WESTERN POWER DISTRIBUTION
Serving the Midlands, South West and Wales

Company Directive

STANDARD TECHNIQUE: TP21AB

Earthing Design Fundamentals
Part B
Safety Limits For Touch Voltages On Electrified Railways & Tramways

Summary

This Standard Technique defines the safety limits for touch voltages on ac railways & dc tramways when designing earthing systems which are to be owned or adopted by Western Power Distribution.

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Implementation Date: **December 2020**

Approved by

[signature]

Carl Ketley-Lowe
Engineering Policy Manager

Date: **11th December 2020**

Target Staff Group	**Network Services Teams & ICPs**
Impact of Change	**AMBER - The changes have an impact of current working practices that are not safety critical - Communication at next team meeting or as part of a retraining programme**
Planned Assurance Checks	**None**

IMPLEMENTATION PLAN

Introduction

This Standard Technique defines the safety limits for touch voltages on ac railways & dc tramways when designing earthing systems which are to be owned or adopted by Western Power Distribution.

Main Changes

This document is a new ST.

Impact of Changes

This Standard Technique is relevant to staff, Contractors and Independent Connection Providers involved with the design / assessment of earthing systems for safe touch voltage.

Implementation Actions

Managers should notify relevant staff that this Standard Technique has been published, and brief them on its requirements.

There are no retrospective actions.

Implementation Timetable

This ST shall be implemented with immediate effect.

REVISION HISTORY

Document Revision & Review Table		
Date	**Comments**	**Author**
December 2020	• Initial issue	Graham Brewster

Contents

1.0 INTRODUCTION

This Standard Technique defines the safety limits for touch voltages on ac railways & dc tramways when designing earthing systems which are to be owned or adopted by Western Power Distribution.

The rise of earth potential associated with current passing through an earthing system under fault conditions can present an electric shock hazard. A potential difference across parts of the human body causes current to flow. There is a risk of fatal electric shock if the current flows for sufficient time to cause ventricular fibrillation of the heart. IEC 60479-1 defines a series of time-current curves for judging whether this will occur. These curves are used to derive the permissible touch voltages.

The safety limits for touch voltages are described in tabular form, and the data is based on BS EN 50122-1 (the standard that applies to the rail industry). The underlying assumptions about body impedance, probability of ventricular fibrillation, and footwear resistance differ from those employed is BS EN 50522 (the standard that applies to the distribution network), which results in much lower voltage safety limits. The following table summarises the different assumptions made by the standard:

	BS EN 50122 (Rail Industry)	**BS EN 50522 (Electricity Industry)**
Current path	Left hand to both feet	Left hand to both feet
Body impedance	Large surface areas of contact in dry conditions	Large surface areas of contact in dry conditions
Probability of body impedance lower than assumed value	50%	5%
Probability of ventricular fibrillation	0% (i.e. C_1 curve)	5% (i.e. C_2 curve)
Additional resistance – Footwear	2kΩ for old wet shoes included for clearance times < 0.7s	4kΩ
Additional resistance - standing surface	Not accounted for	Accounted for

In order for the railway / tramway to comply with these touch voltage safety limits it is necessary for these limits to be realised at the interface between the distribution network and the railway / tramway, in other words:

- When HV or EHV supplies are provided to an electrified railway or tramway for traction purposes i.e. at a traction supply point substation
- When non-traction HV supplies are provided to an electrified railway or tramway, for example, a HV supply to a train station
- When Grid, Primary or Distribution substations are located in proximity to electrified railways and tramways

Note that these touch voltage limits apply to railway or tramway infrastructure only i.e. WPD substations may be designed in accordance with the safety limits specified in Standard Technique TP21AA provided that the potential transferred to the railway / tramway complies with the limits specified in this document.

2.0 DEFINITIONS

For the purpose of this document the following definitions are employed:

TERM	DEFINITION
Touch Voltage	The potential difference between a person's hands and feet when standing 1m away from the object they are touching
Ventricular Fibrillation	A state of the heart in which the lower chambers (ventricles) twitch randomly (fibrillate) instead of contacting in a co-ordinated fashion, resulting in an inability to pump blood. Considered to be the main mechanism of death in fatal electrical accidents
Traction Supply Point	A supply to a railway or tramway which is used to provide motive power (traction) to locomotives and trams.

3.0 REFERENCES

This document makes reference to, or should be read in conjunction with, the documents listed below. The issue and date of the documents listed below shall be those applicable at the date of issue of this document, unless stated otherwise.

3.1 IEC Standards

NUMBER	TITLE
IEC 60479-1	Effects of current on human beings and livestock - Part 1: General aspects

3.2 British Standards

NUMBER	TITLE
BS EN 50552	Earthing of power installations exceeding 1 kV a.c.
BS EN 50122-1	Railway applications - Fixed installations - Electrical safety, earthing and the return circuit - Part 1: Protective provisions against electric Shock

4.0 REQUIREMENTS

4.1 Touch Voltage Limits On Electrified Railways & Tramways For Typical Fault Clearance Times

The touch voltage limits listed below shall apply on electrified railway or tramway infrastructure as follows:

- At all new traction supply point substations and, where reasonably practicable, when major modifications are carried out to existing traction supply point substations
- At all new non-traction HV supplies and, where reasonably practicable, when major modifications are carried out to existing non-traction HV supplies
- At all new Grid, Primary or Distribution Substation located in proximity to the railway or tramway and, where reasonably practicable, when major modifications are carried out at existing substations in a similar location

Fault Clearance Time (s)	Touch Voltage Limit (V)
0.02	865
0.05	835
0.1	785
0.2	645
0.3	480
0.4	295
0.5	220
0.6	180
< 0.7	155
0.7	90
0.8	85
0.9	80
1.0	75
300	65
> 300	60

The touch voltage limits for fault clearance times less than 0.7 seconds are derived assuming an additional resistance (i.e. footwear) of 1kΩ. The touch voltage limits for fault clearance times greater than 0.7 seconds are derived assuming no additional resistance is present.

The change that occurs at 0.7s is because BS EN 50122 subdivides the permissible touch voltage into long-term values for normal operation of the railway / tramway, and short-term values for fault conditions.

The current path hand to hand is less restrictive than the current path hand to feet, even when an additional resistance is included for old wet shoes.

5.0 BACKGROUND INFORMATION

5.1 Effects on the Human Body of 50Hz Alternating Current

This section describes the effects of 50Hz sinusoidal alternating current passing through the human body.

5.1.1 Threshold of Perception

The threshold of perception is the minimum value of current which causes any sensation for the person through which it is flowing.

The threshold depends on several parameters, such as the contact surface area, the conditions of contact (dry, wet, contact pressure), and also on the physiological characteristics of the individual. It will be less than the threshold of reaction.

5.1.2 Threshold of Reaction

The threshold of reaction is the minimum value of current which causes involuntary muscular contraction for the person through which it is flowing.

The threshold depends on the same factors as per the threshold of perception. The IEC Standard uses a value of 0.5mA for the threshold of reaction when touching a conductive surface.

5.1.3 Threshold Of Ventricular Fibrillation

Ventricular fibrillation is a state of the heart in which the lower chambers (ventricles) twitch randomly (fibrillate) instead of contacting in a co-ordinated fashion, resulting in an inability to pump blood. It is considered to be the main mechanism of death in fatal electrical accidents.

The threshold of ventricular fibrillation is the minimum value of current through the body which causes ventricular fibrillation.

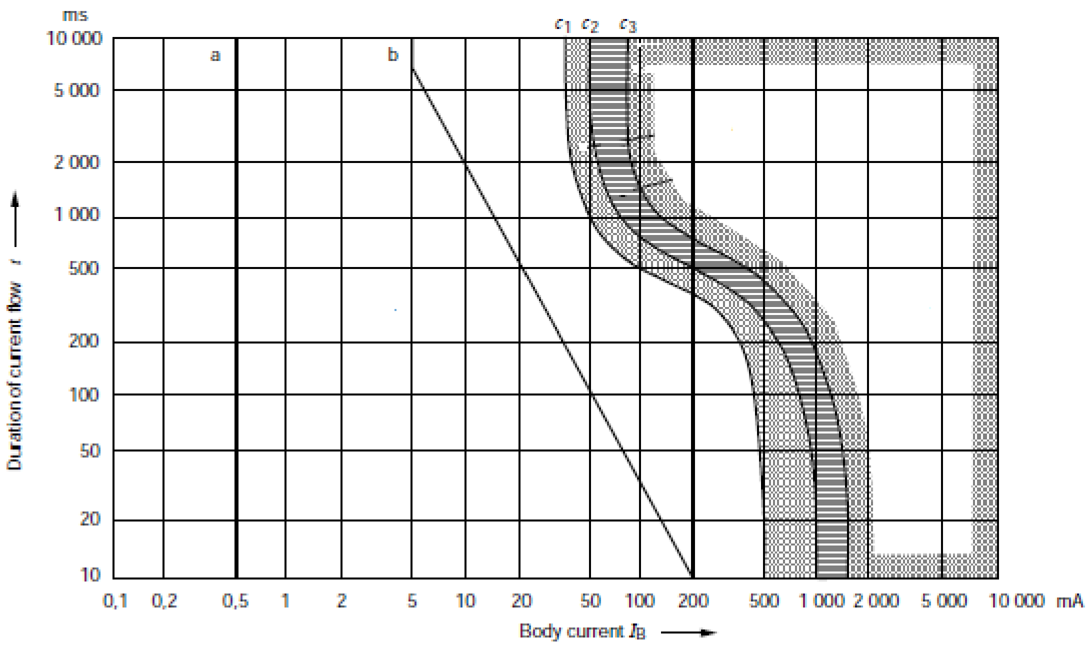
The threshold depends on physiological parameters (anatomy of the body, state of cardiac function, etc.) as well as on electrical parameters (duration and pathway of current flow, etc.).

5.1.4 Time-Current Curves

IEC 60479-1 provides time-current curves for a hand-to-hand current path, where the probability of ventricular fibrillation occurring in a population is 0%, 5% and 50%.

The diagram below shows the time-current curves for the human body for 50Hz alternating current.

Up to a	= threshold of perception
a to b	= involuntary muscular contractions
b to c	= Strong involuntary muscular contractions
c_1	= Limit of 0% probability of ventricular fibrillation
c_2	= Limit of 5% probability of ventricular fibrillation
c_3	= Limit of 50% probability of ventricular fibrillation



5.1.5 Body Current Limit

The time-current curve used in the rail / tram industry for earthing system design is the C_1 curve i.e. where the probability of ventricular fibrillation occurring in a population is 0%.

The Body Current Limit for the left hand to both feet current path (i.e. C_1 time-current curve) in tabular form is shown below:

Duration of Current Flow (s)	Body Current (mA)
0.02	495
0.05	475
0.1	440
0.2	350
0.3	252
0.4	145
0.5	100
0.6	78
< 0.7	66
0.7	66
0.8	58
0.9	52
1.0	50
300	38
> 300	37

5.1.6 Heart Current Factor

The rail industry only considers current paths for a left hand to both feet condition and hence a 'heart-current factor' is not employed (i.e. if it was it would always be unity).

5.2 **Electrical Impedance Of The Human Body**

From an earthing design perspective, it is more convenient to refer to body voltages rather than body current, and this requires an understanding of the electrical impedance of the human body.

The electrical impedance of the body depends on a number of factors, including the:

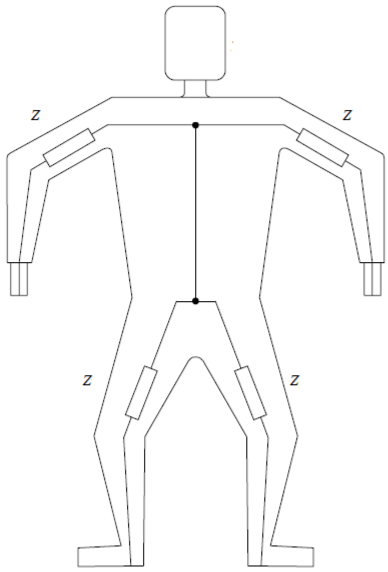
- Magnitude of the touch voltage
- Path of the current through the body
- Duration of current flow
- Degree of moisture of the skin
- Surface area of contact
- Contact pressure exerted

5.2.1 Impedance Of The Skin

The impedance of the skin is mostly resistive. Its value depends on the magnitude of the touch voltage, duration of the current flow, surface area of contact, pressure of contact, and the degree of moisture of the skin.

5.2.2 Internal Impedance Of Human Body

The internal impedance of the human body is mostly resistive. The internal impedances are mainly located in the limbs (arms and legs), and a simplified schematic diagram for the internal impedances of the human body is shown in the diagram below.



If Z is the internal impedance of an arm or a leg, then the hand to hand internal impedance is 2Z, as is the one hand to one foot internal impedance.

It is apparent that the internal impedance from one hand to both feet is 1.5Z, or 75 % of the hand to hand impedance. Likewise, the impedance from both hands to both feet is Z, or 50 % of the hand to hand impedance.

5.2.3 Body Impedance

IEC 60479-1 includes tables of the total impedance of the human body for a hand-to-hand current path and a range of touch voltages, for large, medium and small surface areas of contact, and for dry, water-wet and saltwater-wet conditions. Values are provided for total body impedances that are not exceeded for 5%, 50% and 95% of the population.

BS EN 50122-1 (the standard used by the rail / tram industry) requires earthing systems to be designed assuming large surface area of contact, dry conditions, and body impedances not exceeded by 50% of the population.

The body impedance for these conditions (from IEC 60479-1) is shown in the table below:

Body Voltage (V)	Body Impedance (Ω)
25	3250
50	2500
75	2000
100	1725
125	1550
150	1400
175	1325
200	1275
225	1225
400	950
500	850
700	775
1000	775

5.2.4 Reduction Factor

A ‘reduction factor’ is utilised in order to calculate the body impedance for shock paths other than hand-to-hand. Note that in the standards used by the electricity industry this is known as the ‘body factor’.

$$Body\ Impedance_{hand\ to\ feet} = Body\ Impedance_{hand\ to\ hand} \times Reduction\ Factor$$

BS EN 50122-1 (the standard used by the rail / tram industry) specifies a left hand-to-both feet current path, and from Section 5.2.2 it is apparent that the Reduction Factor is 0.75.

For example, the left hand to both feet body impedance where the hand-to-hand body impedance is 800Ω is:

$$Body\ Impedance = 800\Omega \times 0.75 = 600\Omega$$

5.3 Additional Resistances

Additional resistances include that presented by gloves, footwear and the type of standing surface covering.

BS EN 50122-1 (the standard used by the rail / tram industry) specifies additional resistance for short-term conditions (less than 0.7 seconds), and no additional resistance for long-term conditions (longer than 0.7 seconds).

The change that occurs at 0.7s is because BS EN 50122-1 subdivides the permissible touch voltage into long-term values for normal operation of the railway / tramway, and short-term values for fault conditions.

5.3.1 Additional Resistance - Feet

BS EN 50122-1 (the standard used by the rail / tram industry) specifies an additional resistance of 2kΩ for old wet shoes for short-term conditions.

The resistance of the standing surface is not taken into account.

Touch potentials are normally assessed using the left hand to both feet condition and consequently the additional resistance is calculated taking into account the effect of two shoe and standing surfaces in parallel. In other words:

$$R_{additional-feet} = \frac{R_{shoe} + R_{standing\ surface}}{2}$$

Accordingly

$$R_{additional-feet} = \frac{2000 + 0}{2} = 1000\ \Omega$$

5.3.2 Additional Resistance - Hands

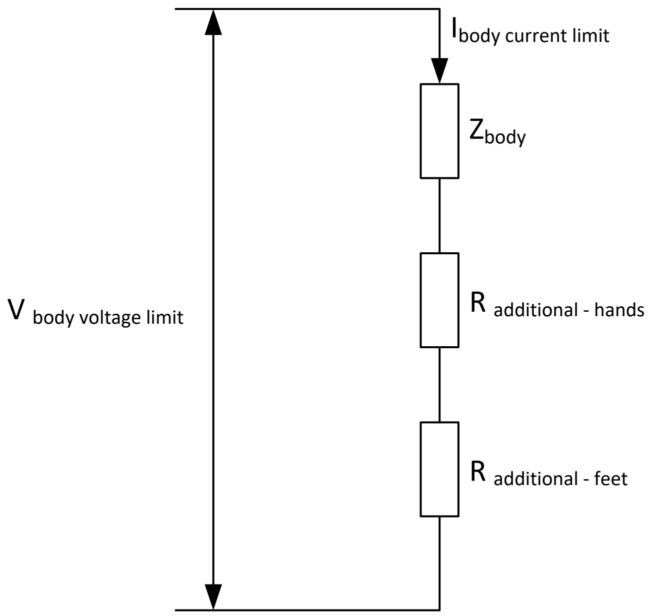
Touch potentials are normally assessed using the left hand to both feet condition and consequently the additional resistance is calculated taking into account the effect of a single glove. In other words:

$$R_{additional-hands} = R_{glove}$$

BS EN 50122-1 (the standard used by the rail / tram industry) assumes that gloves will not be worn i.e. $R_{additional - hands} = 0\ \Omega$.

5.4 **Calculation Of Body Voltage Limits**

Consider the following diagram:



The body current limit is obtained from Section 5.1.5.

From Sections 5.2.3 and 5.2.4

$$Z_{body} = Body\ Impedance_{hand\ to\ hand} \times Reduction\ Factor$$

$$Z_{body} = Body\ Impedance_{hand\ to\ hand} \times 0.75$$

From Sections 5.3.1 and 5.3.2

$$V_{body\ voltage\ limit} = I_{body\ current\ limit}\ x\ [Z_{body} + R_{additional-hands} + R_{additional-feet}]$$

Therefore the body voltage limit (i.e. touch voltage limit) for fault clearance times less than 0.7 seconds is

$$V_{body\ voltage\ limit} = I_{body\ current\ limit}\ x\ [Z_{body} + 1000]$$

And the touch voltage limit for fault clearance times greater than 0.7 seconds is

$$V_{body\ voltage\ limit} = I_{body\ current\ limit}\ x\ Z_{body}$$

5.4.1 Worked Example

Consider an assessment of the permissible left hand to both feet touch voltages in a location where there is bare soil. Personnel should be assumed to be wearing old wet shoes, but no gloves.

Additional resistance is taken into account where the fault clearance time is less than 0.7 seconds. The table overleaf was constructed using the above information in conjunction with the table in Section 5.2.3.

If the fault clearance time was 200ms then, from the table in Section 5.1.5, the Body Current Limit is 350mA. From the table overleaf it is apparent that a body voltage of 500V equates to a current of 305.3mA. The body voltage limit (i.e. touch voltage limit) is therefore somewhere in the range of 500V and 700V.

If the fault clearance time was 500ms then, from the table in Section 5.1.5, the Body Current Limit is 100mA. From the table overleaf it is apparent that a body voltage of 200V equates to a current of 102.2mA. The body voltage limit (i.e. touch voltage limit) is therefore a little under 200V.

Body Voltage [A]	Body Impedance	Reduction Factor x Body Impedance [B]	Additional Resistance [C]	Total Resistance [D] = [B]+[C]	Body Current [A] / [D]
25 V	3250 Ω	2438 Ω	1000 Ω	3438 Ω	7.3 mA
50 V	2500 Ω	1875 Ω	1000 Ω	2875 Ω	17.4 mA
75 V	2000 Ω	1500 Ω	1000 Ω	2500 Ω	30.0 mA
100 V	1725 Ω	1294 Ω	1000 Ω	2294 Ω	43.6 mA
125 V	1550 Ω	1163 Ω	1000 Ω	2163 Ω	57.8 mA
150 V	1400 Ω	1050 Ω	1000 Ω	2050 Ω	73.2 mA
175 V	1325 Ω	994 Ω	1000 Ω	1944 Ω	90.0 mA
200 V	1275 Ω	956 Ω	1000 Ω	1956 Ω	102.2 mA
225 V	1225 Ω	919 Ω	1000 Ω	1919 Ω	117.2 mA
400 V	950 Ω	713 Ω	1000 Ω	1713 Ω	233.5 mA
500 V	850 Ω	638 Ω	1000 Ω	1638 Ω	305.3 mA
700 V	775 Ω	581 Ω	1000 Ω	1581 Ω	442.8 mA
1000 V	775 Ω	581 Ω	1000 Ω	1581 Ω	632.5 mA

APPENDIX A

SUPERSEDED DOCUMENTATION

None

APPENDIX B

RECORD OF COMMENT DURING CONSULTATION

The comments received are recorded in the following document.

APPENDIX C

ANCILLARY DOCUMENTATION

POL: TP21 - Fixed Earthing Systems

APPENDIX D

KEY WORDS

Earthing; Shock; Touch; Voltage; Railway; Rail; Tramway; Tram