltage levels between the tracks' rails and earth for alternating current of 1000 A in each case, under the most unfavourable conditions with only one return cable operating, have the value of 11 V. In a normal operation mode of the power supply system (two return cables operating), this value is several times lower. Voltages are therefore lower than the allowable continuous voltage of 60 V.

3.2 Short-circuit mode – cleared by a high speed breaker (HSB) and a convection power breaker

Metallic short-circuits are characterised by a rapid increase of current with time constant of a dozen of milliseconds. When operating properly, high speed breakers can limit the maximum value of current to approx. 4 kA. Short-circuit clearance occurs in less than 0.1 s. Results of voltage levels between the tracks' rails and earth for alternating current of 4000 A in each case, under the most unfavourable emergency conditions, have the value of up to 45 V. They are also lower than the allowable continuous voltage of 60 V. Current of a metallic short-circuit can reach a set value in a case of high speed breaker failure (lock). Due to high values of power supply system short-circuit power and expected simultaneous operation of rectifier units under steady states, these currents can exceed 20 kA. High speed breaker that does not operate properly (closed) limits the maximum value of current only to a small extent and does not stop its flow. These phenomena are of changeable nature, hence it is difficult to estimate influence of such a breaker on the value of steady-state current. For this case the analyses of short-circuit current values have been assumed as for the metallic short-circuit, and without a limiting effect. Switching off of power supply takes place using a power breaker (PCB) on the side of alternating current in less than 0.2 s. Fig. 3 shows an exemplary initial process of short-circuit that is cleared by a power breaker when there is a failure of a high speed breaker.

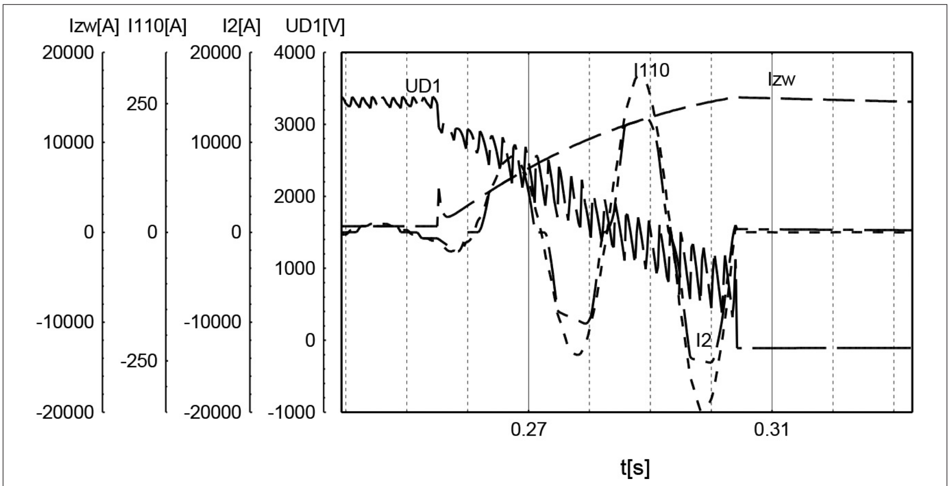

Figure 3 Exemplary waveform of Izw short-circuit current with a faulty high speed breaker (HSB) (short-circuit clearance by a power breaker (PCB) on the AC side of substation supply – 110 kV 50 Hz – current I110)

For this case one has conducted an analysis of borderline states. The obtained results of voltage levels between tracks' rails and earth for short-circuit with a steady current for all the cases are up to 195 V, with duration time of 0.2 s (under the most unfavourable emergency conditions). The analysis and calculations of the system have been conducted in an exemplary hall, with all return cables operating (normal operation mode), and they showed that voltage between a short-circuit point and a negative bus of a substation is 66 V. Upon taking into account distribution of line-to-ground voltages in relation to local earth, voltage shall not exceed the value of 33 V. Voltages, both in the normal and emergency operation mode, have lower values than the permitted value of 245 V for a duration time of 0.2 s. In order to reduce voltages between rails and earthed structures, it is required to connect earthing circuits with the rails by means of limiters. When operating in the emergency mode, voltage between the rails and earthing in the hall shall activate an electronic limiter TZD, thus reduce voltage to 2 V in 1 ms.

3.3 State of short-circuit to earthing circuit

In case of a short-circuit of an overhead contact line to elements connected to earthing (insulator failure), line voltage of 600 V or 3 kV might appear at certain points of the structure. When voltage exceeds 60 V, an electronic voltage limiter of TZD type shall be activated, as in case of the system presented in Fig. 4, and voltage in the structure will be reduced to 2 V in 1 ms. Until tripping of a limiter thyristor (time up to 1 ms), voltage is limited to the level of approx. 300 V by varistors [3].
Permitted voltage for time of less than 20 ms is 870 V. Earth fault shall also activate electronic earth fault protection (EZZ). In a traction substation, when voltage between a rail and an earth electrode is too high, the EZZ closes the negative rail with the earth electrode (activation range from 80 to 140 V DC). In the event of continued earth fault (not cleared by an appropriate high speed breaker), the EZZ forces the power breaker to disconnect rectifier units of a traction substation.
Maximum voltage between the rails in a hall and earth, and earthed elements during normal operation of a return power supply system does not exceed 60 V, regardless the values of current. It pertains to the states of load, but also to short-circuits that are cleared or not by a high speed breaker of a feeder. In such conditions, the electronic voltage limiter of a TZD type between the rail system and earthing will not trip. Isolation between earthing and rails will remain unchanged; hence the flow of stray currents will not be possible. Fig. 4 shows the proposed protection connections system with the use of TZD limiters.

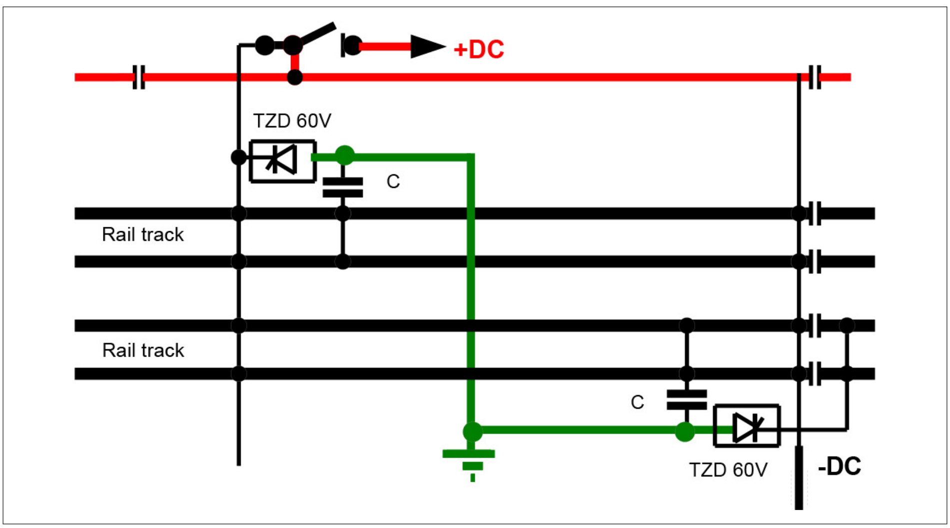

Figure 4 Example of a protection system employing low-voltage limiters for tracks and the earthing circuit in the hall

Such solution also provides protection for halls and devices in the case of a current flow from lightning discharge. Such discharge might take place to a hall's structure or nearby supporting structures of catenary outside the hall. It is necessary to take into account the possibility of several cases of lightning discharge during a year. When a lightning discharge occur – direct lightning strike – current of the main channel is typically 100 kA. Discharge time is several tens of μs. Even when the flowing current is that high, a varistor inside the limiter decreases voltage to approx. 300 V. Voltage limiters TZD are, in most cases, a second, additional level of protection, since the high speed breaker and power breaker provide a sufficiently rapid solution for switching off power supply. They constitute a primary way for limiting a voltage level in the event of failure of the basic protection, earth fault in the hall and lightning discharge that occur in close proximity.

4 Connections of a traction return network in a hall

Solutions that have been widely used in the halls and workshops consist in isolation of the rails from track systems outside the hall and their direct earthing. Such approach resulted from the need to use earthing for electric circuits, housing of devices and hall's structures. The quality of hall's rails isolation from rails on the outside decreases. When the train is entering the hall, short-circuit of the hall's earthing system with the rails on the outside occur. In order to avoid that, rails are switched over in the hall. These solutions are unreliable. Currently, it is also possible to directly connect the electrified tracks' rails with tracks' rails outside the hall. Due to electric corrosion in DC current traction systems, rails, as the elements of the return circuit, are isolated from earth, and in this case, they are also isolated from earth circuits, which provides protection against stray currents flow – according to the recommendations of the PN-EN 50122-2:2003 Standard [2]. Availability of electronic – thyristor TZD limiters [3] enables maintaining isolation between the rails of the traction system and earthed elements for the permissible voltage level. At the same time, the limiters provide a constant control of voltage between earth (earthing system) and rails. Exceeding permissible voltage will result in these circuits being closed by a thyristor. It is an element of protection against electric shock. Time of occurrence of voltage, which is restricted by varistors to approx. 300 V, before activation of the thyristor is approx. 1 ms. After interrupting the current flow, the limiter returns to a state, in which it provides isolation for these two circuits.
Non-traction electric devices and structures in the hall shall be earthed. The earthing system should not be directly connected with a traction rails system. Capacitor's capacitance of several μF will provide such flow of AC current so a residual current device operates properly. This breaker will switch-off a device supplied from a 50 Hz network in a case of an isolation breakdown and flow of current to the rails. Capacitor's capacitance depends on the required value of residual current.

5 Conclusions

The paper discusses problems of electric shock-protection coordination in depots and workshops of electric traction vehicles supplied by DC voltage. Some exemplary safety measures implemented in a newly build depot of electric rolling stock in Poland are presented. Results of analysis of electric shock voltage under normal and different fault conditions of operation are described. A multi-track model of a return network was applied in the analysis. Assessment of values of maximum voltages, which could appear during fault condition has been performed with comparison to proper safety standards. A study-case of a protection system with application of electronic earth fault protection for devices and installations requiring grounding or bonding with assuring isolation of rails from earth during normal operation is presented. The results of analysis confirmed effectiveness of the applied solutions.

References

[1] PN-EN 50122-1:2011 – Zastosowania kolejowe – Urządzenia stacjonarne – Bezpieczeństwo elektryczne, uziemianie i sieć powrotna – Część 1: Środki ochrony przed porażeniem elektrycznym

[2] PN-EN 50122-2:2003 (U) – Zastosowania kolejowe. Urządzenia stacjonarne. Część 2: Środki ochrony przed oddziaływaniem prądów błądzących wywołanych przez trakcję elektryczną prądu stałego

[3] PN-EN 60099-5:1999 Ograniczniki przepięć. Zalecenia wyboru i stosowania. (ze zmianą A1:2004)

[4] PN-EN 50122-3:2011 – Zastosowania kolejowe – Urządzenia stacjonarne – Bezpieczeństwo elektryczne, uziemianie i sieć powrotna – Część 3: Oddziaływanie wzajemne systemów trakcji prądu przemiennego i stałego

[5] Szeląg, A.: Obliczanie tramwajowej sieci powrotnej w celu zmniejszenia upływu z szyn jezdnych prądów błądzących. Konf. N-T "Trakcja elektryczna w komunikacji miejskiej " TRAM'96, Gdańsk 9-11 V 1996, pp. 95-102

[6] Drążek, Z., Mierzejewski, L., Szeląg, A.: Obliczenia metodami analitycznymi parametrów sieci zasilającej i powrotnej układów zasilania trakcji tramwajowej (2). Technika Transportu Szynowego 9/2001, pp. 25-33

[7] Drążek, Z., Mierzejewski, L., Szeląg, A.: Metoda symulacyjna obliczania obciążeń sieci tramwajowej. Technika Transportu Szynowego 2/2002, pp. 66-76

[8] http://www.elester-pkp.com.pl/ezz.php

[9] Szeląg A., Maciołek T.: A 3 kV DC electric traction system modernisation for increased speed and trains power demand-problems of analysis and synthesis. Przegląd Elektrotechniczny 3a/2013, pp. 21-28

[10] Szeląg, A., Mierzejewski, L.: Ground transportation systems (in) Encyclopaedia of Electrical and Electronic Engineering, Supplement I, John Wiley & Sons, pp. 169-194, 1999

[11] Szeląg, A.: Применение моделей и технологий моделирования как методов для технико-экономического обоснования и проектирования систем тягового электроснабжения, Электрификация транспорта, pp. 56-65. 8/2014