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MAXIMUM PERMISSIBLE TOUCH AND STEP VOLTAGES ASSESSMENT IN HIGH VOLTAGE SYSTEMS (> 1 kV)

Alexandru DINA[1], Valentin ZAHARESCU[2], Basarab GUZUN[3], Gheorghe COMĂNESCU[4],

Lucrarea de față prezintă o metodă de determinare a tensiunilor electrice de atingere şi de pas maxim admise prin corpul omului pentru zonele cu circulație frecventă şi redusă aferente stațiilor electrice de înaltă tensiune pornind de la valorile curenților electrici maxim admişi prin corpul uman şi rezistența acestuia funcție de tensiunea electrica aplicată, pe baza ipotezelor simplificatoare realizând şi o analiză comparativă față de valorile actuale din legislația din România.

This paper presents a method for determining the touch and step voltages maximum allowed by the human body in low and frequent areas traffic for high voltage power stations from the maximum allowed current values through the human body and its resistance, depending on the voltage electrical magnitude, making simplifying assumptions and comparison to the current values of law in Romania.

Keywords: touch voltage, step voltage, earthing system, body impedance, ventricular fibrillation, current path

1. Introduction

For the correct operation of the high voltage power substations in compliance with the safety technique norms, it is necessary to perform an earthing system. By the earthing system, we understand the assembly made of earthing conductors and the earthing electrode by which the earthing operation is performed [1]. These earthing conductors represent the touch accessible part of the electrical equipment, in any time, by persons, through which the fault current passes to earth, at the moment of the fault. In this case the potential distribution earthing system gets electric potential that can become dangerous to persons and can transmit this danger to the other equipment connected to it.

[1] Eng., Institute for Studies and Power Engineering, Romania, e-mail: dina_alexandru@yahoo.com
[2] Eng., Sibiu Branch Transelectrica, Romania, e-mail: Valentin.Zaharescu@transelectrica.ro
[3] Prof., Faculty of Energetics, University POLITEHNICA of Bucharest, Romania, e-mail: guzunbasarab@yahoo.com
[4] Prof., Faculty of Energetics, University POLITEHNICA of Bucharest, Romania, e-mail: ghcom@study.energ.pub.ro

Thus, there are necessary different criteria to assess the sizing data for the earthing systems, namely:

- depending on the permissible touch and step voltages;
- depending on the dangerous electric current which passes through human body.

The Romanian regulations in force (STAS 2612-87) are based on the dimension criterion of the earting system, according to the permissible touch and step voltages, determined by the values of the maximum permissible electrical currents through the human body, according to the researches from that date.

Thus, taking into account the new research field (IEC 61201, 60479-1, 60479-2, 60479-5) the maximum permissible electrical current flowing through the human body depends on the contact surface, the presence or absence of humidity, the variation of the internal resistance body (which depend by the applied voltage and electric current path), this article will present a methodology to assess the maximum permissible touch and step electrical voltages, determining a more economical sizing for the earthing systems without endanger human life.

2. Human body impedance

Touch voltage thresholds are related to touch current thresholds by the body's impedance according to Ohm's law. Also human body impedance is a function of several factors, such as: [2]

- the type of power source (DC or AC);
- the magnitude of the touch voltage;
- the pathway of the current through the body (hand-to-hand or both-hands-to-feet or hand to- seat);
- the area of contact with the skin;
- the condition of the skin contact area (saltwater-wet, water-wet, dry);
- duration of the current flow through human body.

Internal impedance of the human body as a percentage indicated is shown in Fig. 1.

Thus, one can calculate the percentage for the current path of the hand - the hand is [3]:

$$26{,}4\% + 10{,}9\% + 6{,}9\% + 6{,}1\% + 6{,}9\% + 10{,}9\% + 26{,}4\% = 94{,}5\% \qquad (1)$$

Applying the same reasoning, as indicated in Fig. 1, it will be calculated the percentage for the current route of the hand –feet:

$$26,4\% + 10,9\% + 9,9\% + 1,3\% + \frac{(5,1\% + 14,1\% + 32,3\%)}{2} = 74,25\% \qquad (2)$$

and for current path foot - foot:

$$32,3\% + 14,1\% + 8.7\% + 14,1\% + 32.3\% = 101,5\% \qquad (3)$$

Table 1 shows the total human body impedance values for a current path hand – hand, AC, 50/60 Hz, for important contact surfaces, representing the most complete knowledge of the total impedance for adult subjects [4].

Table 1

Total body impedances for a current path hand to hand a.c. 50/60 Hz, for large surface areas of contact in dry conditions. [4]

Touch voltage (V)	***Values for the total body impedances (Ω) that are not exceeded for:***		
	5% of the population	***50% of the population***	***95% of the population***
25	1 750	3 250	6 100
50	1 375	2 500	4 600
75	1 125	2 000	3 600
100	990	1 725	3 125
125	900	1 550	2 675
150	850	1 400	2 350
175	825	1 325	2 175
200	800	1 275	2 050
225	775	1 225	1 900
400	700	950	1 275
500	625	850	1 150
700	575	775	1 050
1 000	575	775	1 050
Asymptotic value	575	775	1 050

Taking as a reference the value for the percentage of the hand - hand current path [3] (equation 1) and total body impedance values human (Table 1) we will determine the impedance values for different current path through the human body.

Thus we can calculate the internal resistance of the human body for hand - feet path (which will be used to determine the touch voltage) and foot - foot path (which will be used to determine the step voltage) from the value of internal resistance hand - hand path, namely:

$$R_{i\_hand\text{-}feet} = R_{i\_hand\text{-}hand} \cdot 0,786 \qquad (4)$$

respectively:

$$R_{i\_foot\text{-}foot} = R_{i\_hand\text{-}hand} \cdot 1{,}074 \qquad (5)$$

where: $0{,}786 = \dfrac{74{,}25\%(see\_eq.2)}{94{,}5\%(see\_eq.1)}$ and $1{,}074 = \dfrac{101{,}5\%(see\_eq.3)}{94{,}5\%(see\_eq.1)}$

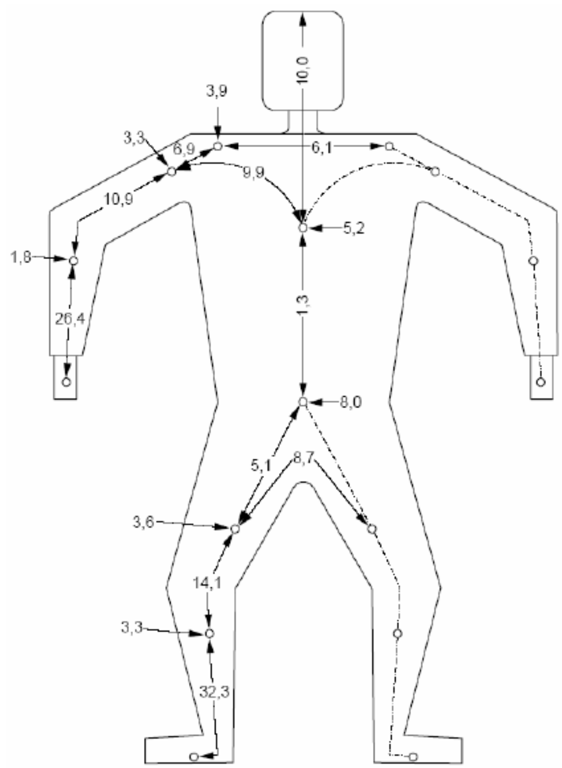

Fig. 1. Percentage of internal resistance of the human body for the part of the body concerned. [4]

Applying relations (4) and (5) we derived in Table 2 and 3, the total impedance values of the human body for a current path hand - feet, and foot-foot AC, 50/60 Hz for important surface contact, in dry conditions.

In Tables 2 and 3 were passed only 50% of the population values (which will be assimilated to the traffic area) and 90% of the population (which will be treated for limited traffic area).

Table 2

Total body impedances for a current path hand to feet, a.c. 50/60 Hz, for large surface areas of contact in dry conditions.

Touch voltage (V)	***Values for the total body impedances (Ω) that are not exceeded for:***	
	50% of the population	***95% of the population***
25	2 554	4 794
50	1 965	3 615
75	1 572	2 829
100	1 355	2 456
125	1 218	2 102
150	1 100	1 847
175	1 041	1 709
200	1 002	1 611
225	962	1 493
400	746	1 002
500	668	903
700	609	825
1 000	609	825

Table 3

Total body impedances for a current path foot to foot, a.c. 50/60 Hz, for large surface areas of contact in dry conditions.

Touch voltage (V)	***Values for the total body impedances (Ω) that are not exceeded for:***	
	50% of the population	***50% of the population***
25	3 490	6 551
50	2 685	4 940
75	2 148	3 866
100	1 852	3 356
125	1 664	2 872
150	1 503	2 532
175	1 423	2 335
200	1 369	2 201
225	1 315	2 040
400	1 020	1 369
500	912	1 235
700	832	1 127
1 000	832	1 127

Thus with the equivalent impedance for electrical current paths through the human body: hand - feet and foot – foot, the maximum permissible current value must be known by human body to determine the maximum allowed touch and step voltages (under certain assumptions that will be presented in Chapter 4).

3. Conventional time/current zones of effects of a.c. currents (15 Hz to 100 Hz) on persons for a current path corresponding to left hand to feet

The conventional time/current zones of effects of a.c. currents (15 Hz to 100 Hz) on persons for a current path corresponding to left hand to feet is shown in Fig. 2:

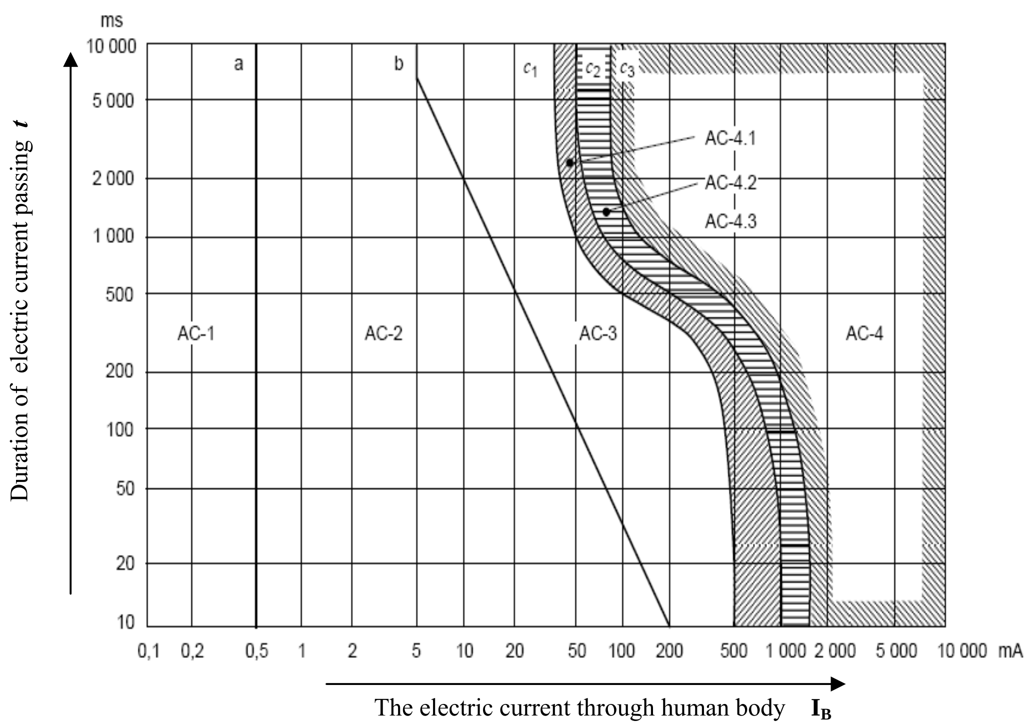

Fig. 2. Conventional time/current zones of effects of a.c. currents (15 Hz to 100 Hz) on persons for a current path corresponding to left hand to feet. [4]

where [4]:

- zone AC-1 with boundaries up to 0,5 mA (curve a), where perception possible but usually no ‘startled’ reaction;

- zone AC-2 with boundaries from 0,5 mA (curve a) up to curve b, where perception and involuntary muscular contractions likely but usually no harmful electrical physiological effects;

- zone AC-3 with boundaries from curve b up to curve c_1, where could appear: strong involuntary muscular contractions, difficulty in breathing, reversible disturbances of heart function, immobilization may occur. Effects increasing with current magnitude. Usually no organic damage to be expected.

- zone AC-4 with boundaries from above curve c_1, where patho-physiological effects may occur such as cardiac arrest, breathing arrest, and burns or other cellular damage. Probability of ventricular fibrillation increasing with current magnitude and time.

- zone AC-4.1 with boundaries from above curve c_1 up to curve c_2 where the probability of ventricular fibrillation increasing up to about 5 %;

- zone AC-4.2 with boundaries from above curve c_2 up to curve c_3 where the probability of ventricular fibrillation up to about 50 %;

- zone AC-4.3 with boundaries beyond curve c_3 where the probability of ventricular fibrillation above 50 %;

Fig. 2 represents the effects of electric current passing from left hand to feet, to determine the value of current path foot - foot (left foot to right foot) is recommended to apply a heart-current factor 0.04 [4].

4. Calculation of maximum permissible values for touch and step voltages into high voltage systems (> 1 kV)

To assessment the maximum permissible values of touch and step voltages we will make the following assumptions, which provides an increased safety against electric shock:

- will be considerate that the maximum permissible current through the circuit (the human body) which do not produce ventricular fibrillation, meaning the values on curve AC-4.1, from Fig. 2, such to calculate the touch and step voltages;

- large surface areas of contact in dry conditions of human body with the object energized;

- does not consider the emplacement isolation;

- current path through the human body is hand to feet (for touch voltage), and foot to foot (for the voltage step);

- for the foot – foot path (left leg to the right leg) heart-current factor will be considered 1. Heart-current factor relates the electric field strength (current density) in the heart for a given current path to the electric field strength (current density) in the heart for a touch current of equal magnitude flowing from left hand to feet [4];

- values of human body impedance (resistance) differ depending on voltage range which is applied to it (according to table 2 and 3) proper to different areas:

* with frequent traffic area (corresponding to 50% of the population);
* with limited traffic area (corresponding to 95% of the population);

Considering the above remarks, in Table 4 are presented the new maximum permissible values for touch and step voltages. Table 5 presents the maximum permissible values for touch and step voltages according to STAS 2612-87 (in this Table the values for touch and step voltages are considered equal).

Table 4

The new maximum permissible touch and step voltages (in V) in case of a fault in high voltage electrical system side.

No	System type	Location area	Irrespective of network type (I, T)	Maximum permissible touch and step voltage for the disconnecting time of main protection:								
				≤0,2 s	0,3 s	0,4 s	0,5 s	0,6 s	0,7 s	0,8 - 1,2 s	1,2 - 3 s	>3 s
				V								
1.	Electrical equipment	a) frequent traffic area (corresponding to 50% of the population)	U_{step}	408	326	284	193	171	153	120	102	93
			U_{touch}	377	320	243	171	157	127	112	97	89
		b) limited traffic area without individual protection insulating means(corresponding to 95% of the population)	U_{step}	494	438	408	344	284	251	222	187	172
			U_{touch}	479	442	341	254	226	183	162	137	126

Table 5

The maximum permissible touch and step voltages (in V) in case of a fault in high voltage electrical system side. [5].

No.	System type	Location area	Network type	Maximum permissible touch and step voltage for the disconnecting time of main protection:								
				≤0,2 s	0,3 s	0,4 s	0,5 s	0,6 s	0,7 s	0,8 - 1,2 s	1,2 - 3 s	>3 s
				V								
1.	Electrical equipment	a) frequent traffic area	I, T_1	125	100	85	80	75	70	65	65	50
			T_2	250	200	165	150	140	130	125	65	50
		b) limited traffic area without indi vidual protection insulating means	I, T_1	250	200	165	150	140	130	125	125	125
			T_2	500	400	330	300	280	260	250	125	125

where [1]:

I – electrical network in which all active power supply parts are isolated from ground or neutral of the power supply is earthed through a high value impedance;

T – electrical network in which at least one point in the active power supply parts is connected directly or through a low resistance to earthing system;

T_1 – electrical network, with one fault detection system;

T_2 – electrical network, with two fault detection system.

5. Conclusions

The achievement of optimal operation conditions, from techno-economic point of view, to the electrical system and safety conditions of people in its exploitation depends greatly on proper sizing of earthing systems related to its.

Therefore the purpose of this paper has to develop an original model calculation based on the most complete information of the moment (admissible electric currents through the human body, human body resistance variation with applied voltage) resulting a new set of values for maximum permissible touch and step voltages, which leading to relaxation of conditions for earthing systems sizing and lower development cost to achieve the earthing systems.

In force Romanian voltages values (STAS 2612-87) are obsolete and lead to excessive size of earthing systems, so this paper proposes to replace them, presented in Table 5, with values from Table 4, which were determined according to the above assumptions (from chapter 4).

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