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DOI: 10.15199/48.2025.04.10

Analysis of the influence of the earthing structure on the effects of electric shock in electrical installations placed on construction sites

Analiza wpływu konstrukcji uziomu na skutki porażenia prądem elektrycznym w instalacjach elektrycznych użytkowanych na placach budowy

Abstract: *Electrical installations on construction sites are operated under difficult environmental conditions and are often incorrectly utilized and maintained. The above factors increase the risk of electric shock. To reduce it, it is necessary to provide effective electric shock protection, of which grounding is one of the elements. The article presents calculations of the electrical potential distribution of the grounding model using the finite element method in ANSYS. Based on the calculations, the values of touch and step voltages were determined. Then the values of shock currents were calculated for the impedance of the human body determined by three methods. On this basis, the pathophysiological effects caused by the flow of the shock current were estimated.*

Streszczenie: *Instalacje elektryczne na placach budowy eksploatowane są w trudnych warunkach środowiskowych i często są niepoprawnie użytkowane i konserwowane. Powyższe czynniki powodują wzrost ryzyka porażeniem prądem elektrycznym. W celu jego ograniczenia należy zapewnić skuteczną ochronę przeciwporażeniową, której jednym z elementów są uziemienia. W artykule przedstawiono obliczenia rozkładu potencjału elektrycznego modelu uziomu z wykorzystaniem metody elementów skończonych w programie ANSYS. Na podstawie obliczeń wyznaczono wartości napięć dotykowego i krokowego. Następnie obliczono wartości prądów rażeniowych dla impedancji ciała człowieka wyznaczonej trzema metodami. Na tej podstawie oszacowano skutki patofizjologiczne spowodowane przepływem prądu rażeniowego.*

Słowa kluczowe: uziom, napięcie dotykowe, napięcie krokowe, impedancja ciała człowieka.
Keywords: grounding grid, touch voltage, step voltage, human body impedance.

Introduction

The basic task of electrical installations is to provide electricity from the distribution network to receivers. Due to the use time, electrical installations can be divided into permanent and temporary installations. According to [1], use time of temporary installations should not exceed 3 years. Temporary installations include electrical installations on construction or demolition sites. These installations operate in both difficult environmental and operational conditions. The configuration of these installations often changes with the progress of construction works. In addition, many electrical devices are used on construction sites, including hand-held electric devices. It happens that power tools and other devices included in the temporary installation are not properly maintained and repaired. Additionally, considering that construction workers usually do not have professional knowledge in using electrical devices and protecting against electric shocks, the electric shocks, including fatal ones, occur much more often on construction and demolition sites. In 2023, 3,597 accidents occurred in construction, including 39 fatal ones. The accident rate (per 1,000 employees) for cases where the cause was contact with electric current, temperature, hazardous substances or hazardous mixtures and materials containing harmful biological factors is 3.4 [2].

Temporary installations on construction and demolition sites can be powered from existing or purpose-built transformer-distribution stations, LV distribution lines, generating sets or investor installations. It is recommended that temporary installations on construction and demolition sites be made in the TN-S system. For the LV power grid operating in the TN system, operational earthing of the protective or protective-neutral conductor is required. This earthing must be designed and made properly to ensure the safe operation of the network and the correct operation of shock protection measures.

In most cases, LV distribution networks are made in the TN-C system, and at the point of separation of the protective-neutral conductor into neutral and protective conductors, earthing of this point is required.

Usually, earthing in temporary installations is made in the form of the simplest structures, i.e. vertical rods connected with a flat bar (tape) and single-mesh grids with vertical rods placed in the corners of the grid. The requirements for this type of earthing are slightly more lenient in terms of their resistance, compared to the operational earthing of, for example, a power station. According to the guidelines in [1], the resistance of such an earthing R_B should be less than 30 Ω. The value of the earthing resistance is primarily influenced by the soil resistivity ρ and its extent, therefore for high soil resistivity (ρ > 500 Ωm) the inequality (1) should be met.

$$R_{rd} \leq \frac{\rho}{16} \qquad (1)$$

The obtained value of the earthing resistance depends on factors such as the geometric dimensions of the earthing, the type of soil (its resistivity) and environmental conditions: temperature, humidity, and chemical composition of the soil [1-3]. Analytical calculation of the distribution of electric potential on the ground surface above the buried earthing, which is identical to calculating the values of touch and step voltages for complex earthing structures, is very difficult and time-consuming. These calculations can be performed using numerical methods, including the finite element method, which is widely used in electrical engineering and which can also be used in other areas of electrical engineering applications [4-14]. The article presents the results of simulation calculations of the distribution of electric potential on the ground surface for two selected earthing structures, which can be used in temporary installations. Earthing models and simulation calculations were performed in the ANSYS program [15].

Results of calculations of electric potential on the ground surface

For the assumed construction of earthing electrodes and the value of earthing current, calculations of electric potential on the ground surface were made. Figure 1 shows the distribution of electric potential for an earthing electrode built of three vertical rods. Figure 2 shows the distribution of electric potential for the case of a grid earthing electrode with vertical rods.

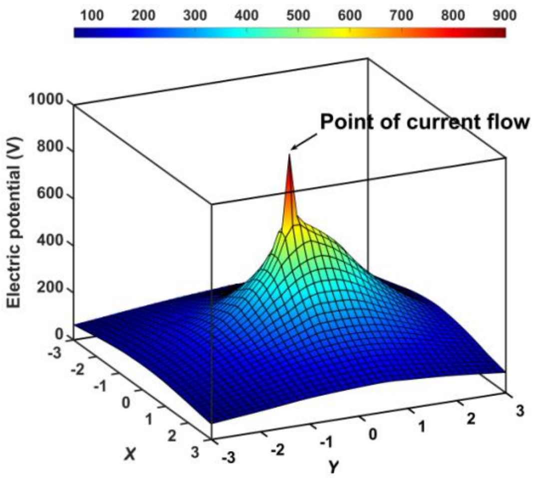

Fig. 1. Distribution of electric potential on the ground surface for an earthing electrode composed of three vertical rods 1.5 m long.

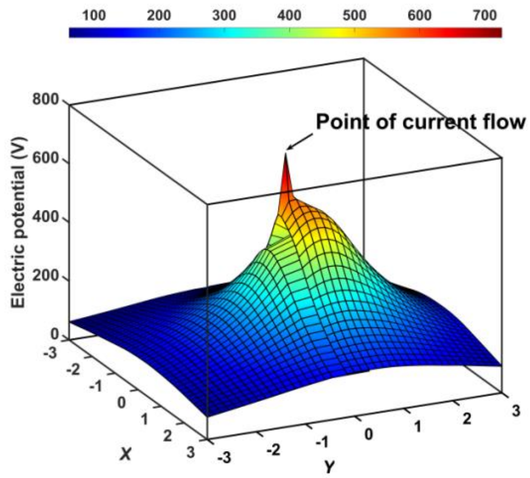

Fig. 2. Distribution of electric potential on the ground surface for a grid earthing with vertical rods 1.5 m long

The shock voltage, step voltage as well as touch voltage, is calculated as the potential difference between the current flow point and a point located 1 m away from it. Analyzing the distribution of electric potential on the ground surface, the maximum values of the shock voltage are listed in Table 1.

Table 1. Step and touch voltages for the analyzed grounding grid constructions

	Step voltage V_{STEP} (V), touch voltage V_{TOUCH} (V)
The grounding system built of three vertical rods of 1.5m in length (Fig.1)	701
The one-eyed grid of the grounding system with vertical rods of 1.5m in length (Fig. 2)	445

Based on the analysis, it can be concluded that for both earthing designs, the touch and step voltages are too high in light of the requirements of the standard [3]. They can cause serious pathophysiological effects caused by the flow of shock current resulting from the values of these voltages.

Calculations of shock currents taking into account work effort and climatic conditions

Work on a construction site is classified as work requiring high physical effort. Additionally, the employee performs work in difficult climatic conditions. During hard work performed at elevated temperatures, the human body secretes a significant amount of sweat. Increased sweat secretion affects the value of the human body impedance. The work [16] presents the results of research on the effect of work effort and climatic conditions on the body impedance of underground miners. Based on the research carried out, the Author in [16] determined an analytical relationship describing changes in the impedance of the human body as a function of the thermal discomfort index δ, shock voltage Ushock and the shock path transformation coefficient ξ (formula 2).

$$Z_{hb} = \frac{70\cdot(1+\delta)^{-0.7}}{\sqrt[3]{U_{\text{shock}}}\cdot\xi} \qquad (2)$$

According to [16], the value of the transformation coefficient of the striking path for the hand-hand striking path was assumed to be $\xi = 6$, and for the hand-foot striking path $\xi = 6$. If the value of the coefficient $\delta < 0$, the work is performed in a cool environment. For work in the most favourable conditions, $0 < \delta < 0.2$ is assumed. Satisfactory working conditions occur for $0.2 < \delta < 0.5$. In the case of work performed in difficult and very difficult conditions, the values of the thermal discomfort coefficient are within the following limits: $0.5 < \delta < 0.8$ and $0.1 < \delta < 1$, respectively. For conditions in which there is a health hazard, $\delta \geq 1$ [16]. The value of the striking current was calculated using formula (3).

$$I_{\text{shock}} = \frac{U_{\text{shock}}}{Z_{\text{hb}}} \quad (3)$$

The results of the shock current calculations for the calculated touch and step voltage values are presented in Figures 3 and 4 for the hand-hand and hand-leg shock paths, respectively.

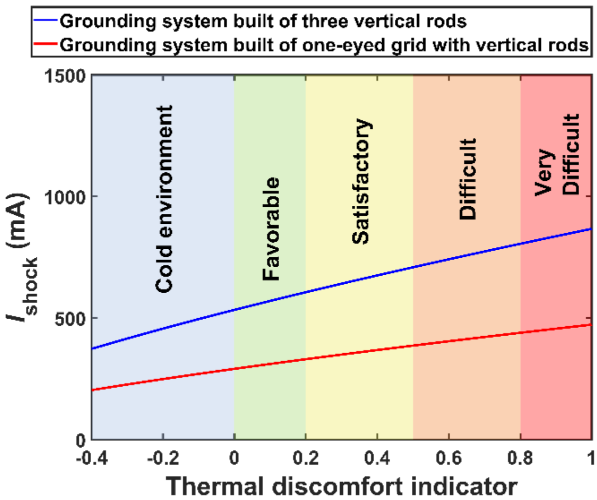

Fig. 3 Calculated values of the shock current for the considered earthing structures and hand-to-hand shock path.

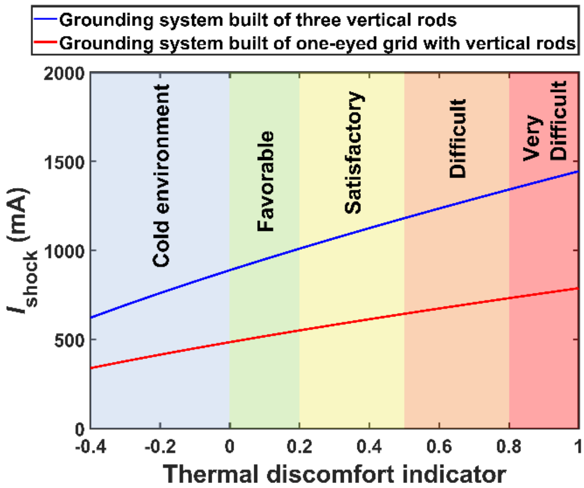

Fig. 4. Calculated values of the shock current for the considered earthing structures and the hand-foot shock path.

Based on the calculations performed, it can be stated that the pathophysiological effects caused by the flow of shock current will pose a threat to human life and health.

Comparison of shock current values calculated for human body impedance under IEEE 80, IEC 60479-1 and work effort and climatic conditions

Under the IEEE 80 [17] standard, the shock current calculations assume a human body impedance value of 1000Ω for all potential shock current flow paths. The human body impedance value determined in accordance with IEC 60479-1 [18] depends on environmental conditions and areas of contact. The standard distinguishes between dry, water - wet and saltwater - wet conditions. For the hand to foot shock path, the IEC 60479-1 [18] standard recommends adopting a factor of 0.8. The human body impedance calculations in accordance with the IEC 60479-1 [18] standard were performed for the following assumptions. It was assumed that the surface areas of contact for hands are medium and for dry and water-wet conditions. For the adopted assumptions, the values of the human body impedance for the 50th percentile rank were read from the appropriate tables of the standard. For a touch/step voltage of 445 V, the value of the human body impedance was calculated as the arithmetic mean of the human body impedance for voltages of 400 V and 500 V. The calculations of the human body impedance taking into account the influence of climatic conditions and workload according to [16] were described in the previous chapter. The values of the human body impedance assumed in the calculations are presented in Table 2. The value of the shock current was calculated using formula (3) and the calculation results are presented in Table 3. The values of the human body for the considered values of touch and step voltages are the same for dry and water–wet conditions. Table 2 presents the results of the calculations of the human body impedance and shock current taking into account workload and climatic conditions for δ = -0.4, δ = 0 and δ = 1.

Table 2. The values of the human body impedance used in the calculations

Path	Human body impedance [kΩ]									
	Step voltage V_{STEP} (V), touch voltage V_{TOUCH} = 445V					Step voltage V_{STEP} (V), touch voltage V_{TOUCH} = 701V				
	IEEE 80	IEC 60479-1	Impdedance with work effort and climatic conditions according to [16]			IEEE 80	IEC 60479-1	Impdedance with work effort and climatic conditions according to [16]		
			δ= -0.4	δ= 0	δ= 1			δ= -0.4	δ= 0	δ= 1
Hand to hand	1,000	0.900	2.185	1.528	0.941	1,00	0.775	1.878	1.313	0.808
Hand to feet		0.720	1,311	0.917	0.564		0.620	1.127	0.788	0.485

Table 3. Calculated shock current values

Path	Electric shock current (touch current) [mA]									
	Step voltage V_{STEP} (V), touch voltage V_{TOUCH} = 445V					Step voltage V_{STEP} (V), touch voltage V_{TOUCH} = 701V				
	IEEE 80	IEC 60479-1	Impdedance with work effort and climatic conditions according to [16]			IEEE 80	IEC 60479-1	Impdedance with work effort and climatic conditions according to [16]		
			δ= -0.4	δ= 0	δ= 1			δ= -0.4	δ= 0	δ= 1
Hand to hand	445	494.44	203.66	291.21	473.07	0.701	904.52	373.29	533.75	867.09
Hand to feet		618.06	339.43	485.34	788.44		1130.65	622.15	889.60	1445.20

If the conventional time/current zones of effect of AC currents included in the IEC 60479-1 [18] standard are used to assess the effects of electric shock, it can be stated that all calculated values of shock currents (depending on the shock time) are located in zones AC-3 and AC-4.1, AC-4.2, AC-4.3 and AC-4. Shocking a person with such values will cause a significant threat to human health and life. For example, for zone AC-3, the following may occur: strong involuntary muscular contractions, difficulty in breathing and reversible disturbances of heart functions. For shock currents located in zone AC-4, the effects of shock are even more serious and include, for example: cardiac arrest, breathing arrest, cellular burns and damages, probability of ventricular fibrillation occurs.

Conclusions

Electrical installations on construction sites are operated in difficult environmental conditions and are often improperly used and maintained. The above factors increase the risk of electric shock. To reduce it, effective protection against electric shock should be provided, one of the elements of which is grounding.

The article presents the results of calculations of the electric potential on the ground surface above the earthing electrode buried in the ground, made using a model developed in the ANSYS program. Two sample earthing structures that can be used on the construction site were selected for analysis. Based on the above calculations, the values of touch and step voltages were determined. The pathophysiological effects caused by the flow of shock current through the human body can be assessed by knowing its value. The value of shock current depends on the touch and step voltage and the impedance of the human body. The article presents calculations of shock currents for the impedance of the human body determined using three methods described in the literature. All calculated shock current values are dangerous to human health and life. To limit the values of touch and step voltages, a different earthing structure or methods for shaping the distribution of the electric potential on the ground surface should be used, for example by using ballast with appropriately selected resistivity.

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