



RELIABILITY AND OPERATING PROPERTIES OF THE ELECTRONIC SAFETY SYSTEM USED FOR UNINTENDED ELECTROMAGNETIC RADIATION SOURCES

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Abstract

The advanced electronic devices used in the safety systems function in a particular environment depending on the facility in which they are installed. Typically, quite diverse operating conditions occur. Thus, the proper functioning of electronic systems depends not only on the reliability of individual components constituting the system, but also on the level of electromagnetic interference that can be generated by external sources. The article presents selected issues related to the impact of electromagnetic interference on electronic safety systems. In this regard, the measurements were taken into account for a facility over which there were two power lines with a 110 kV rated voltage, while a power line with a 220 kV voltage was located in the near (10 m) vicinity. The reliability and operating analysis that takes into account the electromagnetic interference was carried out. It allows to assess various types of solutions that can be implemented in order to minimise the impact of electromagnetic interference on the operation of the electronic safety systems.

Keywords: reliability, operation, electromagnetic interference, electronic devices

WŁASNOŚCI NIEZAWODNOŚCIOWO-EKSPLOATACYJNE ELEKTRONICZNEGO SYSTEMU BEZPIECZEŃSTWA UŻYTKOWANEGO PRZY NIEZAMIERZONYCH ŹRÓDŁACH PROMIENIOWANIA ELEKTROMAGNETYCZNEGO

Streszczenie

Zaawansowane urządzenia elektroniczne stosowane w systemy bezpieczeństwa funkcjonują w określonym środowisku uzależnionym od obiektu w jakim są zainstalowane. Zazwyczaj występują dość zróżnicowane warunki eksploatacyjne. Zatem poprawne funkcjonowanie układów elektronicznych jest uzależnione nie tylko od niezawodności poszczególnych części składowych tworzących system, ale także od poziomu zakłóceń elektromagnetycznych, które mogą być generowane przez zewnętrzne źródła. W artykule przedstawiono wybrane zagadnienia związane z oddziaływaniem zakłóceń elektromagnetycznych na elektroniczne systemy bezpieczeństwa. Uwzględniono przy tym pomiary dla obiektu, nad którym przebiegały dwie linie energetyczne o napięciu znamionowym 110 kV, zaś w bliskim (10 m) sąsiedztwie budynku znajdowała się linia o napięciu 220 kV. Została przeprowadzona analiza niezawodnościowo-eksploatacyjna uwzględniająca zakłócenia elektromagnetyczne. Umożliwia to ocenę różnego rodzaju rozwiązań, które mogą być wdrożone w celu zminimalizowania wpływu zakłóceń elektromagnetycznych na funkcjonowanie elektronicznych systemów bezpieczeństwa.

Słowa kluczowe: niezawodność, eksploatacja, zakłócenia elektromagnetyczne, urządzenia elektroniczne

1. INTRODUCTION

The electronic safety systems are operated under different conditions of their surrounding electromagnetic environment [3, 20]. From the scientific perspective, the environment occurring in the vast railway area is particularly interesting. The reason for this situation includes numerous intended and unintended (static and mobile) electromagnetic interference, which may interfere with the functioning of electronic devices [8, 10], and thus, result in a decrease in the readiness indicator value.

Since the electronic safety systems function in the transport process and provide protection for travellers [7, 13], their reliable functioning is so important [5, 14].

The electronic safety systems functioning in the railway transport facilities are used in the particular electromagnetic environment [11, 15, 18]. The natural electromagnetic environment shaped by the phenomena that occur on the Earth is most often seriously distorted within the railway area. It is caused by the occurrence of a large number of electromagnetic field sources radiating in intended

or unintended ways [4]. An electrical or electronic device powered by electricity generates its own electromagnetic field. It is associated with its operation. Within the railway area, there are the electronic safety systems which should operate properly irrespective of interference having an impact on them (in the acceptable range of levels). The systems' mutual coexistence as well as their proper functioning within the railway area in the particular electromagnetic environment, and operation without the implementation of unacceptable interference to the environment were defined as electromagnetic compatibility.

The issue of assessing the impact of electromagnetic interference on the operation of railway equipment is considered in a wide sense. In the publication [6], the authors presented the issues on the Mass Rapid Transit project and the high probability (by using the electronic devices) of increasing the emissions of electromagnetic radiation to the surrounding environment. The EMC measurement results within the railway area, which allowed to assess whether the permissible levels are not exceeded, were presented. The obtained test results allowed to conclude whether the measured values meet the requirements in the scope of electromagnetic compatibility included in the IEC (International Electrotechnical Commission) standards.

A part of the research communities analyses the impact of the operation of devices used in mobile means of railway transport, among others, on the railway traffic control equipment. Such an approach was presented in the publication [19]. The emission model for electromagnetic interference emitted by the Eddy Current Brakes (ECB) system affecting the trackside equipment was presented. Such an approach, at the design stage, allows to apply the specific construction in the railway traffic control equipment in order to limit the adverse impact of electromagnetic interference emitted by ECB.

A very important issue is also the assessment of electromagnetic compatibility taking into account the impact of lightning on the operation of electronic devices used in the railway transport. The electronic devices are applied in many systems used in the railway transport (e.g., railway traffic control systems, systems installed at level crossings, GSM-R (Global System for Mobile Communications – Railway), visual monitoring systems, etc.). The considerations in this area were presented in the paper [21]. The previously implemented methods of protection against adverse phenomena of this type were presented. Furthermore, the solutions aimed at increasing the efficiency of protection (i.a., through arrangement of electronic devices adequate to the environmental conditions already at the design stage of systems and protective elements) were proposed.

The considerations carried out so far (presented above) in the field of electromagnetic compatibility of the electronic devices used in the railway

transport do not include reliability and operational modelling. Therefore, the authors of this article decided to apply such an approach.

The article presents the measurements of the electromagnetic field emitted by high-voltage power lines running near the tested civil structures. The analysis of the obtained results allows to develop a research model of the electronic safety system, and to carry out a further reliability-operational analysis, taking into account electromagnetic interference.

2. ELECTROMAGNETIC INTERFERENCE OCCURRING IN THE RAILWAY AREA

The electromagnetic compatibility concept can be defined as the possibility of the useful signal and interference coexistence without the loss of information included in the signal. By extending the compatibility concept in the application for the electronic safety systems, the definition can be formulated as follows: an element of the electromagnetic environment of the electronic safety system is considered compatible, if the mutual interaction of a given element (e.g. control panel, expansion modules, manipulators, etc.) with other elements of this environment (e.g. rail traffic control systems, railway station lighting systems, power supply systems, railway telecommunications systems, etc.) can be mutually tolerated [1, 9].

The electronic safety systems operated in the large railway area are susceptible to the electromagnetic interference impact. Long distances between the individual devices, which form the system, result in the necessity to use the power supply and signal cables as well as transmission buses with significant lengths. It may be a reason for the induction of interference signals in them, and at the same time, it may cause the system malfunctioning. It is particularly important in case of functioning in their close distance from the transmission power lines. Therefore, the authors measured the electromagnetic field parameters at high-voltage power lines that run close to the tested civil structures.

The measurements were made in the adjacent area and inside the single-floor building including office rooms. Above the building, there were two power lines with a rated voltage of 110 kV. In the vicinity of the building, there was a 220 kV voltage line, which was approximately 10 m away from the property.

The measurements on the property (outside the building) and in the ground floor workshop part were carried out at every 1 m, in the direction perpendicular to the transmission lines. The ranges of the measured values of electric and magnetic fields, with a frequency of 50 Hz, on the square in front of the building, were given in Table 1.

Table 1. The ranges of the measured values of the electric field strength E and magnetic induction B on the premises around the building

Measurement place	Range of the electric field strength values E [V/m]	Range of the magnetic induction values B [μ T]
In front of the building	100 – 520	0,27 - 0,963
Behind the building	130 – 550	0,23 - 0,694

The measurements inside the building were carried out after performing a preliminary diagnosis in the entire space of each tested room. During the measurement of the electric field strength in the building, in most rooms, very low values of this parameter (a few to several V/m) were found. Only at some measurement points, E values of 100 V/m or more were obtained. On the first floor, the maximum value of the field was approximately 126 V/m, and on the ground floor of the building, the value of this field reached several V/m. The reason for this is that the electric field is strongly attenuated by the ceilings and walls of the building.

The magnetic field from the power lines only slightly attenuates because building obstacles (ceilings, walls) fundamentally do not affect the propagation of the electromagnetic wave from this frequency range.

The magnetic induction values in the rooms were in the range from 0.3 μ T to 3.6 μ T, with a significant variation in the value of B between individual rooms. The limit values of the magnetic induction B , found on individual floors (in the tested rooms), are included in Table 2.

Table 2. The ranges of the magnetic induction value B in the rooms on individual floors of the building

Name of the tested room (floor)	Range of B values [μ T]
Conference room (basement)	0.40 - 0.60
Reception (ground floor)	0.80 - 1.00
Room 1 (ground floor)	0.30 - 0.60
Room 2 (ground floor)	0.29 - 3.00
Room 3 (ground floor)	0.39 - 0.80
Utility room (ground floor)	0.60 - 1.59
Workshop (ground floor)	0.28 - 0.93
Passageways (1st floor)	1.80 - 3.20
Room 4 (1st floor)	0.99 - 3.60

All the measurements were carried out at positive outside temperatures and air humidity close to normal.

3. RELIABILITY AND OPERATION ANALYSIS OF THE ELECTRONIC SAFETY SYSTEM INCLUDING ELECTROMAGNETIC INTERFERENCE

The operation process models of the electronic safety systems used in railway transport, including electromagnetic interference, require the analysis of their functioning in actual conditions (also

including the diagnostic signals [2, 16, 17]). Therefore, it is possible to obtain the relationships, which allow to determine the values of probabilities of the considered systems staying in the distinguished operation states [12].

By conducting the operation analysis of the electronic safety systems used in railway transport, including electromagnetic interference, it is possible to illustrate the relationships occurring in this structure, in terms of reliability and operation, as it is presented in Fig. 1.

If the electronic safety system is in the state of complete usability S_{PZ} and there is electromagnetic interference (in the acceptable range), the system transits to the state of impendancy over safety S_{ZB1} with the intensity λ_{ZB1} . If the system is in the state of impendancy over safety S_{ZB1} , it is possible to transit into the state of complete usability S_{PZ} with the intensity μ_{ZB1} provided that the activities on reducing the electromagnetic interference consequences are undertaken.

If the electronic safety system is in the state of impendancy over safety S_{ZB1} and there is electromagnetic interference (exceeding the permissible values, but the system still operates), the system transits into the state of impendancy over safety S_{ZB2} with the intensity λ_{ZB2} . If the system is in the state of impendancy over safety S_{ZB2} , it is possible to transit into the state of impendancy over safety S_{PZ} with the intensity μ_{ZB2} provided that the activities on reducing the electromagnetic interference consequences (to the level of permissible values) are undertaken.

If the electronic safety system is in the state of impendancy over safety S_{ZB2} and there is electromagnetic interference (exceeding the permissible values and resulting in the system operation interruption), the system transits into the state of unreliability of safety S_B with the intensity λ_{ZB3} . If the system is in the state of unreliability of safety S_B , it is possible to transit into the state of impendancy over safety S_{ZB2} with the intensity μ_{ZB3} provided that the activities on reducing the electromagnetic interference consequences (to the level exceeding the permissible values, but the system still operates) are undertaken.

If the electronic safety system is in the state of impendancy over safety S_{ZB2} , it is possible to transit into the state of complete usability S_{PZ} with the intensity μ_{B0} provided that the activities on reducing the electromagnetic interference consequences (to the level below the permissible values) are undertaken.

If the electronic safety system is in the state of unreliability of safety S_B , it is possible to transit to the state of complete usability S_{PZ} with the intensity μ_{B1} provided that the activities on reducing the electromagnetic interference consequences (to the level below the permissible values) were undertaken.

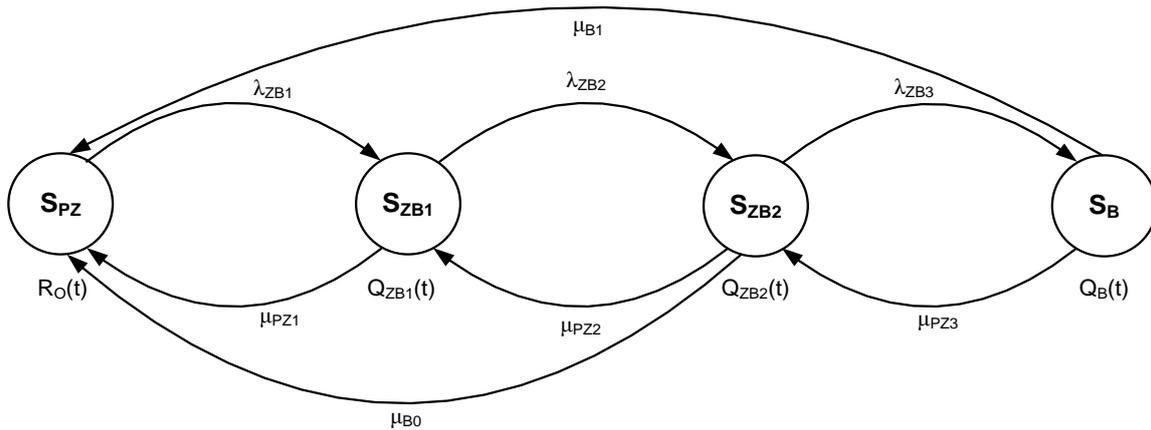


Fig. 1. Relationships in the electronic safety system including the electromagnetic interference [source: own development] Markings in Fig.: $R_0(t)$ – probability function of the system staying in the state of complete usability S_{PZ} , $Q_{ZB1}(t)$ – probability function of the system staying in the state of impedency over safety S_{ZB1} , $Q_{ZB2}(t)$ – probability function of the system staying in the state of impedency over safety S_{ZB2} , $Q_B(t)$ – probability function of the system staying in the state of unreliability of safety S_B , λ_{ZB1} – intensity of transitions from the state of complete usability S_{PZ} to the state of impedency over safety S_{ZB1} , λ_{ZB2} – intensity of transitions from the state of impedency over safety S_{ZB1} to the state of impedency over safety S_{ZB2} , λ_{ZB3} – intensity of transitions from the state of impedency over safety S_{ZB2} to the state of unreliability of safety S_B , μ_{ZB1} – intensity of transitions from the state of impedency over safety S_{ZB1} to the state of complete usability S_{PZ} , μ_{ZB2} – intensity of transitions from the state of impedency over safety S_{ZB2} to the state of impedency over safety S_{ZB1} , μ_{ZB3} – intensity of transitions from the state of unreliability of safety S_B to the state of impedency over safety S_{ZB2} , μ_{B0} – intensity of transitions from the state of impedency over safety S_{ZB2} to the state of complete usability S_{PZ} , μ_{B1} – intensity of transitions from the state of unreliability of safety S_B to the state of complete usability S_{PZ} .

The system presented in Fig. 1 can be described by the following Chapman–Kolmogorov equations:

$$\begin{aligned} \dot{R}_0(t) &= -\lambda_{ZB1} \cdot R_0(t) + \mu_{PZ1} \cdot Q_{ZB1}(t) + \mu_{B0} \cdot Q_{ZB2}(t) + \mu_{B1} \cdot Q_B(t) \\ \dot{Q}_{ZB1}(t) &= \lambda_{ZB1} \cdot R_0(t) - \mu_{PZ1} \cdot Q_{ZB1}(t) - \lambda_{ZB2} \cdot Q_{ZB1}(t) + \\ &+ \mu_{PZ2} \cdot Q_{ZB2}(t) \\ \dot{Q}_{ZB2}(t) &= \lambda_{ZB2} \cdot Q_{ZB1}(t) - \mu_{PZ2} \cdot Q_{ZB2}(t) - \lambda_{ZB3} \cdot Q_{ZB2}(t) + \\ &+ \mu_{PZ3} \cdot Q_B(t) - \mu_{B0} \cdot Q_{ZB2}(t) \\ \dot{Q}_B(t) &= \lambda_{ZB3} \cdot Q_{ZB2}(t) - \mu_{PZ3} \cdot Q_B(t) - \mu_{B1} \cdot Q_B(t) \end{aligned} \quad (1)$$

Assuming the baseline conditions:

$$R_0(0) = 1 \quad (2)$$

$$Q_{ZB1}(0) = Q_{ZB2}(0) = Q_B(0) = 0$$

and applying the Laplace transform, we obtain the following system of linear equations:

$$\begin{aligned} s \cdot R_0^*(s) - 1 &= -\lambda_{ZB1} \cdot R_0^*(s) + \mu_{PZ1} \cdot Q_{ZB1}^*(s) + \mu_{B0} \cdot Q_{ZB2}^*(s) + \\ &+ \mu_{B1} \cdot Q_B^*(s) \\ s \cdot Q_{ZB1}^*(s) &= \lambda_{ZB1} \cdot R_0^*(s) - \mu_{PZ1} \cdot Q_{ZB1}^*(s) - \lambda_{ZB2} \cdot Q_{ZB1}^*(s) + \\ &+ \mu_{PZ2} \cdot Q_{ZB2}^*(s) \\ s \cdot Q_{ZB2}^*(s) &= \lambda_{ZB2} \cdot Q_{ZB1}^*(s) - \mu_{PZ2} \cdot Q_{ZB2}^*(s) - \lambda_{ZB3} \cdot Q_{ZB2}^*(s) + \\ &+ \mu_{PZ3} \cdot Q_B^*(s) - \mu_{B0} \cdot Q_{ZB2}^*(s) \\ s \cdot Q_B^*(s) &= \lambda_{ZB3} \cdot Q_{ZB2}^*(s) - \mu_{PZ3} \cdot Q_B^*(s) - \mu_{B1} \cdot Q_B^*(s) \end{aligned} \quad (3)$$

The probabilities of the system staying in the distinguished functional states from the symbolic (Laplace's) perspective have the following form:

$$R_0^*(s) = \frac{b \cdot \lambda_{ZB3} \cdot \mu_{PZ3} - b \cdot c \cdot d \cdot s + d \cdot s \cdot \lambda_{ZB2} \cdot \mu_{PZ2}}{a \cdot b \cdot \lambda_{ZB3} \cdot \mu_{PZ3} + \mu_{B1} \cdot \lambda_{ZB1} \cdot \lambda_{ZB2} \cdot \lambda_{ZB3} + \\ - \lambda_{ZB1} \cdot \mu_{PZ1} \cdot \lambda_{ZB3} \cdot \mu_{PZ3} + a \cdot d \cdot s \cdot \lambda_{ZB2} \cdot \mu_{PZ2} + \\ + c \cdot d \cdot s \cdot \lambda_{ZB1} \cdot \mu_{PZ1} + d \cdot s \cdot \mu_{B0} \cdot \lambda_{ZB1} \cdot \lambda_{ZB2} + \\ - a \cdot b \cdot c \cdot d \cdot s}$$

$$Q_{ZB1}^*(s) = \frac{\lambda_{ZB1} \cdot \lambda_{ZB3} \cdot \mu_{PZ3} - c \cdot d \cdot s \cdot \lambda_{ZB1}}{a \cdot b \cdot \lambda_{ZB3} \cdot \mu_{PZ3} + \mu_{B1} \cdot \lambda_{ZB1} \cdot \lambda_{ZB2} \cdot \lambda_{ZB3} + \\ - \lambda_{ZB1} \cdot \mu_{PZ1} \cdot \lambda_{ZB3} \cdot \mu_{PZ3} + a \cdot d \cdot s \cdot \lambda_{ZB2} \cdot \mu_{PZ2} + \\ + c \cdot d \cdot s \cdot \lambda_{ZB1} \cdot \mu_{PZ1} + d \cdot s \cdot \mu_{B0} \cdot \lambda_{ZB1} \cdot \lambda_{ZB2} + \\ - a \cdot b \cdot c \cdot d \cdot s}$$

$$Q_{ZB2}^*(s) = \frac{d \cdot s \cdot \lambda_{ZB1} \cdot \lambda_{ZB2}}{a \cdot b \cdot \lambda_{ZB3} \cdot \mu_{PZ3} + \mu_{B1} \cdot \lambda_{ZB1} \cdot \lambda_{ZB2} \cdot \lambda_{ZB3} + \\ - \lambda_{ZB1} \cdot \mu_{PZ1} \cdot \lambda_{ZB3} \cdot \mu_{PZ3} + a \cdot d \cdot s \cdot \lambda_{ZB2} \cdot \mu_{PZ2} + \\ + c \cdot d \cdot s \cdot \lambda_{ZB1} \cdot \mu_{PZ1} + d \cdot s \cdot \mu_{B0} \cdot \lambda_{ZB1} \cdot \lambda_{ZB2} + \\ - a \cdot b \cdot c \cdot d \cdot s}$$

$$Q_B^*(s) = \frac{\lambda_{ZB1} \cdot \lambda_{ZB2} \cdot \lambda_{ZB3}}{a \cdot b \cdot \lambda_{ZB3} \cdot \mu_{PZ3} + \mu_{B1} \cdot \lambda_{ZB1} \cdot \lambda_{ZB2} \cdot \lambda_{ZB3} + \\ - \lambda_{ZB1} \cdot \mu_{PZ1} \cdot \lambda_{ZB3} \cdot \mu_{PZ3} + a \cdot d \cdot s \cdot \lambda_{ZB2} \cdot \mu_{PZ2} + \\ + c \cdot d \cdot s \cdot \lambda_{ZB1} \cdot \mu_{PZ1} + d \cdot s \cdot \mu_{B0} \cdot \lambda_{ZB1} \cdot \lambda_{ZB2} + \\ - a \cdot b \cdot c \cdot d \cdot s}$$

where:

$$a = s + \lambda_{ZB1}$$

$$b = s + \mu_{PZ1} + \lambda_{ZB2}$$

$$c = s + \mu_{PZ2} + \lambda_{ZB3} + \mu_{B0}$$

$$d = s + \mu_{PZ3} + \mu_{B1}$$

By conducting the further mathematical analysis, the relationships which allow to determine the probabilities of the electronic safety system staying in the states of: complete usability S_{PZ} , impendency over safety S_{ZB1} and S_{ZB2} , and unreliability of safety S_B are obtained.

The presented considerations and the developed model allow for numerical assessment of various types of solutions that can be implemented in order to minimise the impact of electromagnetic interference on the functioning of the electronic safety systems.

4. SUMMARY AND CONCLUSIONS

The issues presented in this article, which are related to the electromagnetic compatibility of the electronic safety systems, show the importance of the reliability and operation analysis issues. The use of numerous electronic safety systems results in the fact that they operate located close to each other. It may result in an increase of the interference probability occurrence in their operation. Therefore, while designing the electronic safety systems, it is important to take into account their operation in the actual conditions, that is among other devices. It means that the device operation should not be affected by any external sources of interference, and the electronic safety system itself should not be a source of interference (a concept of external and internal electromagnetic compatibility).

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Prof. Mirosław SIERGIEJCZYK, PhD. Eng. - scientific fields of interest of the paper co-author concern among other issues of architecture and services provided by telecommunications networks and systems, especially from perspective of their applications in transport, reliability and operation of telecommunications networks and systems, modelling, designing and organising telecommunications systems for transport.



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Adam ROSIŃSKI - Associate Professor PhD. Eng. - research interests include Intelligent Transportation Systems, electronics (analog and digital) and issues related to reliability, exploitation, diagnostics and design of electronic security systems (intrusion detection, video surveillance systems, access control systems, fire alarm systems, voice evacuation systems, monitoring systems, systems integration), with special regard to their use in transport. He has academic achievements (as author or co-author) six books and over 100 articles, and many unique solutions in the field of security of a special nature.