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A Comparison of IEC 479-1 and IEEE Std 80 on Grounding Safety Criteria

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ABSTRACT

This paper provides a comparison of the safety criteria of two widely accepted standards, i.e., IEC 479-1 and IEEE Std 80. The two standards differ in their definition of the permissible body current and their definition of body resistance. Another difference is that the IEC 479-1 does not provide guidance on human feet/soil contact impedances. It tacitly assumes that these impedances can be computed by the designer. This paper includes a comprehensive study of permissible touch and step voltages under these two standards for a wide range of conditions which enables direct comparison of the two standards. It is shown that differences exist. These differences are quantified in this paper.

Key Words: permissible body current, body resistance, permissible touch and step voltages, contact resistance

I. Introduction

Since the early days of the electric power industry, safety of personnel in and around electric power installations has been a prime concern. A mechanism by which safety of personnel is affected is the ground potential rise of grounded structures during electric power faults and the possibility of humans touching grounded structures and, therefore, subjecting themselves to voltages. A 50 or 60 Hz electric current conducted through a human body as a result of an accidental conduct with a grounded structure, under adverse conditions, should be of magnitude and duration below those that cause ventricular fibrillation. Over the years and after many investigations on the effects of electric current on humans, safe limits have been established and standards have been developed which provide permissible values of body currents to avoid electrocution. Two such standards are (1) IEEE Std 80 and (2) the IEC 479-1.

IEEE Std 80 had three editions (1961, 1976 and 1986), is currently being revised, and has been in use in the USA and several other countries. IEC publication 479-1 was released in 1984. The purpose of both standards is to establish safe (permissible) body currents. The underlying assumption is that the designers of grounding systems will make sure that these values will not be exceeded under adverse conditions of accidental contact of humans with grounded structures. The philosophical difference between the two documents is that while IEC publication 479-1 does not address all relevant computational issues, which may be necessary in the design process (such as feet/soil resistance, etc.), IEEE Std 80 does address most computational issues and provides procedures and guidance for assessing the safety of a grounding system (ANSI/IEEE. Std 80-1986).[1]

With ever increasing fault current levels in today's interconnected power systems, there is renewed emphasis on safety. On the other hand, globalization of national economies has increased interest in harmonization of standards. The first step in this endeavor is the technical comparison of various standards addressing the same issue. This paper provides a technical comparison of two standards addressing the safety of electrical installations.

This paper is organized as follows: first the electric shock model is presented, and all relevant parameters are defined. Next, the safety criteria as stated in the two documents, i.e., IEEE Std 80, 1986 edition,

[1]ANSI/IEEE Std 80-1986, "IEEE guide for safety in AC substation grounding", 1986.

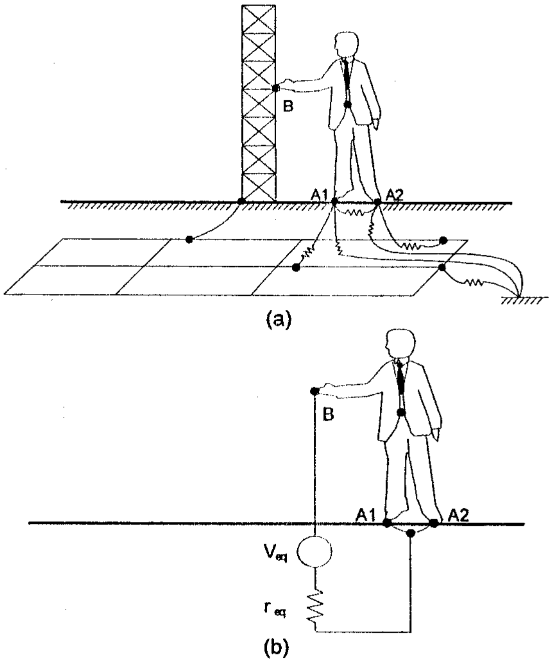

Fig. 1. Definition of the electric shock model parameters-touch voltage.

and IEC 479-1, 1984, are described in detail. A common basis for comparison is developed in terms of permissible touch and step voltages. Finally, a comparison of the two documents is presented over a wide range of parameters.

II. The Electric Shock Model

Electric shock may occur when an individual touches a grounded structure during a fault (touch voltage), walks in the vicinity of a grounding system during a fault (step voltage), touches two separately grounded structures during a fault (metal to metal touch voltage), etc. While each condition can be examined separately and in detail, in order to keep the size of this paper reasonable, we will focus on touch voltages only. The electric shock model is shown in Fig. 1, which illustrates a human standing near the middle point of a ground mesh, subjected to touch voltage. The electric shock model is the circuit which determines the flow of electric current in the human body. The human body may come into contact with a ground or soil at three points (hand and two feet) as illustrated in Fig. 1(a). The grounding system and soil are represented by a Thevenin equivalent at the points of contact. Figure 1(a) illustrates the equivalent resistances between any pair of contact points, B, A1, and A2. When a fault occurs, voltages will appear between any pair of points of contact, B, A1, and A2. The Thevenin equivalent in this case is a three terminal circuit (terminals B, A1, and A2) and can be computed using proper analysis methods (Sakis Meliopoulos *et al.*, 1993). A typical simplification is to assume that the voltage at points A1 and A2 is practically the same, in which case the Thevenin equivalent is simplified to that shown in Fig. 1(b). The Thevenin voltage source V_{eq} equals the open-circuit voltage, meaning in this case the voltage at the points of contact when the human is not touching. The equivalent internal resistance, as shown in Fig. 1(b), between the points of contact can be accurately computed using numerical techniques (EPRI Report[2]) (Sakis Meliopoulos, 1988; Sakis Meliopoulos *et al.*, 1993). For the electric shock model of Fig. 1(b), the following definitions apply:

(1) **Touch Voltage** (or **Thevenin Equivalent Voltage**)
The open circuit potential difference between a grounded structure (point B) and the surface potential at the point where a person is standing (points A1 and A2).

(2) **Body Voltage**
The voltage across the human body when the electric shock circuit is closed.

(3) **Body Resistance**
The resistance of the human body between the points of contact, i.e., in the case of Fig. 1, between point B and points A1 and A2 (hand to two feet). It depends on many factors, such as size, skin condition, pressure at contact, etc.

(4) **Touch Resistance** (or **Thevenin Equivalent Resistance**)
The resistance of the soil between the point of contact of the human body with the soil (points A1 and A2) and the grounding system, i.e., r_{eq}.

(5) **Body Current**
The electric current through the human body.

The described electric shock model is inherent in both documents. However, the two documents differ in their application of the electric shock model. Table 1 provides an overview of the differences among the two documents with reference to the electric shock model. In subsequent paragraphs, a more detailed discussion of the safety criteria adapted in the two documents will be presented, followed by a comparison.

III. Safety Criteria–The IEEE Std 80

IEEE Std 80 is based on a simplified electric shock model. The parameters of the electric shock model are

[2]EPRI Report EL-2682, "Analysis techniques for power substation grounding system, volume 1, methodology and tests", October, 1982.

Table 1. Electrical Shock Model Differences between IEEE Std 80 and IEC 479-1

	IEEE Std 80	IEC 479-1
Body Resistance	1000 ohms	Voltage Dependent and Path Dependent (Figs. 4 and 5)
Thevenin Equivalent Resistance	$1.5c_s\rho_s$ for touch voltage $6.0c_s\rho_s$ for step voltage	no guidance
Thevenin Equivalent Voltage	Simplified Equations k_i k_r L I or use of computer models is suggested	no guidance
Permissible Body Current	$0.116\text{A}/\sqrt{t}$ for 50 kg person $0.157\text{A}/\sqrt{t}$ for 70 kg person	S-curves independent of human size (Fig. 6)

shown in column 2 of Table 1. This model is usually translated into permissible touch (or step) voltages. As an example, the permissible touch, $V_{T,\text{perm}}$ and step, $V_{S,\text{perm}}$ voltages for a 50 kg person are:

$$V_{T,\text{ perm}} = \frac{0.116}{\sqrt{t}}(1.5c_s\rho_s + 1000),$$

$$V_{S,\text{ perm}} = \frac{0.116}{\sqrt{t}}(6.0c_s\rho_s + 1000).$$

Additional comments and observations regarding the IEEE Std 80 are given below:

The permissible body current has been selected from statistical data and represents a 0.5% probability of ventricular fibrillation. It is believed that the approximate formula for the Thevenin equivalent resistance in IEEE Std 80 was derived as follows. The human foot can be modeled as a circular plate touching the surface of the earth. The resistance of the plate to remote earth is approximately.

$$R = \frac{\rho}{4b}, \tag{1}$$

where ρ is the resistivity of the earth and b is the radius of the plate. The human foot definitely is not a circular plate. However, it has been observed using scale models and numerical studies that the area of the foot in contact with the earth is the most important variable. For this reason, b can be approximated by

$$b = \sqrt{\frac{A}{\pi}},$$

where A is the area of the foot in contact with the earth. For an adult with large feet, the area A of the person's feet is approximately 200 cm^2. Using this value, the radius is $b \cong 0.08$ m, and the resistance of one foot touching the earth is

$$R = \frac{\rho}{(4)(0.08)} \cong 3\rho \text{ ohms},$$

where ρ is expressed in ohm·meters. IEEE Std 80 further assumes that the mutual resistance between the two feet (Fig. 1) has negligible effect; thus, the equivalent resistance is simply the parallel combination of the two feet to soil resistances:

$$r_{\text{eq}} = \frac{(3\rho)(3\rho)}{3\rho + 3\rho} = 1.5\rho. \tag{2}$$

The equivalent resistance, r_{eq}, in Fig. 1, should also take into account the resistance of the grounding system. However, for practical grounding systems, this resistance is typically small compared to the resistance 1.5ρ, and is thus omitted. Only cases in which the effect of the grounding system resistance can account for more than 2% are of academic importance.

The above equations for r_{eq} apply to the case of uniform soil and neglect the effect of grounding system proximity or mutual resistance between the feet. For nonuniform soil or for soil with a cover layer of high resistivity, IEEE Std 80 provides a correction factor $c_s(h_s,k)$. Specifically, the equivalent resistance r_{eq} is given by

$$r_{\text{eq}}=6.0\ c_s(h_s,k)\ \rho_s \quad \text{for step voltage,} \tag{3}$$

$$r_{\text{eq}}=1.5\ c_s(h_s,k)\ \rho_s \quad \text{for touch voltage,} \tag{4}$$

where

$$k=(\rho-\rho_s)/(\rho+\rho_s), \tag{5}$$

ρ_s the resistivity of the upper layer,

ρ the resistivity of the soil below the upper layer,

h_s the thickness of the upper layer,

c_s the reduction factor for derating the nominal value of the surface layer resistivity determined as follows: (1) c_s=1.04 for uniform soil, and (2) for nonuniform soil, IEEE Std 80 provides a graph (Fig. 3 of the standard) for the graphical determination of c_s from k and h_s.

Investigation using computer models has revealed that the IEEE Std 80 approximate formulae are accurate for all practical purposes only for uniform soil. For soil with an upper layer of high resistivity stone, the correction factor $c_s(h_s,k)$ is in error, especially for the

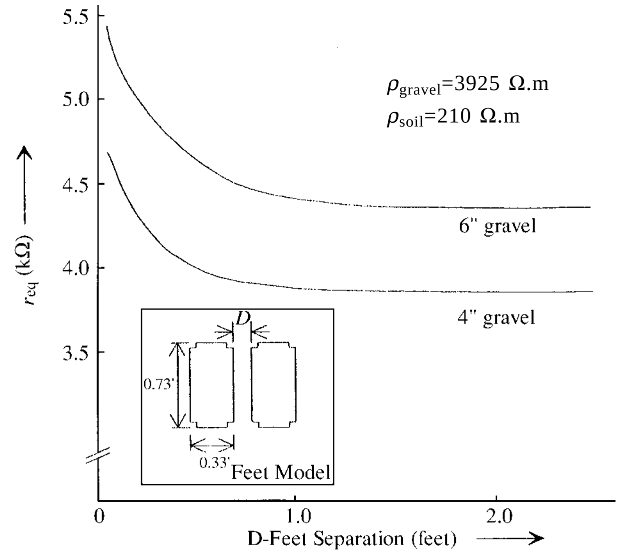

Fig. 2. Feet to soil resistances as a function of feet separation and gravel thickness.

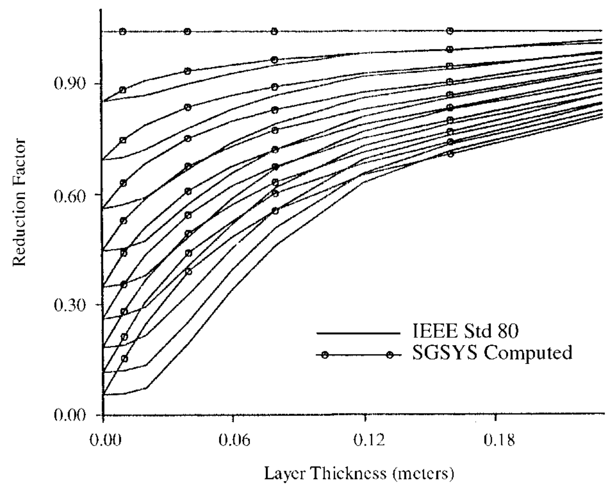

Fig. 3. Reduction factor comparison of IEEE Std 80 and program SGSYS.

practical case of an upper layer thickness of 1 to 4 inches (0.0254 to 0.1016 m). (A note: the IEEE Std 80 committee will modify the correction factor c_s based on the results of three independent researchers in the next edition of the standard).

The computer based method for evaluation of the correction factor $c_s(h_s,k)$ consists of computing an equivalent voltage source connected to the points of contact of the human body with the ground field as indicated in Fig. 1. The points of contact of the human feet with the earth surface are modeled using two metallic plates placed at the location of the feet. The shape and dimensions of the plates are shown in Fig. 2. Then the grounding system together with the contact model is viewed as a system with multiple grounds. This system has three terminals, A1, A2, and B. The elements of the equivalent circuit are computed using the method of moments (EPRI Report EL-2682) (Sakis Meliopoulos, 1988; Sakis Meliopoulos *et al.*, 1993). Then standard network techniques are employed to compute the Thevenin equivalent parameters V_{eq}, r_{eq} as illustrated in Fig. 1. It is important to note that modeling the feet as two plates (surface electrodes) provides a realistic analysis model. The correction factor $c_s(h_s,k)$ is then computed from the following equation:

$$c_s(h_s, k) = \frac{r_{eq}}{1.5\rho_s} .$$

The value of r_{eq} and, therefore, $c_s(h_s,k)$ depends on foot size and spacing between feet. Using a foot model as shown in Fig. 2, the IEEE Std 80 model is matched exactly for uniform soil and assuming feet separation of D=2 feet. Figure 2 also illustrates the effect of the mutual resistance between the two plates representing the two feet. Note that for the usual standing position, D=1 to 2 feet, the effect of the mutual resistance is negligible. However, as the feet come closer than 1 foot, the effect of the mutual resistance is sufficient to increase the value of r_{eq}.

The computed values of $c_s(h_s,k)$ are given in Fig. 3, superimposed on the present values of IEEE Std 80. Note that the region of greatest discrepancy is for layers 1 to 4 inches (or 0.0254 to 0.1016 m) thick, which is the usual case.

IV. Safety Criteria–The IEC 479-1

IEC 479-1 is less specific than IEEE Std 80 for

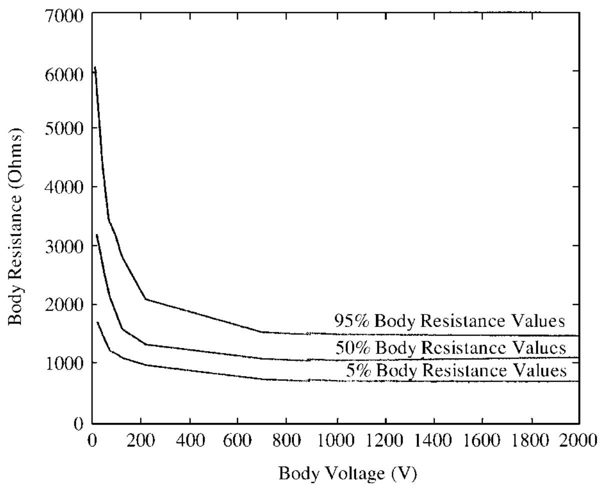

Fig. 4. Human body resistance as a function of body voltage.

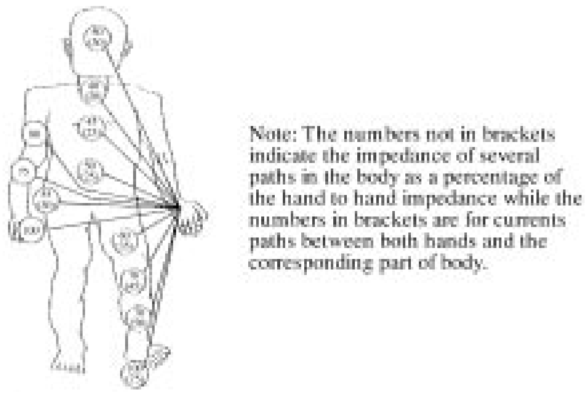

Fig. 5. Internal impedance of the human body as a function of the current path. [Adapted from IEC 479-1]

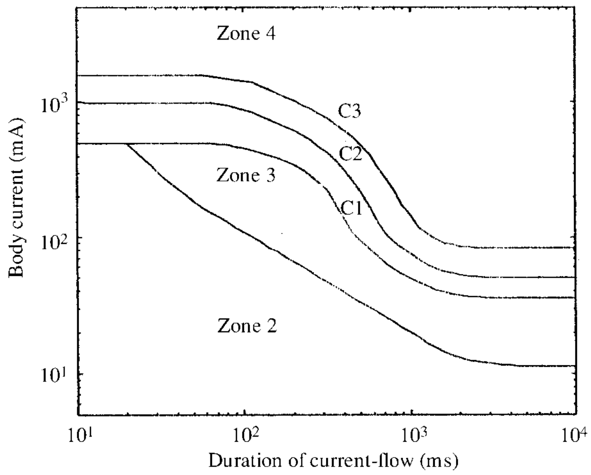

Fig. 6. Permissible body current per IEC 479-1.

design purposes. The standard provides data for body resistances as a function of body voltage, which are illustrated in Fig. 4, and data of body resistance as a function of path, which are illustrated in Fig. 5. In Fig. 4, the 5% curve indicates body resistance values which were not exceeded by 5% of the population, the 50% curve indicates body resistance values which were not exceeded by 50% of the population, etc. All the values in Fig. 4 are for hand to hand resistance. In Fig. 5, the numbers not in brackets indicate the impedance of several paths in the body as a percentage of the hand to hand impedance. The numbers in brackets are for current paths between both hands and the corresponding part of the body. IEC 479-1 also provides values of permissible body current versus electric shock duration as shown in Fig. 6. Points on curve C1 represent 0.14% probability of ventricular fibrillation, points on curve C2 represent 5% probability of ventricular fibrillation and points on curve C3 represent 50% probability of ventricular fibrillation. These curves separate the space of body current and shock duration into zones. As an example, Zone 4 represents all the combinations of body current and shock duration which will lead to ventricular fibrillation with probability more than 50%.[3]

The data of IEC 479-1 can be utilized in two ways: (1) actual body currents can be computed for an individual subjected to touch or step voltage in a specific system and under specific conditions, and (2) permissible touch and step voltages can be computed for a specific system.

1. Permissible Touch and Step Voltage–IEC 479-1

The permissible (or allowable) touch, V_T^a, and step, V_S^a, voltages are computed from the following equations:

$$V_T^a = i_{b,\,\mathrm{perm}}(t)[R_b^T(i_{b,\,\mathrm{perm}}(t)) + r_{\mathrm{eq},\,T}]\,, \quad \mathbf{(6)}$$

$$V_S^a = i_{b,\,\mathrm{perm}}(t)[R_b^S(i_{b,\,\mathrm{perm}}(t)) + r_{\mathrm{eq},\,S}]\,, \quad \mathbf{(7)}$$

where

$i_{b,\mathrm{perm}}(t)$	is the permissible body current per IEC 479-1 for an electric shock duration t. This current is obtained from the data shown in Fig. 6.
$R_b^T(i_{b,\mathrm{perm}}(t))$	is the body resistance for the path specified by the touch voltage (typically, hand to two feet) and for a body current equal to $i_{b,\mathrm{perm}}(t)$. This value can be obtained from the data shown in Figs. 4 and 5.
$R_b^S(i_{b,\mathrm{perm}}(t))$	is the body resistance for the path specified by the step voltage (foot to foot) and for a body current equal to $i_{b,\mathrm{perm}}(t)$. This value can be obtained from the data shown in Figs. 4 and 5.
$r_{\mathrm{eq},T}$	is the feet to soil resistance for touch voltage; i.e., the two feet to soil resistances are in parallel.
$r_{\mathrm{eq},S}$	is the feet to soil resistance for step

[3] International Electrotechnical Commission IEC report, "Effects of current passing through the human body, part 1: general aspects", 479-1, IEC 1984.

Table 2. Permissible Touch Voltages per IEEE Std 80, 1986 Edition, 50 kg Person, Probability of Ventricular Fibrillation 0.5%

	Soil Resistivity						
Shock Duration	10 (Ω•m)	50 (Ω•m)	100 (Ω•m)	200 (Ω•m)	500 (Ω•m)	1000 (Ω•m)	3000 (Ω•m)
0.05 sec	526.9 V	559.2 V	599.7 V	680.6 V	923.4 V	1328.0 V	2946.6 V
0.10 sec	372.5 V	395.4 V	424.0 V	481.3 V	652.9 V	939.1 V	2083.6 V
0.15 sec	304.2 V	322.9 V	346.2 V	393.0 V	533.1 V	766.7 V	1701.2 V
0.20 sec	263.4 V	279.6 V	299.8 V	340.3 V	461.7 V	664.0 V	1473.3 V
0.25 sec	235.6 V	250.1 V	268.2 V	304.4 V	413.0 V	593.9 V	1317.8 V
0.30 sec	215.1 V	228.3 V	244.8 V	277.9 V	377.0 V	542.2 V	1202.9 V
0.35 sec	199.1 V	211.4 V	226.7 V	257.3 V	349.0 V	502.0 V	1113.7 V
0.40 sec	186.3 V	197.7 V	212.0 V	240.6 V	326.5 V	469.5 V	1041.8 V
0.45 sec	175.5 V	186.4 V	199.9 V	226.9 V	307.8 V	442.7 V	982.2 V
0.50 sec	166.6 V	176.8 V	189.6 V	215.2 V	292.0 V	420.0 V	931.8 V

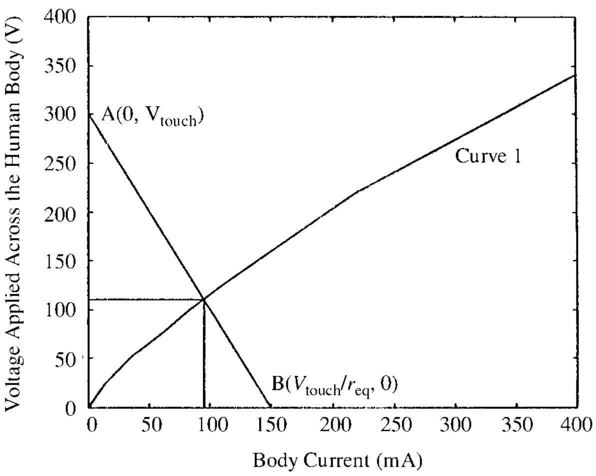

Fig. 7. Graphical method for computing the actual body current.

voltage; i.e., the two feet to soil resistances are in series.

IEC 479-1 does not provide any data for $r_{eq,T}$ or $r_{eq,S}$. For this reason, we shall use the data of IEEE Std 80, i.e., Eqs. (3) and (4).

Note that application of above equations to obtain the permissible touch and step voltages is straightforward and involves the following steps:

Step 1: For a given electric shock duration t and a given assumed probability of ventricular fibrillation, determine the value of permissible body current, $i_{b,\mathrm{perm}}(t)$, from Fig. 6.

Step 2: For the current $i_{b,\mathrm{perm}}(t)$, determine the body resistances R_b^T and R_b^S from the data shown in Figs. 4 and 5. For touch voltage, it is expedient to assume that the path will be one hand to two feet (75% of the body resistance given in Fig. 4), and for step voltage that the path is foot to foot (100% of the body resistance given in Fig. 4).

Step 3: Compute $r_{eq,T}$ and $r_{eq,S}$ per IEEE Std 80.

Step 4: Compute permissible touch and step voltages using Eqs. (6) and (7).

For purposes of comparison with IEEE Std 80, the permissible body current $i_{b,\mathrm{perm}}(t)$ is computed for probability 0.5% of ventricular fibrillation using proper interpolation between curves C1 and C2 in Fig. 6.

2. Computation of Actual Body Current

For a given touch or step voltage, the computation of the body current using the IEC data requires solving a set of nonlinear equations. This solution can be obtained iteratively or using a graphical method described below.

Step 1: Compute the Thevenin equivalent resistance, r_{eq}, of the electrocution circuit.

Step 2: For a given (or computed) touch (or step) voltage and equivalent resistance r_{eq} from step 1, compute the actual body current using the graphical method which is shown in Fig. 7. Specifically, the actual body current is determined by simultaneous solution of the following two equations.

$$V_{touch}=V_b+r_{eq}i_b, \tag{8}$$

$$I_b=V_b/r_b=V_b/f(V_b), \tag{9}$$

where the function $r_b=f(V_b)$ represents the nonlinear characteristics of the *body resistance* as a function of body voltage determined using the data shown in Fig. 4. Note that the Eq. (9) represents a nonlinear function which is illustrated in Fig. 7 as curve 1.

Equation (8) is a straight line in the coordinate system V_b vs I_b. This line is constructed as follows. For a given touch voltage, V_{touch}, this line will pass through the point (0,V_{touch}). This point is shown as point A in Fig. 7. Also the line will pass from point

Table 3. Permissible Step Voltages per IEEE Std 80, 1986 Edition, 50 kg Person, Probability of Ventricular Fibrillation 0.5%

	Soil Resistivity						
Shock Duration	10 (Ω•m)	50 (Ω•m)	100 (Ω•m)	200 (Ω•m)	500 (Ω•m)	1000 (Ω•m)	3000 (Ω•m)
0.05 sec	551.1 V	680.6 V	842.5 V	1166.2 V	2137.3 V	3755.9 V	10230.1 V
0.10 sec	389.7 V	481.3 V	595.7 V	824.6 V	1511.3 V	2655.8 V	7233.8 V
0.15 sec	318.2 V	393.0 V	486.4 V	673.3 V	1234.0 V	2168.5 V	5906.4 V
0.20 sec	275.6 V	340.3 V	421.2 V	583.1 V	1068.7 V	1877.9 V	5115.0 V
0.25 sec	246.5 V	304.4 V	376.8 V	521.5 V	955.8 V	1679.7 V	4575.0 V
0.30 sec	225.0 V	277.9 V	343.9 V	476.1 V	872.6 V	1533.3 V	4176.4 V
0.35 sec	208.3 V	257.3 V	318.4 V	440.8 V	807.8 V	1419.6 V	3866.6 V
0.40 sec	194.9 V	240.6 V	297.9 V	412.3 V	755.7 V	1327.9 V	3616.9 V
0.45 sec	183.7 V	226.9 V	280.8 V	388.7 V	712.4 V	1252.0 V	3410.0 V
0.50 sec	174.3 V	215.2 V	266.4 V	368.8 V	675.9 V	1187.7 V	3235.0 V

Table 4. Permissible Touch Voltages per IEC 479-1, 5% Body Resistance Values, Probability of Ventricular Fibrillation 0.5%, Hand to Two Feet

	Soil Resistivity						
Shock Duration	10 (Ω•m)	50 (Ω•m)	100 (Ω•m)	200 (Ω•m)	500 (Ω•m)	1000 (Ω•m)	3000 (Ω•m)
0.05 sec	342.4 V	375.8 V	417.6 V	501.2 V	751.8 V	1169.6 V	2840.9 V
0.10 sec	319.0 V	349.3 V	387.1 V	462.7 V	689.6 V	1067.7 V	2580.2 V
0.15 sec	287.5 V	313.8 V	346.7 V	412.5 V	609.9 V	938.9 V	2254.9 V
0.20 sec	256.7 V	279.5 V	308.1 V	365.1 V	536.1 V	821.2 V	1961.6 V
0.25 sec	222.2 V	241.3 V	265.2 V	313.1 V	456.6 V	695.9 V	1652.9 V
0.30 sec	187.9 V	203.7 V	223.4 V	262.7 V	380.9 V	577.8 V	1365.3 V
0.35 sec	148.8 V	160.9 V	176.0 V	206.2 V	296.9 V	448.2 V	1053.0 V
0.40 sec	121.7 V	131.0 V	142.7 V	166.1 V	236.1 V	352.9 V	820.1 V
0.45 sec	101.1 V	108.5 V	117.9 V	136.6 V	192.6 V	286.1 V	660.0 V
0.50 sec	88.9 V	95.3 V	103.4 V	119.5 V	167.8 V	248.2 V	570.1 V

Table 5. Permissible Touch Voltages per IEC 479-1, 50% Body Resistance Values, Probability of Ventricular Fibrillation 0.5%, Hand to Two Feet

	Soil Resistivity						
Shock Duration	10 (Ω•m)	50 (Ω•m)	100 (Ω•m)	200 (Ω•m)	500 (Ω•m)	1000 (Ω•m)	3000 (Ω•m)
0.05 sec	449.4 V	482.8 V	524.6 V	608.2 V	858.8 V	1276.7 V	2947.9 V
0.10 sec	415.5 V	445.7 V	483.6 V	559.2 V	786.1 V	1164.2 V	2676.6 V
0.15 sec	374.5 V	400.9 V	433.8 V	499.6 V	697.0 V	1026.0 V	2342.0 V
0.20 sec	334.6 V	357.4 V	385.9 V	442.9 V	614.0 V	899.1 V	2039.5 V
0.25 sec	289.6 V	308.8 V	332.7 V	380.6 V	524.1 V	763.4 V	1720.4 V
0.30 sec	245.1 V	260.8 V	280.5 V	319.9 V	438.0 V	634.9 V	1422.4 V
0.35 sec	193.8 V	205.9 V	221.0 V	251.2 V	341.9 V	493.2 V	1098.0 V
0.40 sec	152.9 V	162.2 V	173.9 V	197.3 V	267.3 V	384.1 V	851.3 V
0.45 sec	128.8 V	136.3 V	145.6 V	164.3 V	220.4 V	313.9 V	687.7 V
0.50 sec	116.0 V	122.5 V	130.5 V	146.6 V	194.9 V	275.4 V	597.3 V

(V_{touch}/r_{eq},0). This point is shown as point B in Fig. 7. The graphical construction consists of drawing a straight line through points A and B. The intersection of this line with curve 1 determines the actual body current for the specified touch voltage, as shown in Fig. 7.

V. Comparison

This section presents a comprehensive comparison between the two standards. The comparison is made in terms of permissible touch and step voltages for ranges of parameters which cover most practical

Table 6. Permissible Step Voltages per IEC 479-1, 5% Body Resistance Values, Probability of Ventricular Fibrillation 0.5%, Hand to Two Feet

	Soil Resistivity						
Shock Duration	10 (Ω•m)	50 (Ω•m)	100 (Ω•m)	200 (Ω•m)	500 (Ω•m)	1000 (Ω•m)	3000 (Ω•m)
0.05 sec	367.5 V	501.2 V	668.3 V	1002.5 V	2005.3 V	3676.5 V	10361.5 V
0.10 sec	341.7 V	462.7 V	614.0 V	916.4 V	1823.9 V	3336.4 V	9386.2 V
0.15 sec	307.2 V	412.5 V	544.1 V	807.3 V	1596.9 V	2913.0 V	8177.1 V
0.20 sec	273.8 V	365.1 V	479.1 V	707.2 V	1391.4 V	2531.8 V	7093.2 V
0.25 sec	236.5 V	313.1 V	408.8 V	600.2 V	1174.4 V	2131.5 V	5959.6 V
0.30 sec	199.7 V	262.7 V	341.5 V	499.0 V	971.5 V	1759.1 V	4909.3 V
0.35 sec	157.8 V	206.2 V	266.7 V	387.7 V	750.6 V	1355.4 V	3774.8 V
0.40 sec	128.7 V	166.1 V	212.8 V	306.2 V	586.5 V	1053.6 V	2922.3 V
0.45 sec	106.7 V	136.6 V	174.0 V	248.7 V	473.1 V	846.9 V	2342.4 V
0.50 sec	93.7 V	119.5 V	151.7 V	216.1 V	409.2 V	731.1 V	2018.7 V

Table 7. Permissible Step Voltages per IEC 479-1, 50% Body Resistance Values, Probability of Ventricular Fibrillation 0.5%, Hand to Two Feet

	Soil Resistivity						
Shock Duration	10 (Ω•m)	50 (Ω•m)	100 (Ω•m)	200 (Ω•m)	500 (Ω•m)	1000 (Ω•m)	3000 (Ω•m)
0.05 sec	474.5 V	608.2 V	775.3 V	1109.5 V	2112.3 V	3783.5 V	10468.5 V
0.10 sec	438.2 V	559.2 V	710.4 V	1012.9 V	1920.4 V	3432.9 V	9482.7 V
0.15 sec	394.3 V	499.6 V	631.2 V	894.4 V	1684.0 V	3000.0 V	8264.2 V
0.20 sec	351.7 V	442.9 V	557.0 V	785.1 V	1469.3 V	2609.6 V	7171.1 V
0.25 sec	304.0 V	380.6 V	476.3 V	667.7 V	1241.9 V	2198.9 V	6027.1 V
0.30 sec	256.9 V	319.9 V	398.6 V	556.1 V	1028.7 V	1816.2 V	4966.4 V
0.35 sec	202.8 V	251.2 V	311.7 V	432.7 V	795.6 V	1400.4 V	3819.8 V
0.40 sec	159.9 V	197.3 V	244.0 V	337.4 V	617.7 V	1084.9 V	2953.5 V
0.45 sec	134.4 V	164.3 V	201.7 V	276.5 V	500.8 V	874.7 V	2370.1 V
0.50 sec	120.9 V	146.6 V	178.8 V	243.2 V	436.3 V	758.2 V	2045.8 V

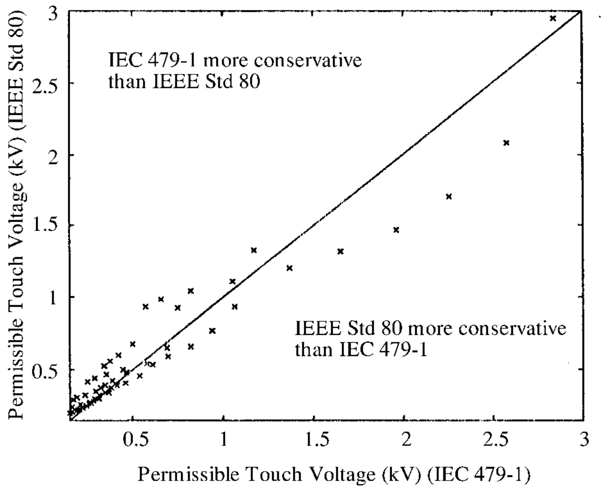

Fig. 8. Permissible touch voltages per IEEE Std 80 vs IEC 479-1, 5% body resistance values, probability of ventricular fibrillation 0.5%, hand to two feet.

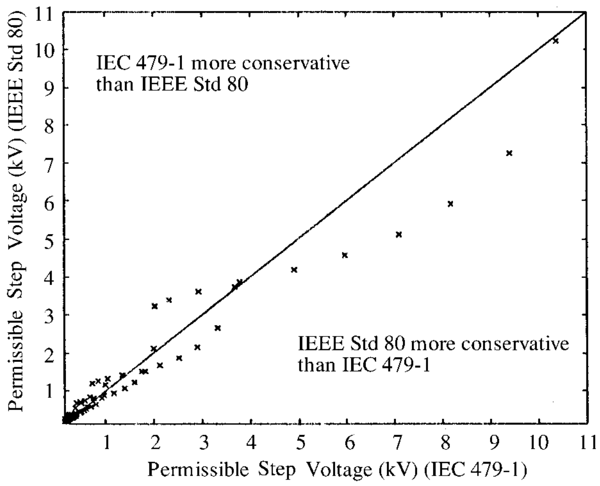

Fig. 9. Permissible step voltages per IEEE Std 80 vs IEC 479-1, 5% body resistance values, probability of ventricular fibrillation 0.5%, hand to two feet.

situations. The ranges of parameters are (1) soil resistivities 10 to 3000 ohm.meters and (2) electric shock duration 0.05 to 0.5 seconds. The results are illustrated in Tables 2-7 and in Figs. 8-13. The tables

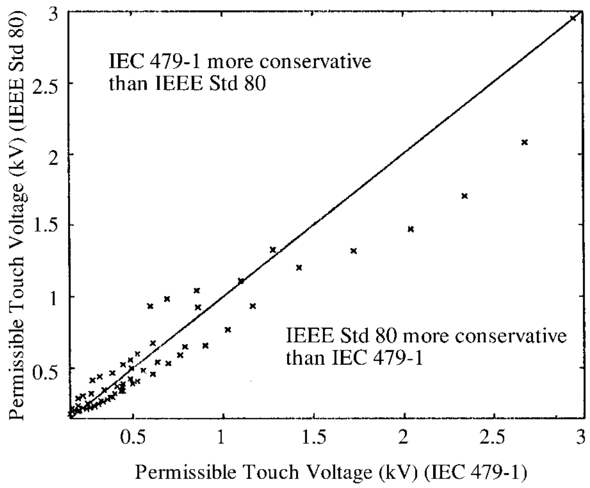

Fig. 10. Permissible touch voltages per IEEE Std 80 vs IEC 479-1, 50% body resistance values, probability of ventricular fibrillation 0.5%, hand to two feet.

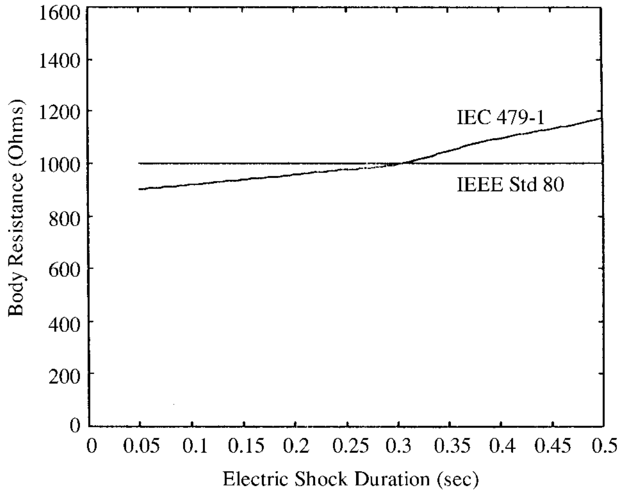

Fig. 12. Body resistance vs electric shock duration at the maximum permissible touch voltage, 5% body resistance values, hand to two feet.

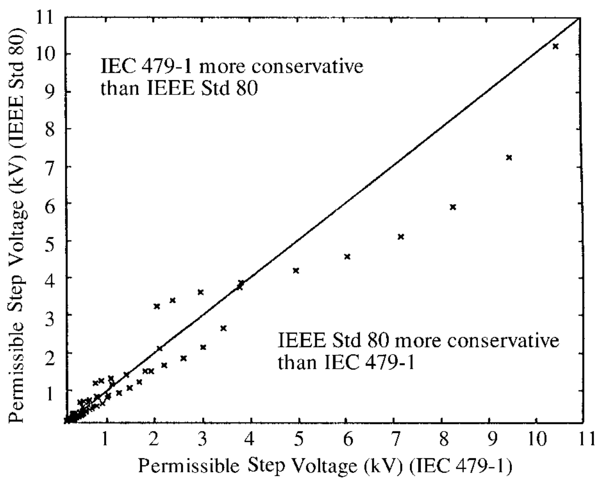

Fig. 11. Permissible step voltages per IEEE Std 80 vs IEC 479-1, 50% body resistance values, probability of ventricular fibrillation 0.5%, hand to two feet.

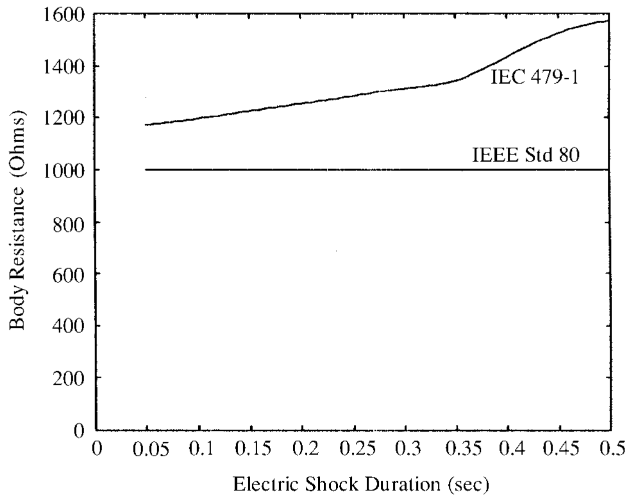

Fig. 13. Body resistance vs electric shock duration at the maximum permissible touch voltage, 50% body resistance values, hand to two feet.

provide the permissible touch and step voltages as defined by the two standards for the ranges of parameters defined above. Figures 8-11 provide the data from Tables 2-7 in graphical form. The coordinates are the permissible touch or step voltages of the two standards respectively. Each point represents permissible voltages as allowed by the two standards computed for the same parameters of soil resistivity and shock duration. By construction, then, each point on the diagonal of the graph represents a case where the two standards yield the same permissible voltages. Points above the diagonal represent cases where IEC 479-1 is more conservative than IEEE Std 80 while points below the diagonal represent cases where IEEE Std 80 is more conservative than IEC 479-1. Note that the points are about evenly distributed around the diagonal. Finally, Figs. 12 and 13 compare the body resistance value used to compute the permissible touch and step voltages using the two standards. Note that for the usual shock durations 0.25 to 0.5 seconds, the 5% body resistance of the IEC 479-1 standard is near 1000 Ω or higher. This is useful information for persons questioning the use of 1000 Ω in IEEE Std 80.

VI. Summary and Conclusions

The safety criteria of IEC 479-1 and IEEE Std 80 have been compared, and their differences have been quantified. There are cases in which IEEE Std 80 is more conservative than IEC 479-1 and vice versa. The IEC 479-1 safety criteria are rather complex while the safety criteria of IEEE Std 80 are simplified. The opinion of the authors is that simplicity is important. Given the fact that the safety criteria include comfortable safety margins, one can conclude that the simplicity of IEEE Std 80 does not compromise safety in grounding system design. Another major difference is that IEC 479-1 does not address all relevant computational issues while IEEE Std 80 provides approximate equations and formulas which are useful to a designer. In conclusion, IEEE Std 80 provides useful procedures for grounding system safety assessment.

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IEC 479-1和IEEE Std 80兩種接地安全標準之比較

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摘 要

本文針對兩種廣泛被接受的接地安全標準（IEC 479-1與IEEE Std 80）作比較。此兩種標準的差異在於允許人體電流（permissible body current）與人體電阻（body resistance）定義上的不同。IEC 479-1標準並沒對人體雙腳與土壤間之接觸阻抗做指引，而設計人員可經由計算來獲得接觸阻抗之大小。本文是針對廣泛條件下作允許接觸電壓與允許步間電壓的研究以直接比較這兩種標準，並證明他們的差異。