Protection Engineers Group

Huntsville, AL - March 13-15, 2018

Shocking Electricity — 2

Effects of Current on Human Beings and Livestock – Part 2: Special Aspects

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Shocking Electricity – 2 is an update of the 2017 PEG Conference Shocking Electricity presentation as a new version of IEC TS 60479-2 was published late in 2017. The 2017 edition includes the following significant technical changes with respect to the previous edition:

• Changes reflecting the change in applicability of frequency from 1 kHz to 150 kHz have been added.
• The handling of successive DC pulses has been clarified.
• The examination of random complex irregular waveforms has been added.

Warning
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Introduction

The previous 2017 Shocking Electricity presentation covered the following topics; IEC 60479 Effects of current on human beings and livestock standards, body current flows, body current-time curve, body resistance, hand to hand and hand to foot differences, c1 no fibrillation boundary line data and multiple current pulses. At that time, multiple current pulses with pulse separations of < 300 ms were not standardised.

The 2017 version of IEC TS 60479-2 defines the cumulative effect of multiple current pulses with pulse separations of < 100 ms with a fuzzy area up to 300 ms. The main topic of this presentation will be discussions on multiple current pulse charge values and a use illustration.

IEC TS 60479-2, Edition 4.0, 2017-10 abstract

IEC TS 60479-2:2017 describes the effects on the human body when a sinusoidal alternating current in the frequency range above 100 Hz passes through it. This document describes the effects of current passing through the human body in the form of single and multiple successive unidirectional rectangular impulses, sinusoidal impulses and impulses resulting from capacitor discharges. This basic safety publication is primarily intended for use by technical committees in the preparation of standards in accordance with the principles laid down in IEC Guide 104 and ISO/IEC Guide 51.

Contents of IEC TS 60479-2, Edition 4.0, 2017-10

- 1 Scope
- 2 Normative references
- 3 Terms and definitions
- **4 Effects of alternating currents with frequencies above 100 Hz**
- 5 Effects of special waveforms of current
- 6 Effects of alternating current with phase control
- 7 Effects of alternating current with multicycle control
- 8 Estimation of the equivalent current threshold for mixed frequencies
- **9 Effects of current pulse bursts and random complex irregular waveforms**
- 10 Effects of electric current through the immersed human body
- 11 Effects of unidirectional single impulse currents of short duration
- *Annex A (informative) Random complex irregular waveform analysis*
- *Bibliography*

IEC 60479-2 (2017) frequency extension to 150 kHz

Adds new Figure 6 showing variation of the threshold of ventricular fibrillation for continuous sinusoidal current from 1 kHz to 150 kHz.

Spot values are 1 kHz 14x, 10 kHz 50x, 100 kHz 140x and 150 kHz 200x.

Ventricular fibrillation charge

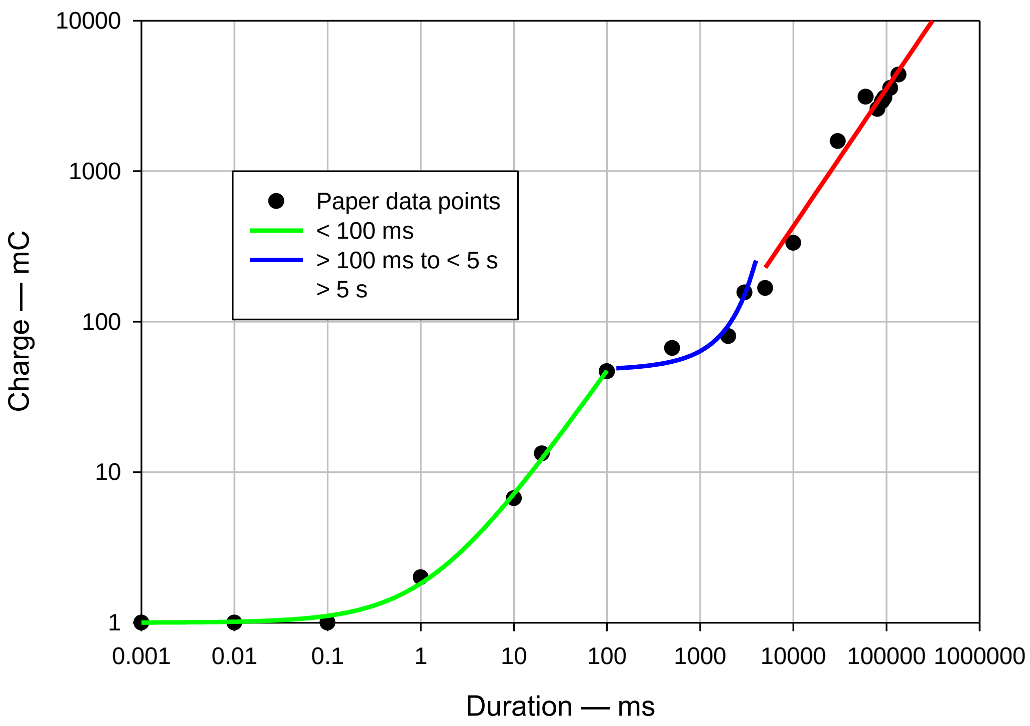
There have been several papers on how charge is the dominant parameter for short duration currents.

Pearce, J.A., et al: *Myocardial stimulation with ultrashort duration current pulses* (1982). Experiments on dogs and turtles showed a constant charge up to a certain time duration, thereafter the charge increased with a roughly A +Bt relationship, where t is the rectangular pulse duration.

Panescu, D., et al: *Transthoracic Ventricular Fibrillation Charge Thresholds* (2015). The summary states 3 behavioural regions can be identified for charge ventricular fibrillation thresholds vs. duration.

- 1 µs – 10 ms, approximates to 1 + 0.494*duration (mC). (10 ms should be 100 ms)
- 10 ms - 5 s, transition zone approximated as constant charge of approximately 100 mC. (10 ms should be 100 ms)
- >5 s, charge approximated to 38 mA rms constant current.

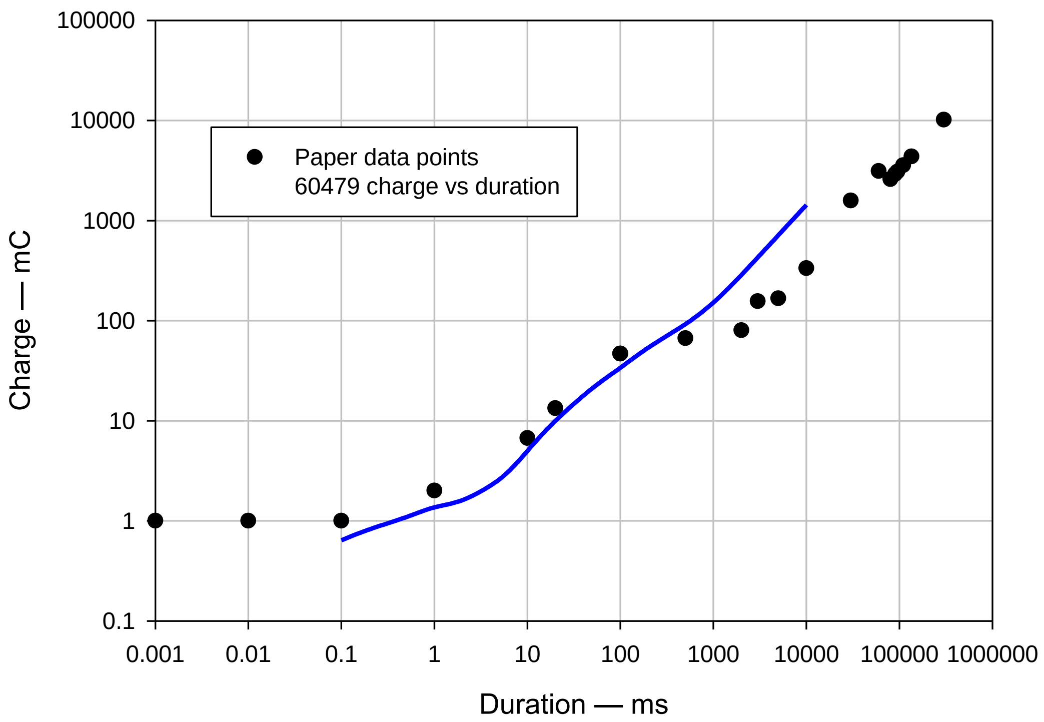
Panescu, D., et al paper data points and curve fits — 1



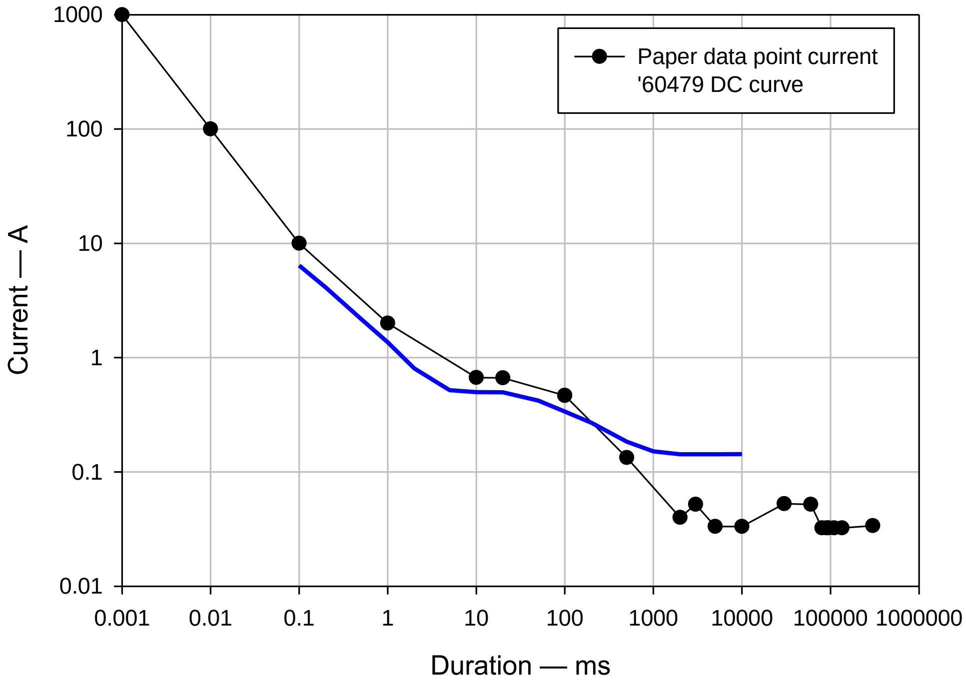
Panescu, D., et al paper data points and curve fits — 2

- In the 1 µs – 100 ms region the best curve fit to the data points was found to be 1+0.824*(Duration^0.875)
- In the 100 ms - 5 s transition the best curve fit to the data points was found to be 29+18.5*EXP(Duration/1590)
- For >5 s, the best curve fit to the data points was found to be 0.095*(Duration^0.914)

‘60479 DC charge boundary & paper data points



'60479 DC & paper data point currents — 1



'60479 DC & paper data point currents — 2

The two curves track up to 1 s, thereafter separate and plateau at different levels. The 60479 curve was created for d.c., which levels out at 140 mA. The paper data plot was for a.c., which levels out at about 40 mA rms.

Application of d.c. gives a heart a single shock, whereas a.c. is repetitively shocks the heart. For this reason the long term value of d.c. is about 3.5 times higher than the a.c. value.

The paper data indicates a constant value of charge below 100 µs. The IEC curve does not do this as its charge value decreases below 100 µs. In turn the IEC current does not increase fast enough below 100 µs.

IEC TS 60479-2 multiple pulses of current

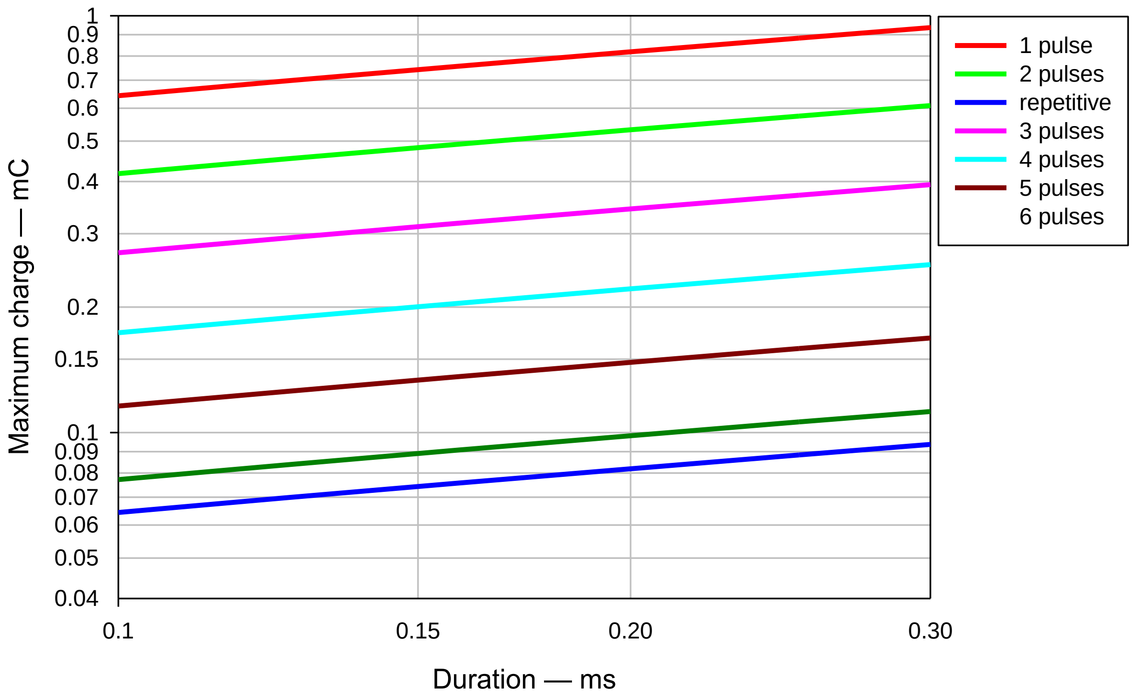
Pulse separation > 300 ms

Pulses do not have cumulative effects on the heart and can be treated as single, non-repetitive pulses of current.

Pulse separation < 300 ms

Repetitive pulses can have cumulative effects on the heart. When the separation is < 100 ms there is a definite cumulative effect.

Maximum multi-pulse charge, separation < 100 ms



Multi-pulse example

A well known multi-pulse device is the TASER®. The X2 model has the following published specification.

- Pulse duration: 50 μs – 125 μs.
- Pulse rate: 19 ± 1 pulses per second. Pulse separation about 50 ms, within the < 100 ms criteria and more than 7 pulses
- Full pulse charge: 63 ± 9 microcoulombs (μC).

IEC TS 60479-2 multi-pulse pulse charge values

- An estimation of the ‘60479 repetitive pulse charge values in the 100 µs region gave: 49 µC at 50 µs, 58 µC at 75 µs, 64 µC at 100 µs and 70 µC at 125 µs. These values are 10 % of the single pulse values, but could be lower as ‘60479-2 says “10 % or less” for repetitive pulses.

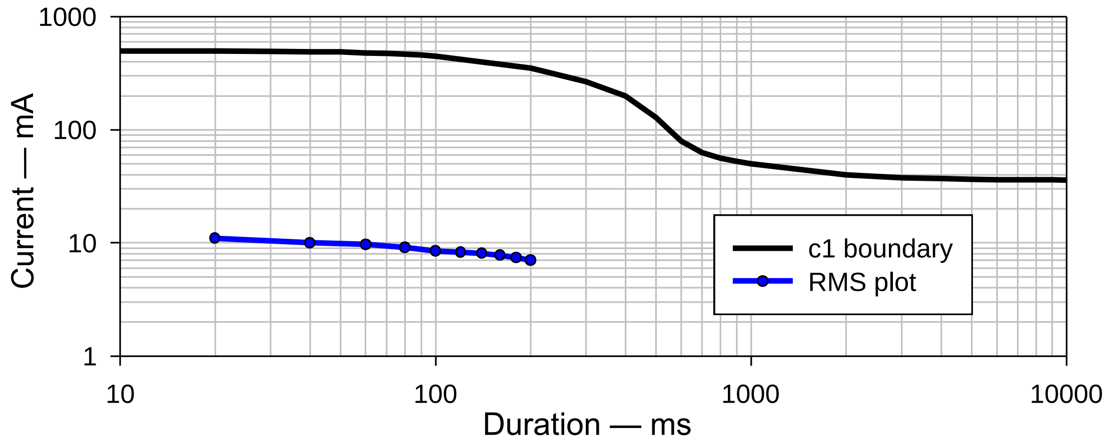
- From the quoted X2 TASER® discharge values of 54 µC to 72 µC at 50 µs – 125 µs, the X2 TASER® plot point is likely to be near the ‘60479 “no fibrillation” c_1 limit line.

The exact position of the plot point would need careful measurement of the charge waveform and conversion of its triangular type waveshape to a rectangular pulse. Also IEC 60479-2 does not declare any “no fibrillation” values below 100 µs.

Random complex irregular waveforms - 1

The first part of this *informative* Annex describes a root-mean-square approach to regularly sampled waveform data. For a succession of increasing time periods the mean-square of the time period samples is calculated. The highest mean-square value is then rooted and used as the plot point for that time period. The resultant rms and time period values are then plotted on the ‘60479 current-time graph for comparison with the limit boundary.

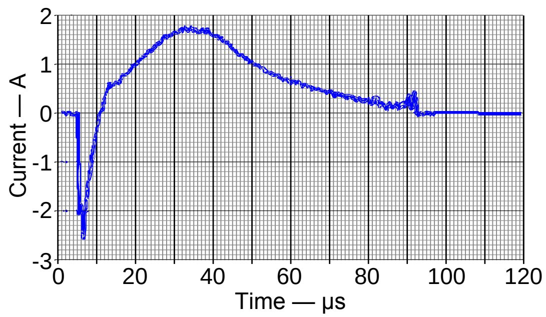
After the regularly sampled example, the Annex then has two examples of random complex waveforms and shows how the rms approach is adjusted to cope with this.



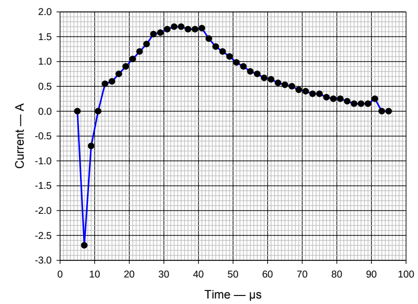
Random complex irregular waveforms - 2

sample time ms	20	40	60	80	100	120	140	160	180	200		
mA	5	7	8	4	9	11	9	7	3	1		
mA^2	25	49	64	16	81	121	81	49	9	1	time ms	mA rms
n=1	25	49	64	16	81	121	81	49	9	1	20	11.0
n=2		37	56.5	40	48.5	101	101	65	29	5	40	10.0
n=3			46	43	53.7	72.7	94.3	83.7	46.3	19.7	60	9.7
n=4				38.5	52.5	70.5	74.8	83	65	35	80	9.1
n=5					47	66.2	72.6	69.6	68.2	52.2	100	8.5
n=6						59.3	68.7	68.7	59.5	57	120	8.3
n=7							62.4	65.9	60.1	51.1	140	8.1
n=8								60.8	58.8	52.8	160	7.8
n=9									55	52.3	180	7.4
n=10										49.6	200	7.0

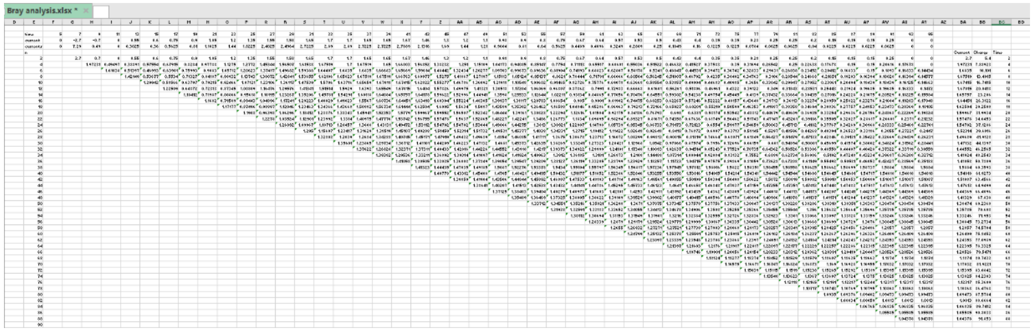
RMS approach to Bray et al data — 1



Mapped waveform



Digitised waveform



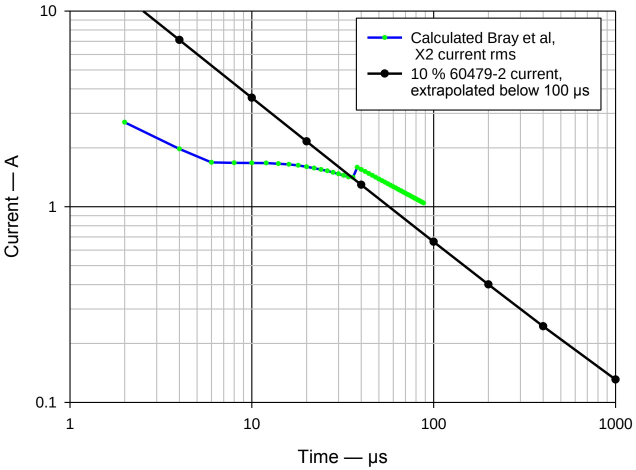
Excel spread sheet

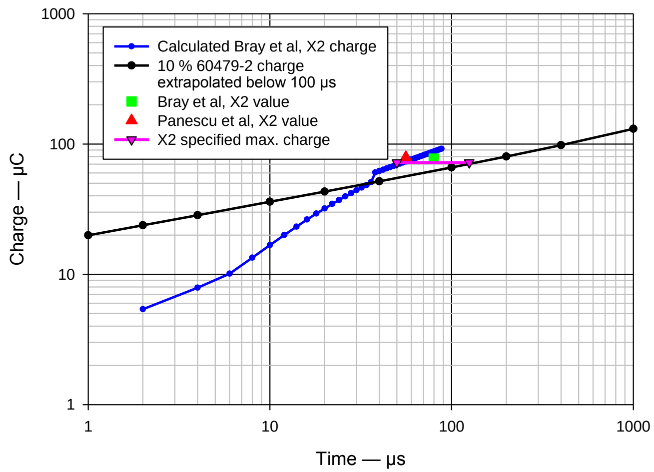
The X2 current waveform in Bray J and Cameron F, Electrical Testing of TASER X2 and TASER X26P Conducted Energy Weapons, Royal military College of Canada was mapped and digitised.

The digitised 2 µs current values were then squared and the square root of the average of various group sizes calculated.

RMS approach to Bray et al data — 2

The calculated waveform RMS current-time line crosses the IEC 60479-2 extrapolated "no fibrillation" 10 % current line, but does not exceed the extrapolated "5% probability fibrillation" current level. The extrapolation was based on a curve fit to the "no fibrillation" current line between 100 µs and 5 ms ($0.1411+199*time^{-0.744}$).





A similar result occurs for the charge-time plot. The X2 specified charge-time values, the Bray et al charge-time values and the Panescu D, Nerheim M and Kroll M, Electrical Safety of Conducted Electrical Weapons Relative to Requirements of Relevant Electrical Standards paper charge-time values are all above the extrapolated 10 % "no fibrillation" charge line.

This presentation has covered the significant technical changes in IEC TS 60479-2 (2017) with respect to the previous edition:

• Frequency limit has been extended to 150 kHz.
Spot values were given.

• The cumulative effect of successive DC pulses separated by <100 ms.
Examples of use are given

• RMS analytic approach to random complex irregular current waveforms.
Simple repetitive sampling examples given

• It has been shown that this revision of IEC 60479-2 fails to provide information on the "no fibrillation" current limits for pulses shorter than 100 µs. An extrapolation of the provided data is not secure as several papers (page 7) have indicated that below 100 µs is a constant charge region and the extrapolation results in a reducing charge region.