# Cardiac Safety Profile for Random Complex Waveforms

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*Introduction:* **A rigorous method for assessing the Ventricular Fibrillation (VF) risk of a Random Complex Waveform (RCW) has not been previously available. Real-life hazardous events motivated us to develop such method. An RCW is observable and recordable. It consists of multiple different components randomly added one to the other. Assessment for VF risk exists for non-random waveforms, particularly VF thresholds for 50/60 Hz alternating currents, but not for RCWs.**

*Methods:* **We developed a method which considers exposure to a segment of an RCW. It transforms complex segment exposure to values which can be compared with AC root-mean-square (rms) magnitude/duration curves, for determination of VF risk. Human contact could occur for any given time duration within the segment. The current of most risk is the greatest found for all possible instances of that duration. This is termed the "Probable Current" (PC) for that duration. All possible exposure durations in the waveform segment are considered, giving a set of PCs, thus allowing the plotting of a PC curve. The PC set is compared with a criterion for VF risk, termed the Justified Current (JC) curve.**

*Results:* **The theory is presented. Demonstrations and examples are given. Code is shown for generating the PC curve.**

*Conclusion:* **VF risk can be found for an RCW using the rigorous algorithm presented.**

*Significance:* **The VF for RCWs has not been considered previously. A rigorous statement of a method for VF risk assessment allows extension from regular waveforms to RCWs.**

***Keywords***: Cardiac Risk, Fibrillation, Random Complex Waveform, Standards.

## I. INTRODUCTION

Electric current can be highly injurious to the body. In physical terms, burns, organ damage and organ dysfunction can be serious, even life threatening. In this latter category the induction of Ventricular Fibrillation (VF), a severe cardiac arrhythmia where the heart ceases coordinated contractions, decreases cardiac output and organ perfusion to the point where death quickly supervenes. It is the most common fatal consequence of an electric shock.

Over the past several decades, a large number of publications have been dedicated to studying VF thresholds (VFT) [1 – 12]. However, most of the focus has been on the effects of 50/60 Hz alternating currents (AC) [1 – 5] with flow durations of up to 10 s. Technical Specifications such as IEC 60479-1 and -2 provide current-based VFTs for regular, predictable or repetitive stimuli durations between 0.1 ms and 10 s [11, 12]. There have been few studies of VFTs for random complex waveforms (RCW), as defined below.

There are several means of examining electric current waveforms to assess their danger of producing VF. This is of obvious importance for equipment design, for forensic examination, and for many other purposes. Each of the existing techniques requires regular, reproducible waveforms to assess the risk of that particular waveform.

For example, the IEC 60479 series of standards [11, 12], detail methods of examining waveforms in each of the following categories:

i. Pure Alternating Current (AC).
ii. Pure Direct Current (DC)
iii. Combined, regular, AC and DC waveforms
iv. Rectified regular AC current
v. Chopper controlled (Phase Controlled) AC current
vi. Multicycle control AC
vii. Mixed Frequency regular AC
viii. Capacitor Discharges and regular unidirectional impulse currents
ix. Modifications for the immersed Body
x. Special Features for livestock

Each technique has limits of applicability, for example, to a limit of frequency in the AC case. The electrical danger of an electric shock is given by the current flowing through an individual and, in some cases, the transmitted charge. In initial formulation, IEC 60479 also provides means of calculating the current through an individual by first determining the impedance of any given pathway within the body. Then applying a given potential, together with the calculation of the impedance of the given pathway, allows an estimation of the current which passes in the pathway. It is then examined for its risk. The matter of impedance calculation is beyond our present scope. In this paper we examine effects of current in a pathway, assuming it has been calculated or measured.

All the above assessments require a waveform which is regular and predictable, and in most cases analytical.

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Consider the "simple" case of exposure to AC. Once the current magnitude in a pathway is determined, along with the time for which it is applied, entry to the magnitude/duration curves for AC may be made. These are shown in Fig. 1 with explanation of regions in Table 1 [11]. It will be noted that this diagram is for quite specific conditions. It is for the hand-foot pathway, and has a definite frequency applicability range. Within the standard, there are means of transforming a current in a different given pathway to its equivalent in the hand-foot pathway for estimation of risk. Frequency may also be adjusted.

Figure 1. Time/current zones of effects of AC (15–100 Hz) on persons for a current path left hand–feet. (with permission from IEC)

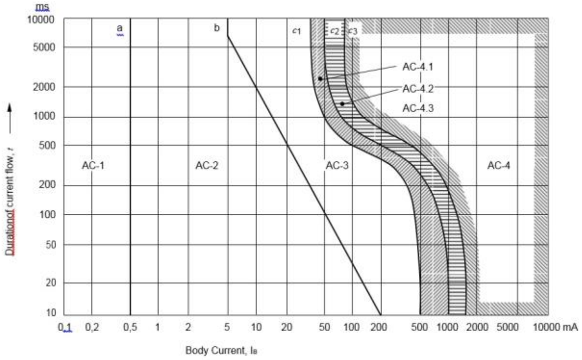


Table 1 – Time/current zones for AC 15–100 Hz for hand–feet pathway– Summary of zones of Fig. 1 [11]. (with permission from IEC)

| Zones | Boundaries | Physiological effects |
|---|---|---|
| AC-1 | Up to 0,5 mA curve a | Perception possible but usually no 'startled' reaction |
| AC-2 | 0,5 mA up to curve b | Perception and involuntary muscular contractions likely but usually no harmful electrical physiological effects |
| AC-3 | Curve b and above | 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 |
| AC-4 1) | Above curve $c_1$ | 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 |
| | $c_1$-$c_2$ | AC-4.1 Probability of ventricular fibrillation increasing up to about 5 % |
| | $c_2$-$c_3$ | AC-4.2 Probability of ventricular fibrillation up to about 50 % |
| | Beyond curve $c_3$ | AC-4.3 Probability of ventricular fibrillation above 50 % |

1) For durations of current flow below 200 ms, ventricular fibrillation is only initiated within the vulnerable period if the relevant thresholds are surpassed. As regards ventricular fibrillation, this figure relates to the effects of current which flows in the path left hand to feet. For other current paths, the heart current factor has to be considered.

Further, there are other factors which affect the previous stage of impedance calculation before making the current calculation. These latter factors include skin wetness, skin type, area of contact, and so on. However once the standardized hand-foot pathway has been reached, the current can be used to estimate risk, and especially risk of VF.

Examples of risk for various currents can be seen from the figure and the table:

i. 0.2 mA flowing for any time is considered safe.

ii. 10 mA contacted for 100 ms risks perceptual and involuntary movement, but is of little harm, whereas for 5000 ms places the victim in a zone of strong involuntary contraction, difficulty breathing, and reversible heart arrhythmia.

iii. 200 mA for 200 ms places the victim in a zone of strong involuntary contraction, difficulty breathing, and reversible heart arrhythmia, whereas if maintained for 500 ms risks VF up to a probability of 50%, and if maintained longer, an even higher probability of VF.

It will be noted however, that all the considered currents are regular, predictable and describable. They are in most cases analytical. This is not necessarily the case for many of the real-life waveforms. For example, motivating this study was a shock to an individual in contact with a crane cable which was in turn in contact with an overhead conductor. Current was transmitted to the individual via a polluted insulator in the cable. The hazardous current which affected this individual fulfilled all the criteria of a random complex waveform, as defined in this paper. In order to more accurately understand the effects of such currents, we wish to propose means for extending the applicability of IEC 60479-1 and -2 to Random Complex Waveforms.

## II. RANDOM COMPLEX WAVEFORMS AND THEIR RISK

Random Complex Waveform, (RCW) are

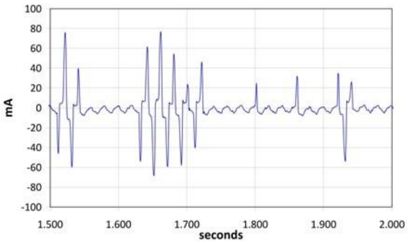
a. *Random*, in the sense that they are statistical in nature, and not predictable from knowledge of the potential source; they are not describable in mathematical detail though they are observable; they are not analytical.

b. *Complex*, in the sense that they include unpredictable elements of several of the elements above.

c. *Waveforms*, in the sense that they are continuous, observable, and measurable, and, though random, are amenable to at least physical explanation, if not prediction.

For ease of illustration, the particular RCWs that we consider are mixtures of AC with random impulses superimposed, random in magnitude duration and occurrence. Such waveforms may for example arise from the unpredictable conduction and arcing across a polluted insulator. A typical RCW is shown in Fig. 2.

Figure 2. Example of typical RCW.



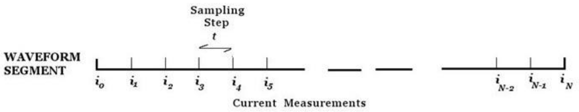
In this example, there is an AC component that appears across an insulator. Also, there is a random breakdown of a pollution film across the insulator surface. The result is a current waveform which is complex, being a combination of several elements above, and random.

A means of determining the danger of such a waveform was the rationale behind developing this methodology [13]. The method still involves the fundamental elements used above, but the IEC 60479 curves and methods referred to for non-random waveforms cannot be applied. This is justification for developing this new method.

An RCW sample, similar to that in Fig. 2, is considered. Nine seconds of the waveform has been chosen as the sample for illustration. As entry will later be made into the curves of Fig. 1, this 9 s value was chosen as close to the upper extremity of that figure. If the sample is to be dangerous, it is dangerous because there will be a segment embedded in it that is excessive in terms of magnitude and duration so that it constitutes risk of VF. With several types of current present, it is not possible to determine this merely by inspection, and a means of determining if such a segment exists is to be found.

The method described is that of Pratt [13] and it is well suited to waveforms which have been sampled discretely providing a set of measurements at known time intervals (see Fig. 3). Such sample sets are readily generated using digital sampling techniques.

Figure 3. Definition of a sample of a Random Complex Waveform.



where:

$N$ is the length in time periods of the sample

$t$ is the sampling step size in seconds

If we contend that there is a segment in this sample that is to constitute risk, then an iterative method of examining all possible segments can be developed to find it. All possible segments, of a size (i) beginning with a duration of one sample each and (ii) up to a final single segment of the length of the whole sample can be examined. Each of the segments so examined can be scrutinized against the criteria of Fig. 1 for danger. A segment will be considered dangerous if it transgresses the $c_1$ line of Fig. 1. To do so requires that the segment scrutinized be expressed in terms of the RMS current it represents and the length of the segment. All segments examined can be used to plot a curve (the PC or "Probable Current" curve) to be entered onto Fig. 1. A single point will be found as a magnitude-time point for a given segment length. The magnitude will be the maximum RMS current developed from all segments of that one duration, and the time will be the duration of that segment currently under consideration. Taking the maximum ensures a conservative value.

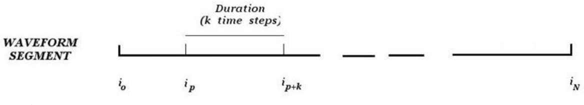
It may therefore be considered that this method is a transform method to map a random complex waveform onto the RMS curve satisfying Fig. 1. Prior to assessing the random complex waveform segment it should first be low pass filtered, using a 100 Hz upper frequency cut-off, as Fig. 1 is considered valid to 100 Hz. Such filtering is consistent with filtering networks required by other international standards, such as IEC 60601-1 [14]. The combination that is the largest in any given duration interval is the PC for that interval. The PC is generated from the processing of the digitized waveform. When all probable currents are found for all the possible duration intervals, a PC curve is able to be plotted on Fig. 1. While the initial waveform was a set of magnitude versus time samples, describing the waveform in real time, generating the PC curve has now transformed the initial waveform into a set of points of "maximum danger of a given duration anywhere within the whole waveform". The algorithm can therefore be seen as a transformative process. The overall worst case magnitude/duration in the waveform segment is therefore found and may be assessed.

The resulting PC curve is in a format that can be compared with 50Hz data for which the experimental data is available. It is plotted on the same axes as Fig. 1. A curve which falls completely beneath the $c_1$ curve may be considered indicative of safety for all exposure times. A curve which falls completely above the $c_1$ curve may be considered dangerous for any exposure. It may be that a part of the PC curve, up to a given time length $t_1$, falls below the $c_1$ line, and a part greater than this length falls above the $c_1$ line. The implication of this finding is that within the sample there exists a dangerous duration of length $t_1$ somewhere in the waveform. If an individual contacts the overall waveform for any time up to $t_1$ they receive a shock which is not "dangerous". Should they contact the overall waveform for longer than $t_1$ then they potentially will receive a shock from the segment (somewhere in the waveform) of longer duration and greater magnitude than "allowable".

## III. THEORETICAL FORMULATION

Consider a sample, measured at time steps $t$, of length $N$ data points (Fig. 3). Therefore, the sample has $N+1$ data points, and is $Nt$ seconds in length. There is no immediate necessity for t to be constant, though in practice it generally will be. Should it vary, the formula below, particularly with respect to interval length should be modified. The following formulation is restricted for simplicity to a constant sampling period $t$. Consider a segment within this sample of length k time steps. There are $k+1$ data points for this segment. Let us suppose it begins within the data at data point $p$. It thus extends to include, and end on, data point $p+k$. This is shown in Fig. 4.

Figure 4. Definition of a Segment within a Sample.



where:

$k$ length of the interval under consideration in time steps

$p$ starting position of the interval

The RMS value of the current over this segment is given by the equation:

$$i_{segment}^{RMS} = \sqrt{\frac{1}{k+1}\sum_{m=p}^{p+k} i_m^2}$$

The next step is to find the RMS value for all possible segments of length $\boldsymbol{k}$ within the sample and take the maximum value found. To generate the RMS value for all possible segments of length $\boldsymbol{k}$, we first take the segment starting at point $\boldsymbol{i_0}$, and which ends at $\boldsymbol{i_k}$, and find the RMS of this segment. We then step through successive segments of length k, successively beginning at $\boldsymbol{i_1}$ $\boldsymbol{i_2}$ $\boldsymbol{i_3}$ ... till there are no further segments of length $\boldsymbol{k}$. The final segment of length $\boldsymbol{k}$ will begin at $\boldsymbol{i_{N-k}}$ and end at $\boldsymbol{i_N}$, and a further step of length $\boldsymbol{k}$ is not possible, and flags the stopping point for consideration of all segments of length $\boldsymbol{k}$. The maximum RMS of these segments gives the point on the PC curve corresponding to time $\boldsymbol{kt}$. That is:

$$\boldsymbol{PC}_{kt} = \boldsymbol{MAX}_{p=0}^{N-k}\left\{\sqrt{\frac{1}{k+1}\sum_{m=p}^{p+k} i_m^2}\right\}$$

This is then repeated for all values of $\boldsymbol{k}$ from **1** to $\boldsymbol{N}$. That is,

$$\boldsymbol{PC}_{kt} = \boldsymbol{MAX}_{p=0}^{N-k}\left\{\sqrt{\frac{1}{k+1}\sum_{m=p}^{p+k} i_m^2}\right\}\forall \boldsymbol{k} = 1 \ldots \boldsymbol{N}$$

Thus, the PC curve is generated and then is plotted on Fig. 1.

It is then compared with a Justified Current Curve (JC), possibly one of the existing curves on Fig. 1, to establish safety criteria. JC is discussed more closely in the next section.

## IV. DEMONSTRATION OF THE CALCULATION

### A. Demonstration

Consider a sample of a given digital waveform digitized with a 20 ms sample step size, $\boldsymbol{t}$ = 20 ms. In this demonstration the current values at 20 ms sampling steps (20, 40, 60 … ms) have magnitudes of 5, 7, 8, 4, 9, 11, 9, 7, 3, and 1 mA, respectively. The PC is to be extracted for all possible segments, considering successively longer segments. For each segment, its maximum RMS is chosen as the PC point. The points thus found for succeeding segments form the PC curve.

The method proceeds as follows.

1) To assist in obtaining the RMS values, the current values are initially squared. The current squared at sampling steps (20, 40, 60 … ms) are sequentially 25, 49, 64, 16, 81, 121, 81, 49, 9, and 1 mA$^2$. Squaring the values also ensures that positive and negative excursions are considered equally.

2) The first segment chosen is 20 ms. There is thus only one sample in this segment. The maximum value is 121 mA$^2$. Therefore, the PC value for all possible 20 ms segments is 11 mA, and is plotted at 20 ms, (see Fig. 5).

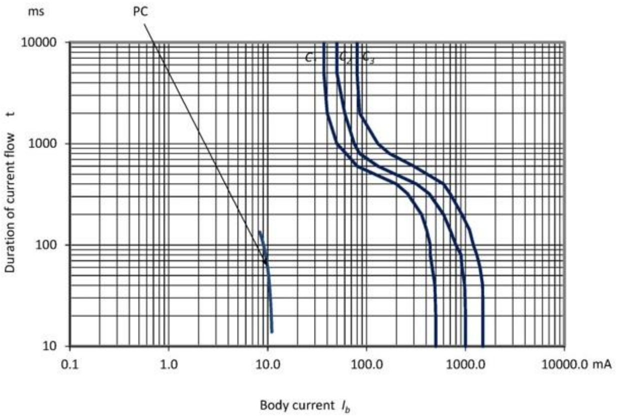


Figure 5. PC for Demonstration Example of the RCW method plotted against time-current curves from Fig. 1.

3) For simplicity, we select the next segment to be of 60 ms length. There are three samples in each such segment. The PC value for each 60 ms segment is calculated thus, recalling the division by the number of points (3) in the time segment:

a) (25+49+64)/3 mA$^2$ = 46.0 mA$^2$
b) (49+64+16)/3 mA$^2$ = 43.0 mA$^2$
c) (64+16+81)/3 mA$^2$ = 53.7 mA$^2$
d) (16+81+121)/3 mA$^2$ = 72.7 mA$^2$
e) (81+121+81)/3 mA$^2$ = 94.3 mA$^2$
f) (121+81+49)/3 mA$^2$ = 83.7 mA$^2$
g) (81+49+9)/3 mA$^2$ = 46.3 mA$^2$
h) (49+9+1)/3 mA$^2$ = 19.7mA$^2$

The maximum value is 94.3 mA$^2$. Therefore, the PC value for three data point groups is 9.7 mA, plotted at 60 ms, (see Fig. 5).

4) The next segment chosen is 120 ms. There are therefore six samples in each such segment. The PC value for each 120 ms segment is calculated, recalling the division by the number of points (6) in the time segment:

a. (25+49+64+16+81+121)/6 mA$^2$ = 59.3 mA$^2$
b. (49+64+16+81+121+81)/6 mA$^2$ = 68.7 mA$^2$
c. (64+16+81+121+81+49)/6 mA$^2$ = 68.7mA$^2$
d. (16+81+121+81+49+9)/6 mA$^2$ = 59.5mA$^2$
e. (81+121+81+49+9+1)/6 mA$^2$ = 57.0 mA$^2$

The maximum value is 68.7 mA$^2$. Therefore, the PC value is 8.3 mA, and is plotted at 120 ms (see Fig. 5).

The computation continues until all segments are exhausted. The resulting PC curve is derived from these values and is plotted, as an example, in Fig. 5. The JC in this demonstration was chosen as $c_1$. At no time does the PC exceed the JC so this situation is considered acceptably safe on the criteria specified.

### *B. Choice of JC*

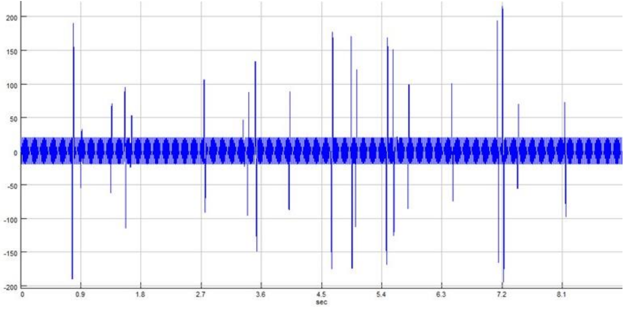
This method allows data to be reduced and compared to traditional RMS data found in Fig. 1 (which is derived from Fig. 20 of IEC 60479-1 [11]). The appropriate level for JC to make this comparison must be chosen. In various applications a more conservative value than $c_1$ might be deemed necessary. For example, a design/product committee may wish to design an application more conservatively for their population. As such, they may choose a JC value of less than $c_1$. It will be noted that the method does not take into account the reduction in VF threshold for closely succeeding pulses, each of which captured the heart. If these pulses are suspected to occur and to have sufficient strength to elicit premature ventricular responses, then a lesser value for the JC can be chosen, recognizing repeated burst analysis as described elsewhere [5, 11].

### *C. Choice of Sampling Step Size*

The choice of sampling step size $\boldsymbol{t}$ is made after scrutiny of the waveform. In one sense, the sample value, $\boldsymbol{i}$, might be considered best as the RMS value of the maximum in that period. This however implies a much faster sampling interval, and substantial processing of the samples before an output at any chosen step $\boldsymbol{p}$. It is considered this adds a greater degree of complexity than warranted. It also requires a much more complex sampling regime than is usually available. Thus, currents $\boldsymbol{i_p}$ are instantaneous values at any step $\boldsymbol{p}$, given the chosen sampling step size $\boldsymbol{t}$. Should this step size be considered to "hide" important detail, a smaller $\boldsymbol{t}$ should be chosen.

## V. EXAMPLES

Figure 6. A RCW typical of those used in Examples 1 and 2.



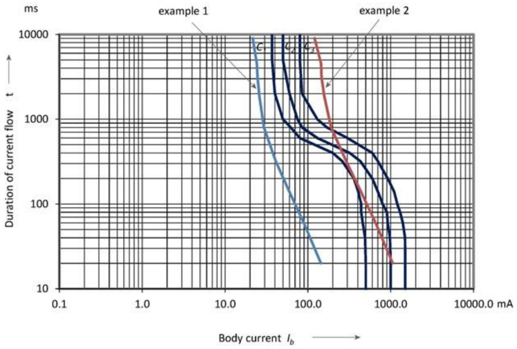
Two examples of the use of the method in more "real" circumstances follow. The waveform that is used in these examples is a waveform that is close to that for which the method would be used in real analysis. The waveforms have been generated on a Monte Carlo basis. The typical appearance of the random complex waveform examples which are generated as shown in Fig. 6.

### *A. Example 1 – A "safe" Waveform*

Example 1 uses a random complex waveform with the following parameters:

1. A 50 Hz 20 $\text{mA}_{\text{RMS}}$ current waveform, safe from the viewpoint of not causing VF, forms a background wave [11]. The length of the data sample is 9 s.
2. Into this sample, 50 pulses, in random positions within the 9 s, of random width up to 10 ms, are added. The set of pulses are inserted with amplitude randomly up to 200 mA. Reference to Fig. 22 of IEC 60479-1 (2005) [11] should convince us that these are also safe.
3. Adjustment: For the sake of these examples only, and this will not be the case in "real" analysis, every pulse is matched by an equal and opposite pulse occurring immediately after. This is simply to ensure that the DC mean of the pulses is zero. It will be appreciated that if the DC mean is not zero, this mean will accumulate throughout the analysis especially in longer segments, and will affect the PC. This may well be what is required in "real" situations, but zero mean is used here so that the expected effects of the pulses versus a cumulating DC offset can be isolated.
4. The signals are filtered by a LPF, with cut-off 100Hz. The filter is a high order LPF, using digital filtering techniques. The RMS values of the segments are found.
5. The 9 s sample is examined at time segments of 20, 50, 100, 200, 500, 1000, 2000, and 5000 ms duration.
6. The PC is calculated at each of these segments, and is plotted on Fig. 7.

Figure 7. PCs for Examples 1 and 2, respectively, plotted against time-current curves from Fig. 1.



In comparison with a JC taken as $c_1$, this waveform is, as expected, not likely to cause VF.

### *B. Example 2 – An "Unsafe" Waveform*

Example 2 is a random complex waveform with the following parameters:

1. A 50 Hz 20 $\text{mA}_{\text{RMS}}$ current waveform, safe from the viewpoint of not causing VF, forms a background wave [11]. The length of the data segment is 9 s.
2. Into this sample, 50 pulses, in random positions within the 9 s, of random width up to 10 ms, are added. The set

of pulses are inserted with amplitude randomly up to 1500 mA. Reference to Fig. 22 of [11] should convince us that these are likely to cause VF.

3. Adjustment: A similar adjustment for clarity is made as in step #3 of Example 1.
4. The signals are filtered by LPF, with cut-off 100 Hz, in the same manner as in Example 1.
5. The 9 s sample is examined at time segments of 20, 50, 100, 200, 500, 1000, 2000, and 5000 ms duration.
6. The PC is calculated at each of these segments, and is also shown in Fig. 7.

In comparison with a JC taken as $c_1$, this waveform is, as expected, likely to cause VF.

Both these examples, therefore yield results in accordance with expectations.

## VI. COMPUTATIONAL ASPECTS

Appendix 1 contains a program designed to calculate the PC points for all possible segments in sampled RCWs. The aim of the program is to consider all segments from length **1** up to the maximum input. The data file consists of single records of the time of the sample, and the value of current at that sample time. In addition, certain spot segment lengths are taken to provide a small summary of some key points along the PC. The code is in C, and is described as follows.

| *LINES* | *DESCRIPTION* |
|---|---|
| 1-12 | Dimensioning and data setup items. |
| 13-26 | Setup for the short summary items which will be printed to display rather than the data file. |
| 27-37 | Requests the input data file name with error checking. |
| 38-48 | Read the data file. Since time steps are equal, the time value is ignored for convenience. For RMS calculations, values are squared. End of file indicates the end of data input. Total number of points is recorded. |
| 49-59 | Defines the PC output file. This may be input to an Excel graph, such as the Time-Duration curves, establishing the overlay of the PC. |
| 60-81 | Calculating loops; ***i*** counts the length of each segment; begin counts where each segment of length ***i*** begins; the sum ***npts-i+1*** is the endpoint of each segment; ***j*** counts through the segment; and the maximum is finally taken. |
| 82-88 | calculates the RMS; and writes the output data file |
| 89-97 | prints the summary values, closes the file and returns. |

Calculating the full PC curve is quite computation intensive. It is possible to modify this code to calculate only the point values, as they are given by the array ***ppts***[..]. For a 9 s sample, with 1 ms step size, i.e. 9000 data points, a DELL Laptop under Windows 7 with an i7 core, takes approximately 416 s to calculate the whole PC.

## VII. CONCLUSION

This paper has presented a technique for determining the VF Risk for RCWs. The RCW was defined as an observable and recordable waveform, which consists of random elements added in a random fashion. The method considered both the effects of the magnitude of the complex exposure and the duration of the complex exposure. It assumed that human contact could occur at any point in a waveform and for an unspecified time duration. The current to be assessed for risk for any given exposure duration was the greatest found for that duration. The method then considered all the possible exposure durations in the chosen waveform segment and the maximum magnitude in each to determine the danger of VF.

The results were presented in a format that can be compared with 50 Hz data for which the experimental data are available. It is plotted on the same axes as Fig. 20 of IEC 60479-1, ed4, (2005) [11]. In order to assess the VF risk, the results may be compared to a Justified Current curve. We discussed considerations for appropriate selections of Justified Current curves. Computer code has been provided for generating the PC curve.

It would be unethical to conduct experiments in which living subjects are exposed to an RCW for the sole purpose of verifying the method. However, as contingency, the examples discussed in section V show that the proposed method is robust. The method is consistent with previously published data [10, 15] and draws on all relevant known techniques, thereby extending their applicability to RCWs.

It is concluded that now VF risk can be determined for RCWs where this has not previously been possible.

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## *APPENDIX 1*

```
#include <stdio.h>
#include <stdlib.h>
#include <math.h>

int main()
{
/* We cope with up to 10,000 data points. C arrays are 0 origin.
So the data points are 0.....9999 but arrays are dimensioned 10000*/

float accum[10000],max, time[10000],dataint, data[10000],begin,sum,d,ri;
int ppts[10];
int i, j, npts, reflg, t;
char fn[100], dum;
FILE *fd, *fo;

/* Initially I ask for a sampling interval in ms. I assumed that subsequent values
were all equally spaced at this interval. This is not entirely necessary but
simpler*/
/* we'll calculate data and print a summary at these points */
ppts [0]=10;
ppts [1]=20;
ppts [2]=50;
ppts [3]=100;
ppts [4]=200;
ppts [5]=500;
ppts [6]=1000;
ppts [7]=2000;
ppts [8]=5000;
ppts [9]=9000;

printf("Sampling Interval (ms):   ");
scanf("%f", &dataint);

/* Now we ask for the input data file name */
reflg=0;
while(reflg==0)
{
reflg=1;
printf("Data File:               ");
scanf("%s", fn);
printf("       >>> Data File %s will be read\n",fn);
fd=fopen(fn,"r");
if (fd==NULL) { printf("Filename is Invalid\n");reflg=0;}
}
/* We now read the data file, and square each value for later RMS calcs. We
accumulate the squares in data[0] to data[total number of points - 1]. The total
number of data points ends up in npts. The data**2 end up in data[0] ...
data[npts-1]. We stop reading when fscanf gives an error (t<0), and this is EOF*/
i=0; t=1;
while(t != 0   &&i<=9999)
{
t=fscanf(fd,"%f %f",&dum,&d);
if (t < 0) break;
data[i]=d*d;
i++;
}
npts=i;
printf("Number of Data Points    %d\n",npts);

/* Now we ask for the output filename - no spaces in the name */
reflg=0;
while(reflg==0)
{
reflg=1;
printf("Output TC file:           ");
scanf("%s", fn);
printf("       >>>  Output File %s will be written\n",fn);
fo=fopen(fn,"w");
if (fd==NULL) { printf("Filename is Invalid\n");reflg=0;}
}

/* I now take intervals along the data of 1 point, 2 points, 3 points ... to get the
whole PC and later print the summary of just a few points on PC.*/
for (i=1;i<=npts;i++)
/* i counts the interval size as we go up*/
/* i counts from 1 to npts, and the data is 0 to npts-1 */
{
printf("Interval length %4i\r",i);
ri=i;
/* we are going to find the max sum of squares in intervals of
1 then 2 then 3 ... uptonpts in size*/
max=0.0;

for(begin=0;begin<=(npts-i+1)-1;begin++)
/* Given the interval size i under consideration, we work out the beginning and
end of each interval. begin starts at the first data point in data[0], and the
beginning of the last interval of size i is the (npts -i +1)th data point, and 1 is
subtracted given the data origin is 0. So this loop is for all the intervals of size i.*/
{
sum=0;
for (j=begin;j<=begin+i-1;j++)
{
/*In a given interval starting at begin we generate the sum of squares for that
interval*/
sum=sum+data[j];
}

/* Now we see if this is the maximum for this size interval*/
if(sum > max)max=sum; /*max  sum of squares */
}

/* So now we have the maximum sum of squares in max*/
/* And we store the RMS in accum at the index of interval size i, subtracting 1
for 0 origin. For completeness also time is generated */
accum[i-1]=sqrt((double) (max/ri));
time[i-1]=i*dataint;

/* and finally write it into the output file */
fprintf(fo,"%7.1f       %f\n",time[i-1],accum[i-1]);
}

printf("\n");
for (j=0;j<=9;j++)
{
i=ppts[j];
printf("%4i:    %6.1f ms  is  %f\n", i, time[i-1],accum[i-1]);
}
fclose(fo);
return(0);
}
```