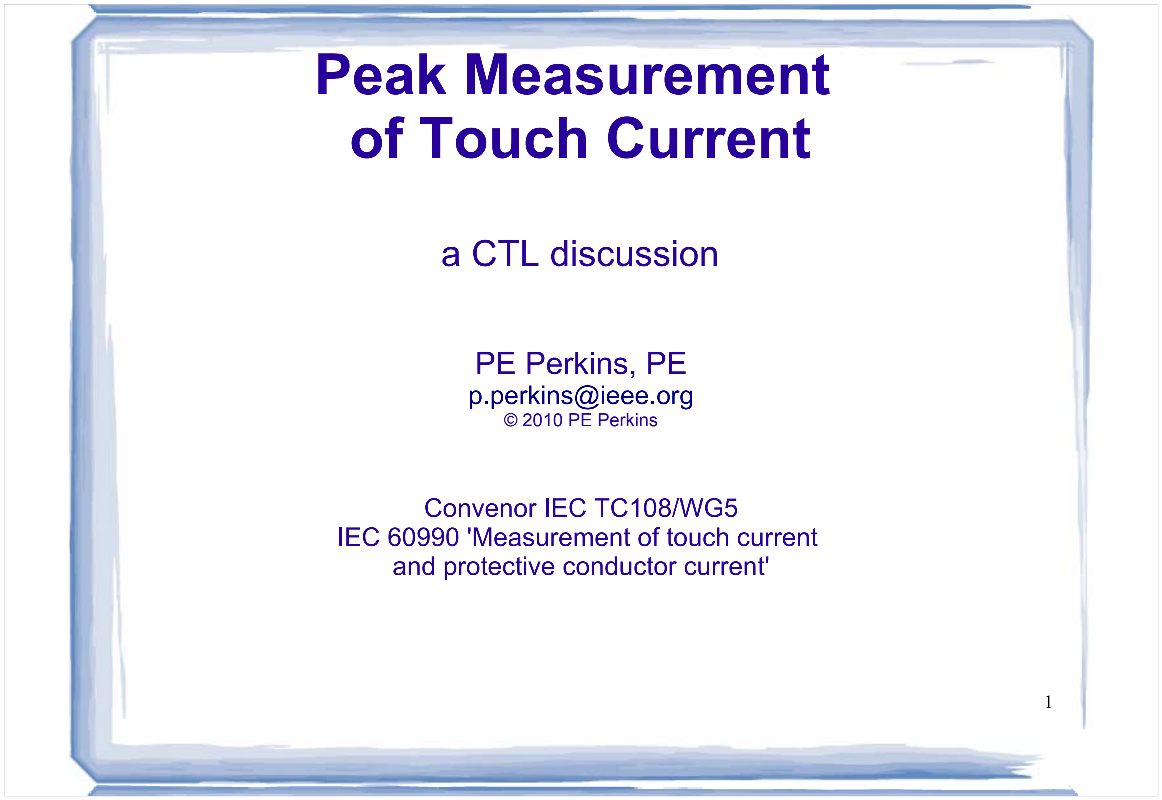


Peak Measurement of Touch Current

a CTL discussion

PE Perkins, PE
p.perkins@ieee.org

Convenor IEC TC108/WG5
IEC 60990 'Measurement of touch current and protective conductor current'

Abstract:

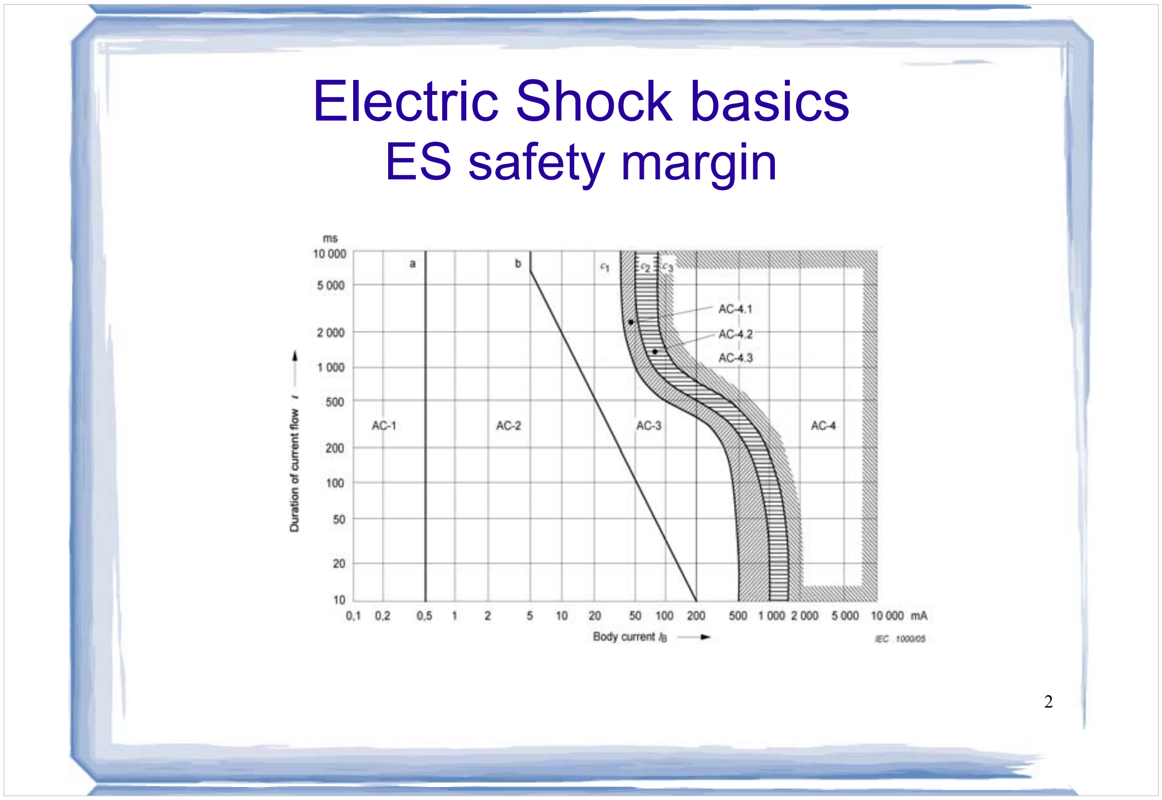
IEC 60990, 'Measurement of touch current and protective conductor current', provides the details needed to properly implement Touch Current measurements in products.

In this standard under the discussion of measurement to touch current it states: Of the responses, perception/ reaction and let-go are related to the peak value of touch current and vary with frequency. Traditionally, concerns for electric shock have dealt with sinusoidal waveforms, for which rms measurements are the most convenient. Peak measurements are more appropriate for non-sinusoidal waveforms.

This comment has always been intended to be used by knowledgeable electrical engineers or other professionals involved in the development and use of technical standards for evaluation of equipment with reference to electric shock.

The expectation has always been that invoking the IEC 60990 Touch Current measurement circuits and methods would involve common sense and that the proper measurement would be based upon the waveshape.

A comparison of the implementation of this Touch Current measurement in several standards is discussed in this paper.



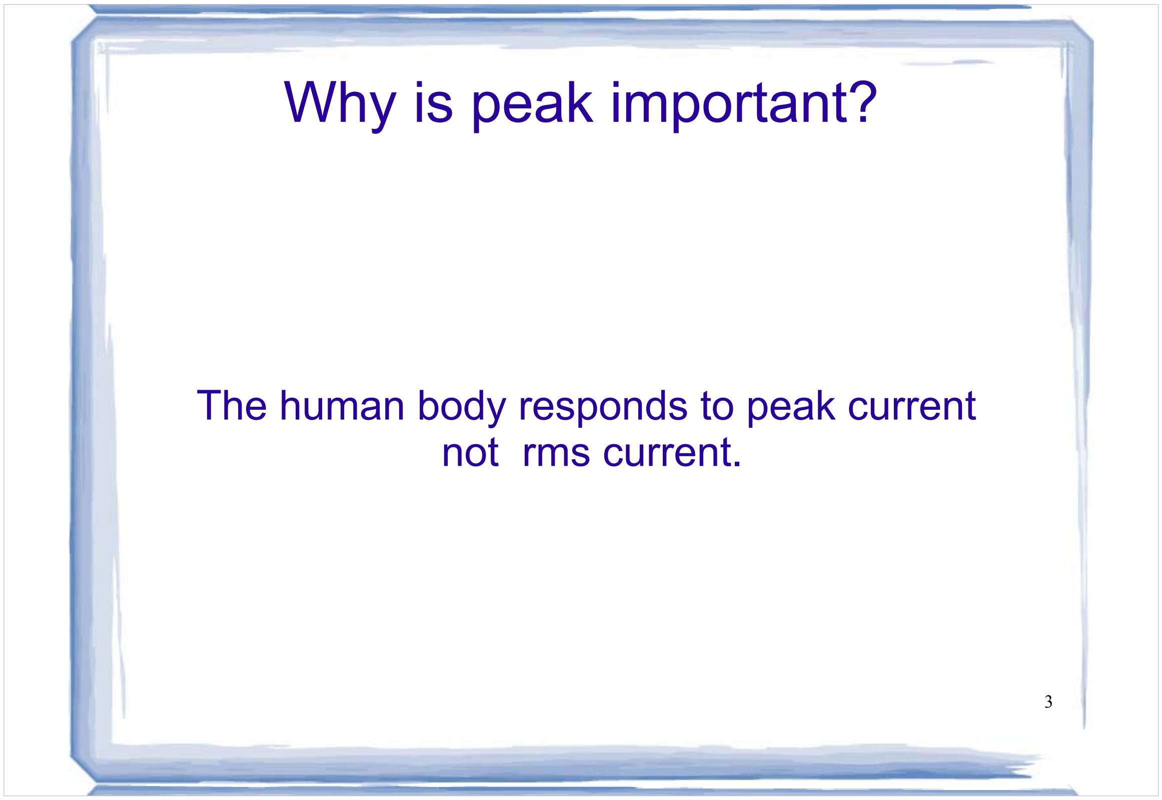
Electric Shock basics

ES safety margin

This is the well known IEC 60479 Fig 20 'Conventional time/current zones of effects of a.c. currents (15 Hz to 100 Hz) on persons for a current path corresponding to the left hand to feet'.

Since electrical engineers don't commonly work with known factors of safety it needs to be pointed out that the usual safety margin or factor of safety is the distance between the b curve and the c1 curve. The minimum is about a factor of 3X (at the 1 sec duration). This VF to let-go ratio is key to providing safe products under all conditions.

Maintaining this safety factor depends upon the pk to rms ratio of sq rt (2), or sinusoidal waveforms.



Why is peak important?

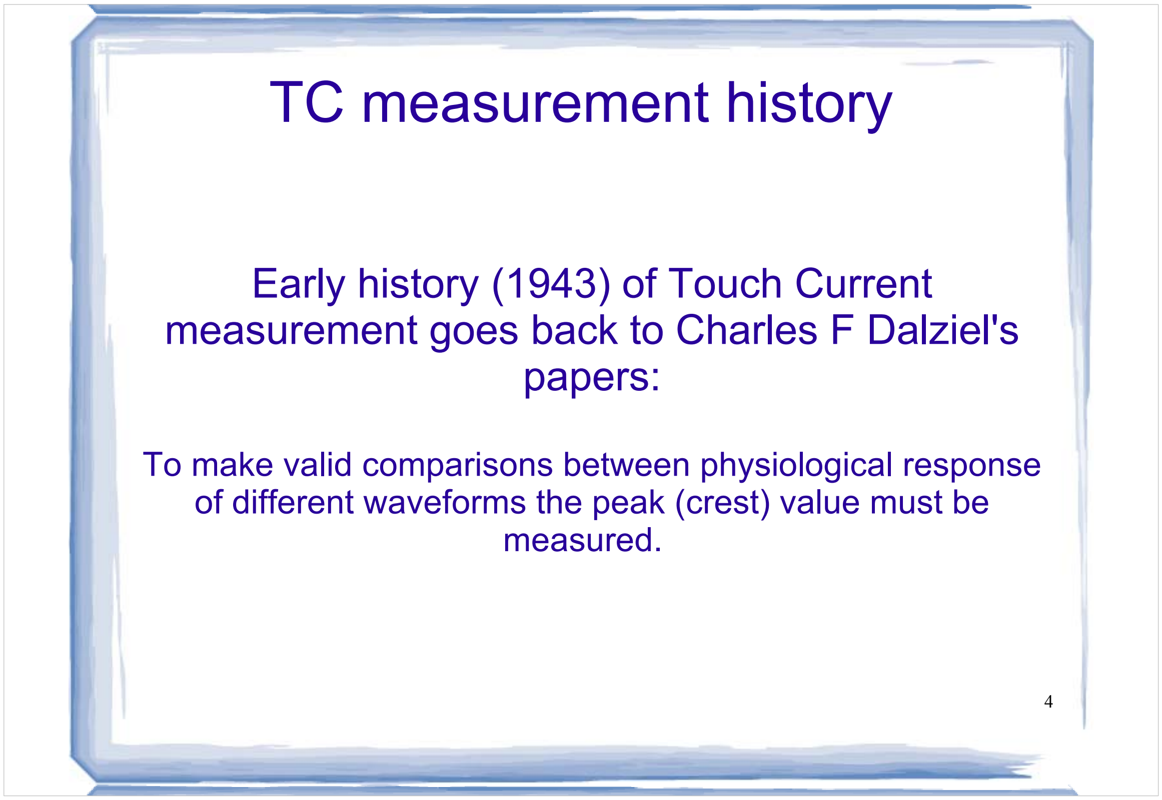
The human body responds to peak current not rms current.

From the time that the first Touch Current measurements were being introduced (in the 1930s) electricity was primarily used as a sinusoidal waveform which allowed easy delivery over a large area (grid).

The development of RMS based limits followed the technology even for electric shock protection.

Some researchers, such as Dalziel, recognized the limitations of these limits and measurements and published proper peak data while allowing RMS for practical measurements.
In other cases, such as vibration, it is recognized that peak measurements better represent the body response.

Present electric shock protection evaluation is lagging technology and needs to update to provide proper protection.



TC measurement history

Early history (1943) of Touch Current measurement goes back to Charles F Dalziel's papers:

To make valid comparisons between physiological response of different waveforms the peak (crest) value must be measured.

Dalziel, in his 1943 paper[1], determined that for various wave shapes the use of peak (crest) values allowed the comparison of let-go current effects in test subjects for the cases examined. He further claimed that because all of these waveforms gave the same physiological response at the same peak current that other waveforms would behave the same way and their measured peak currents would be the indicator of the body-current effect.

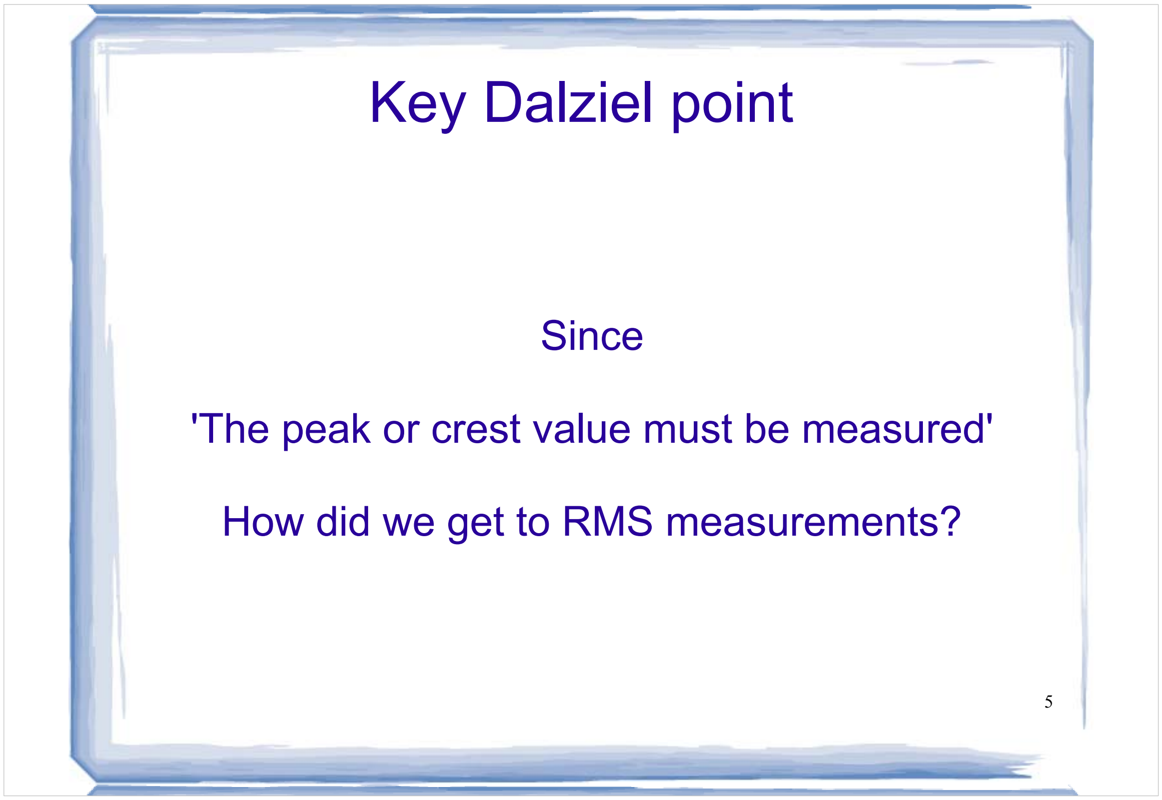
[1] Dalziel; Effects of waveform on let-go currents, AIEE Transactions, Vol 62, Dec 1943

In his 1954 paper[2] Dalziel showed that the Threshold of Perception is related to peak (crest) measurements, confirming his earlier results. This is now called the startle-reaction (s-r) level.

[2] Dalziel; The Threshold of Perception Currents, Electrical Engineering, July 1954

The work of Stevenson at UL ('70's or so) provided ANSI C101 with a statistically defensible data set to justify the 0.5 mArms Touch Current limit that has been commonly used.

The development of SMPS with EMC filtering drove the need to increase the limit and 3.5mArms was introduced in the '80's.



Key Dalziel point

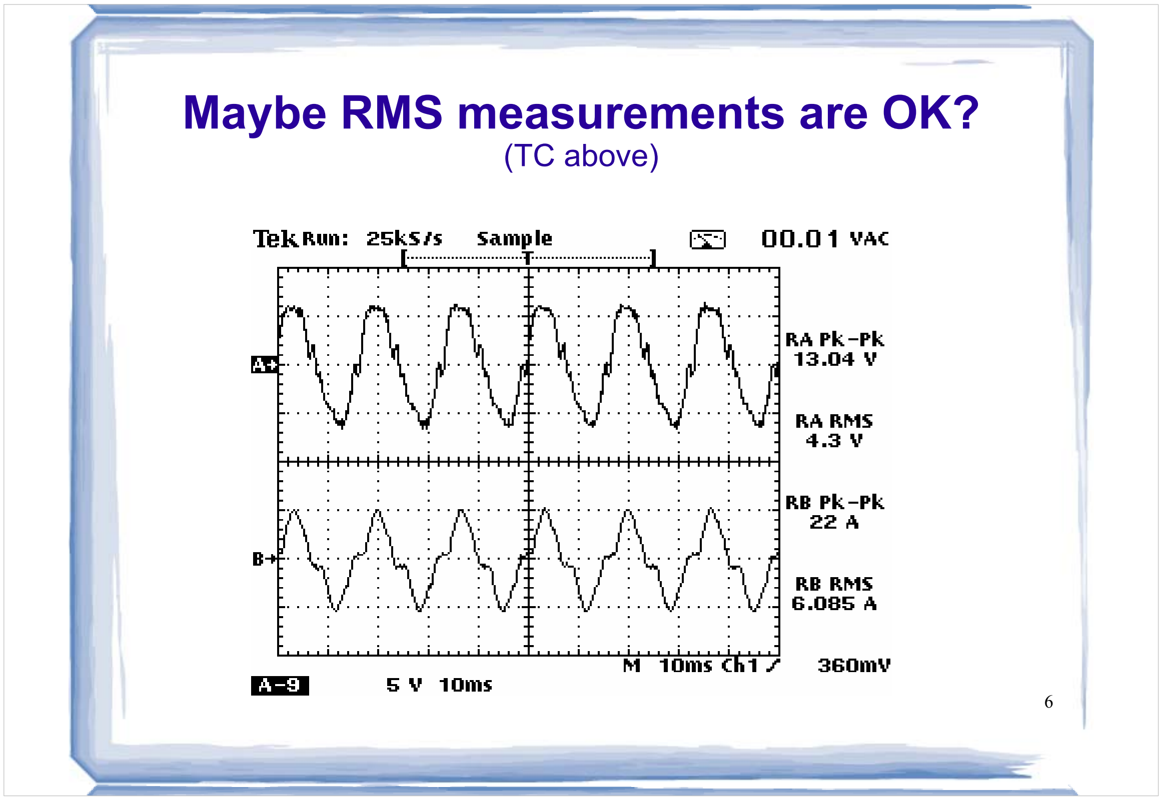
Since

'The peak or crest value must be measured'

How did we get to RMS measurements?

In spite of this experimental finding Touch Current testing has traditionally been done with RMS measurement equipment. This is primarily, in my opinion, due to the difficulty in easily making peak measurements in the early days of measurement development. This restriction is no longer true; peak measurements are easily made with modern equipment.

Remember that RMS measurements were developed to give an equivalent to the DC measurement of V x I = Power. Even though moving coil instruments provided an average measurement, the instruments were always calibrated in RMS (~ 10% higher).



Maybe RMS measurements are OK?

(TC above)

6

When IEC 60990 was developed TC's were starting to look a lot like this – and called almost sinusoidal waveforms[1].

These TC waveforms drove the digital meter manufacturers to develop 'true RMS' reading meters. This was possible because the digitized readings could be manipulated by software and be adjusted for the waveform changes.

Everyone thought that this would take care of the problem.

Remember that the scope shows pk-to-pk and the TCpeak value = Tcpk-pk/2 for these waveforms.

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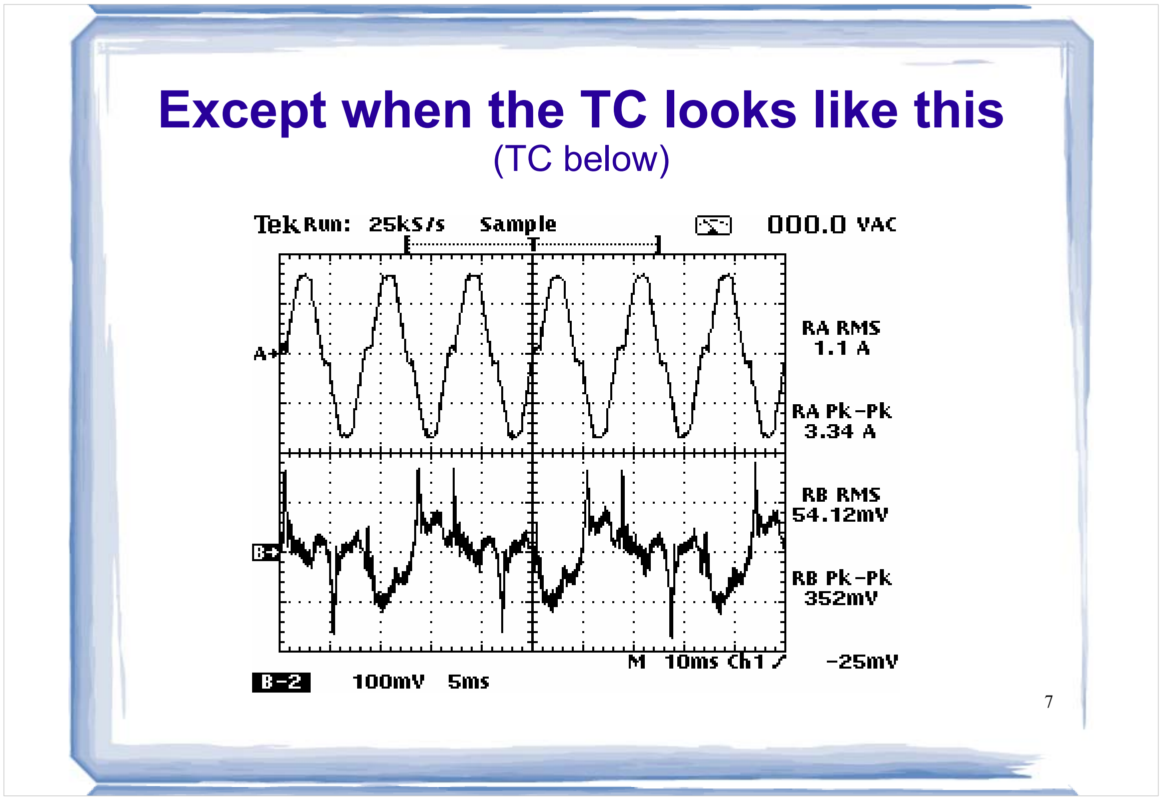
[1] Touch current comparison data; Perkins, 2006. A collection of more than 2 dozen touch current waveforms from a variety of equipment along with analysis; also posted on www.safetylink.com, search on perkins.



Except when the TC looks like this

(TC below)

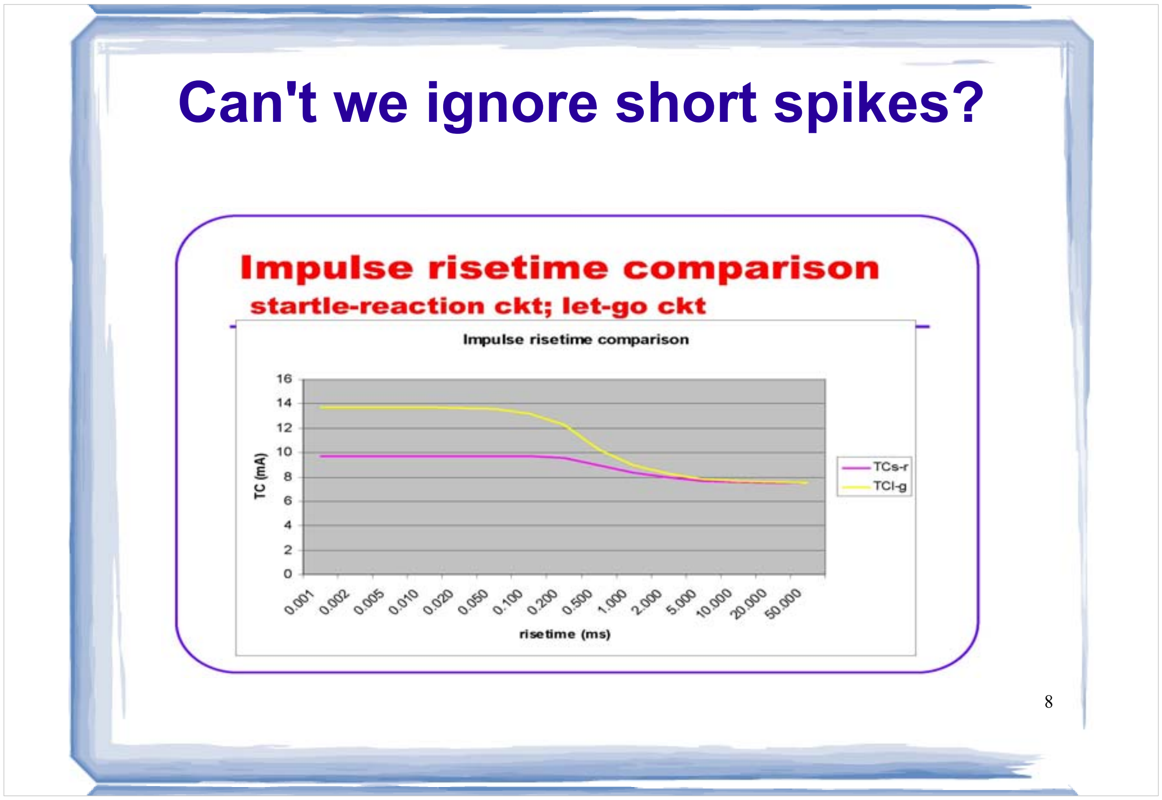
The inclusion of Power Factor Correction to equipment drove the Touch Current to a new level. The TC waveforms are not sinusoidal in any sense of the term.

This has driven further examination of the proper measurement technique for Touch Current in a series of papers given to the IEEE PSES over the past few years[1].

The need for peak measurement is apparent and needs to be established as the proper measurement for these waveforms.

Remember that the heart vulnerability is about 1/3 of the heartbeat – hundreds of ms.

[1] Keeping up with proper Touch Current measurements, PE Perkins, IEEE PSES, Chicago 2005. Touch Current measurement comparison, PE Perkins, IEEE PSES, Anaheim 2006. Electric Shock within the heart cycle, PE Perkins, IEEE PSES, Longmont 2007. Physical body parameter calculations based upon electrical measurement PE Perkins, Austin 2008.



Can't we ignore short spikes?

Impulse risetime comparison

startle-reaction ckt; let-go ckt

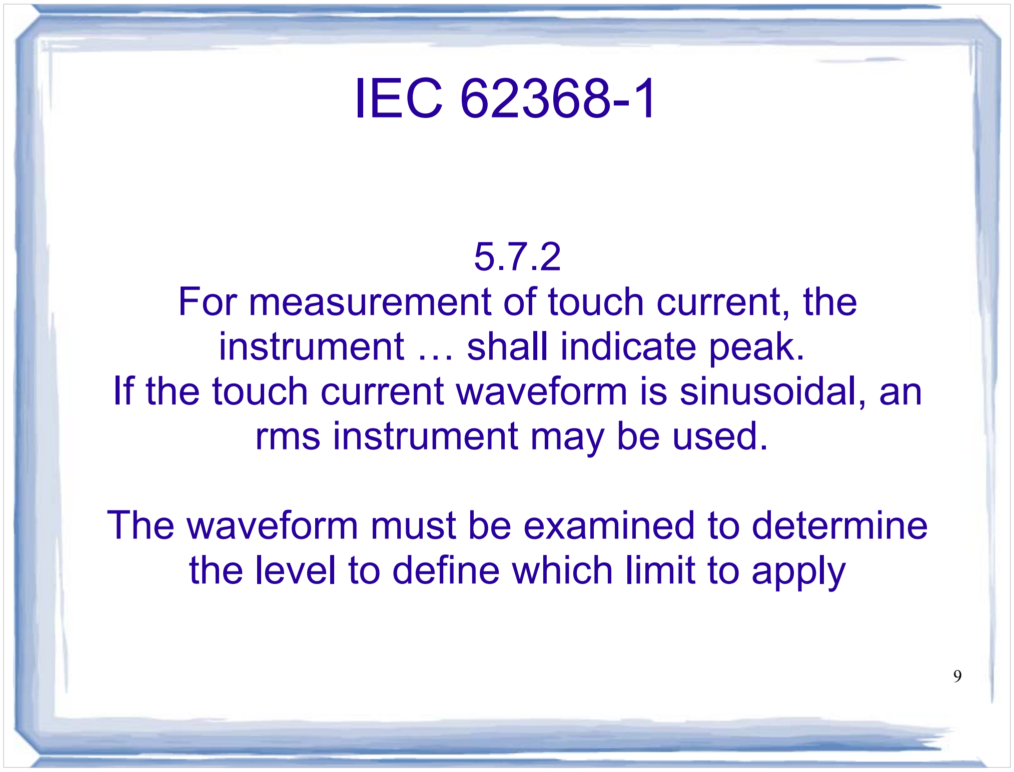
Green et al conducted Ventricular Fibrillation (VF) tests to 1ms and saw no physiological reason that the effect would not extend to shorter times[1].

The pulse parameter that drives it higher and, therefore, leads to higher Touch Current measurements is the risetime of the pulse. Green's 1ms lower value is right where the Touch Current is starting to increase due to risetime (RT).

Here we see that fast pulse RT's lead to measured peak Touch Current that is 40 to 100% higher than the slower pulse.

Peak measurements identify these differences and properly take them into account.

[1] Green, HL, Ross, J and Kurn, P; Danger Levels of short (1ms to 15ms) Electrical shocks from 50Hz Supply. Proceedings of the 1st Symposium on Electrical Shock Safety Criteria (1983), Pergamom Press, 1985.



IEC 62368-1

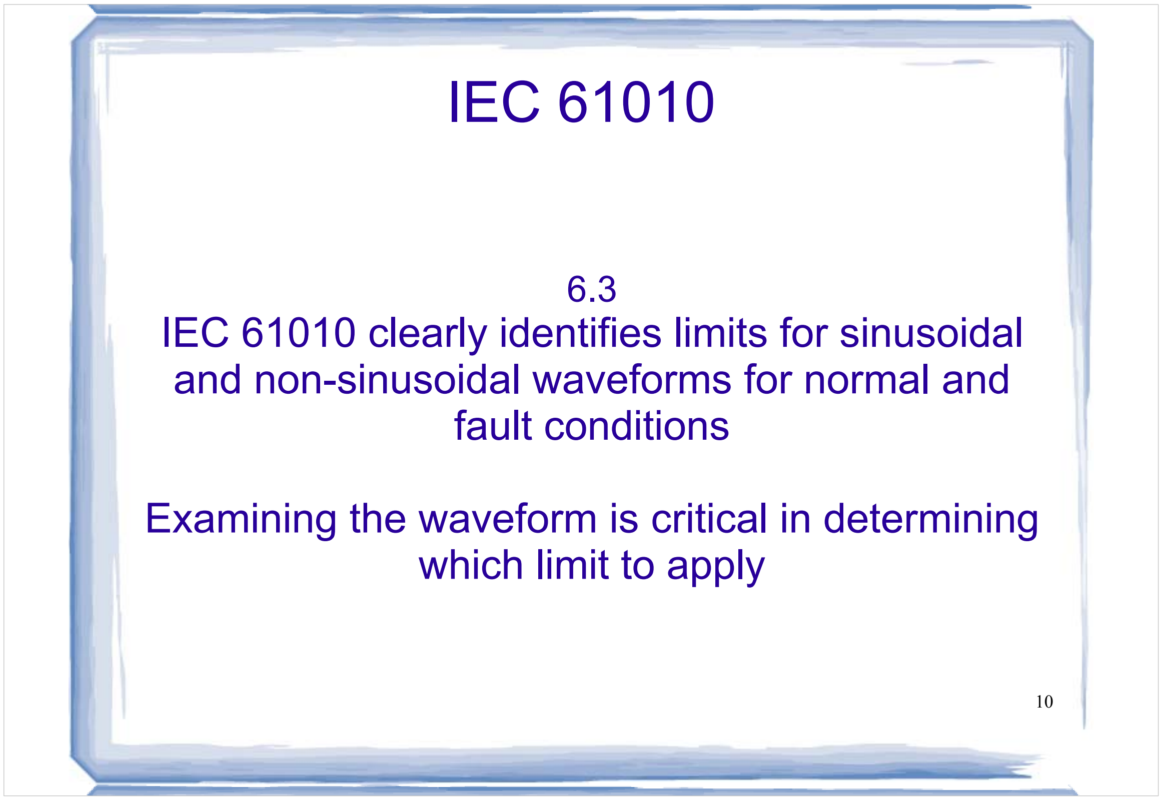
5.7.2
For measurement of touch current, the instrument … shall indicate peak.
If the touch current waveform is sinusoidal, an rms instrument may be used.

The waveform must be examined to determine the level to define which limit to apply

IEC 62368-1 defines safe levels for operators and then others by defining the voltage and current levels that are safe in each case.

This new IEC HBStd measures:
1) the voltage of the exposed part, then
2) the current from the part.

This standard properly differentiates between measurement of low Touch Current, <2mA, (using the s/r circuit) and high Touch Current (using the l/g circuit). Peak measurements are specified for non-sinusoidal waveforms



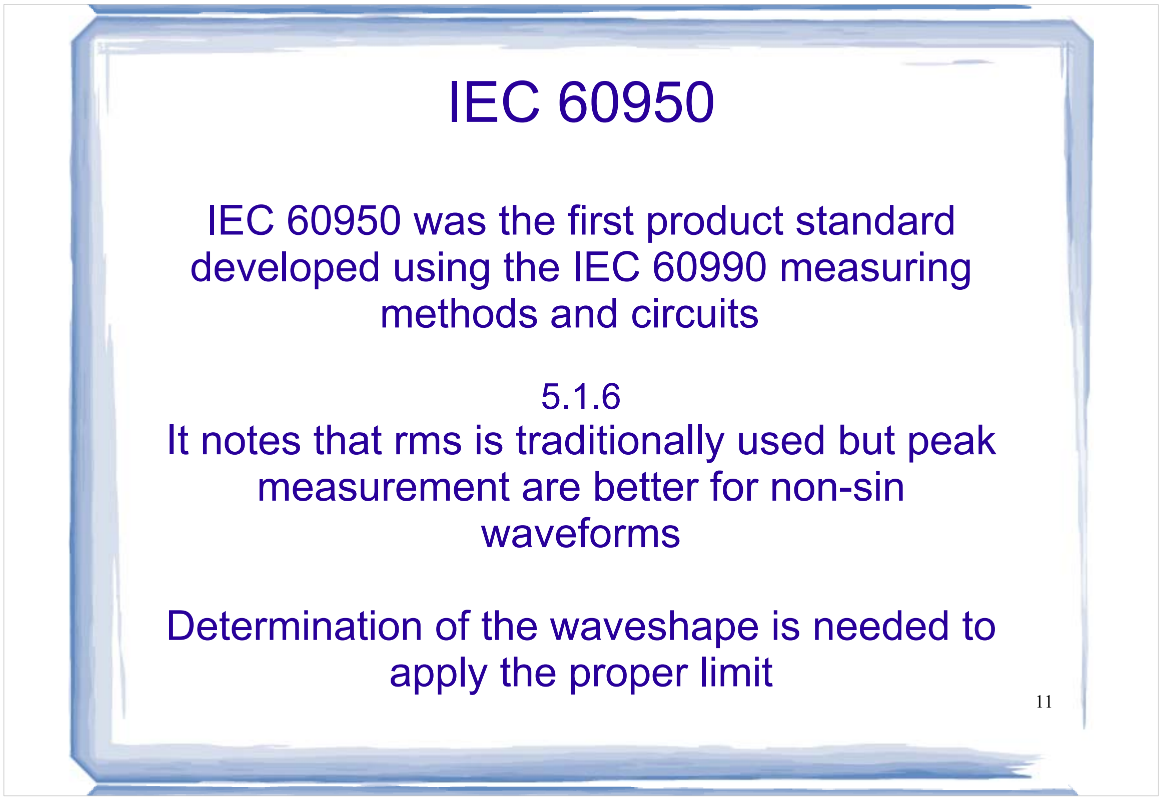
IEC 61010

6.3
IEC 61010 clearly identifies limits for sinusoidal and non-sinusoidal waveforms for normal and fault conditions

Examining the waveform is critical in determining which limit to apply

For IEC 61010 (Measurement, control, laboratory and process control equipment), defines an rms limit for sinusoidal waveforms and peak limits for non-sin waveforms.

Because of this clear specification, the waveform needs to be seen on the oscilloscope to determine which limit should be applied.



IEC 60950

IEC 60950 was the first product standard developed using the IEC 60990 measuring methods and circuits

5.1.6
It notes that rms is traditionally used but peak measurement are better for non-sin waveforms

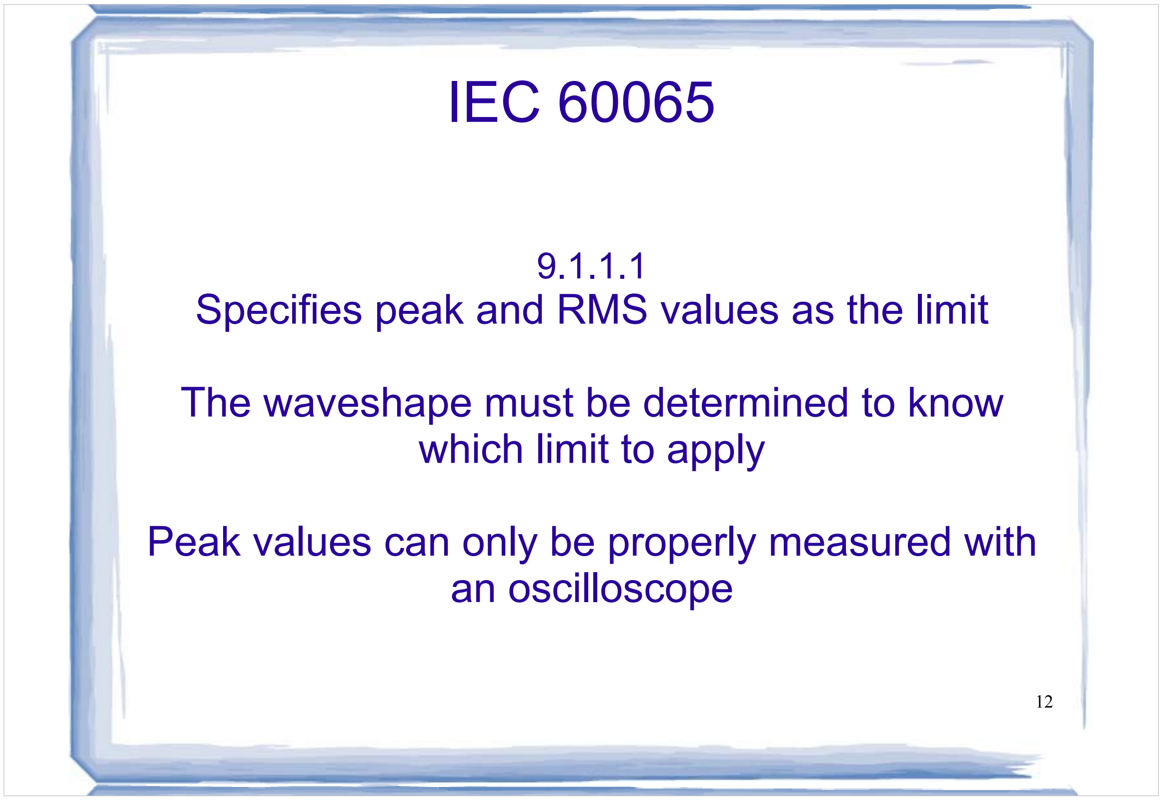
Determination of the waveshape is needed to apply the proper limit

The inclusion of the IEC 60990 circuits and methods here was one of the principle driving forces to develop 'true RMS' meters as the waveforms were considered 'almost sinusoidal' at the time. A popular suggested demarcation has been that for a peak/rms ratio of 1.6 or less the waveforms is almost sinusoidal.

80% of the waveforms in my sample discussed here are >1.6 peak/RMS ratio.

Unfortunately this has led to an ongoing error in not continuing to check the waveforms to determine that a better evaluation was needed and the measurement should have been switched to peak.

This outdated measurement practice needs to change.



IEC 60065

9.1.1.1
Specifies peak and RMS values as the limit

The waveshape must be determined to know which limit to apply

Peak values can only be properly measured with an oscilloscope

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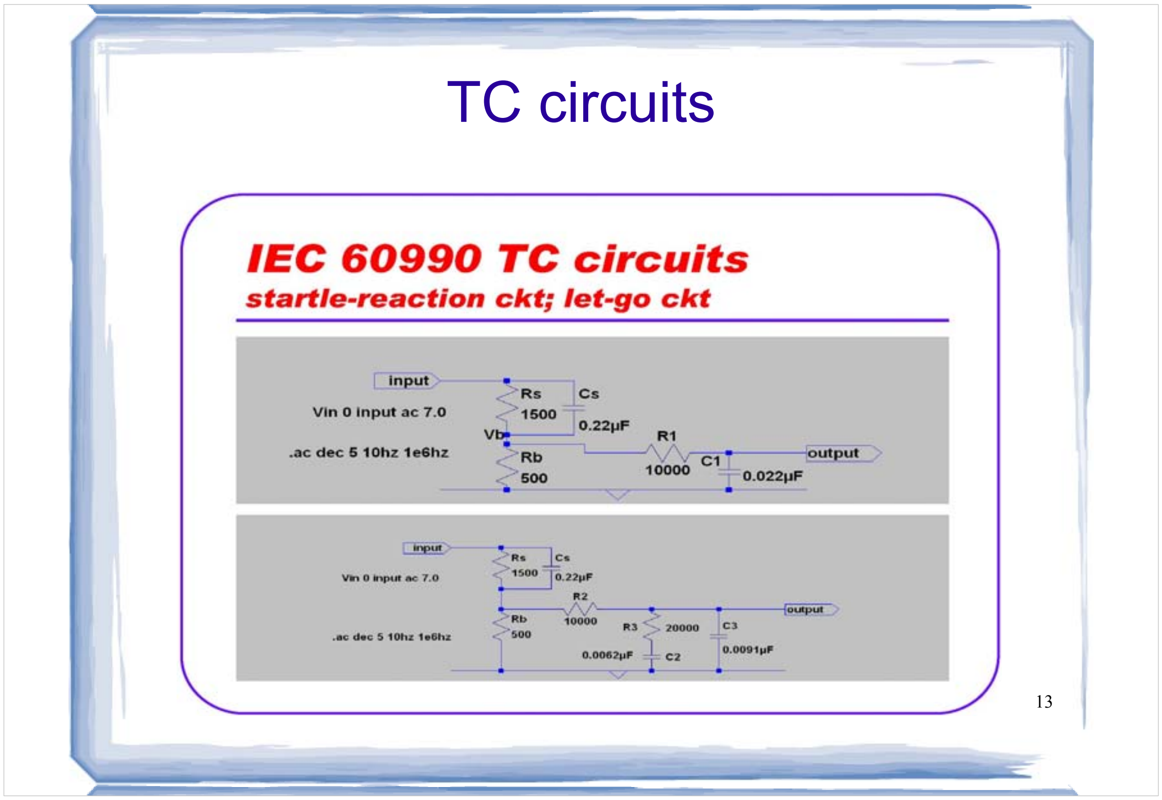
IEC 60065 measures the voltage on any exposed part and, if it above the threshold, measures the TC. The limits are expressed in voltage values for both low frequency and high frequency waveforms.

This standard invokes the use of the IEC 60990 circuits and methodology and this should be fully implemented by moving to peak measurements. The use of rms measurements for Class I products is inadequate to assure the needed protection.

This measurement method described is more difficult than it needs[1] to be as the IEC 60990 circuit properly takes into account the frequency factor.

For **any** product standard or Touch Current measurement: The networks specified for the measurement of perception / reaction (*startle-reaction)* and let-go currents are frequency responsive and are so weighted that single limit power-frequency values can be specified and referenced.

[1] See attached analysis of the IEC 60065 TC measurement description



TC circuits

IEC 60990 TC circuits

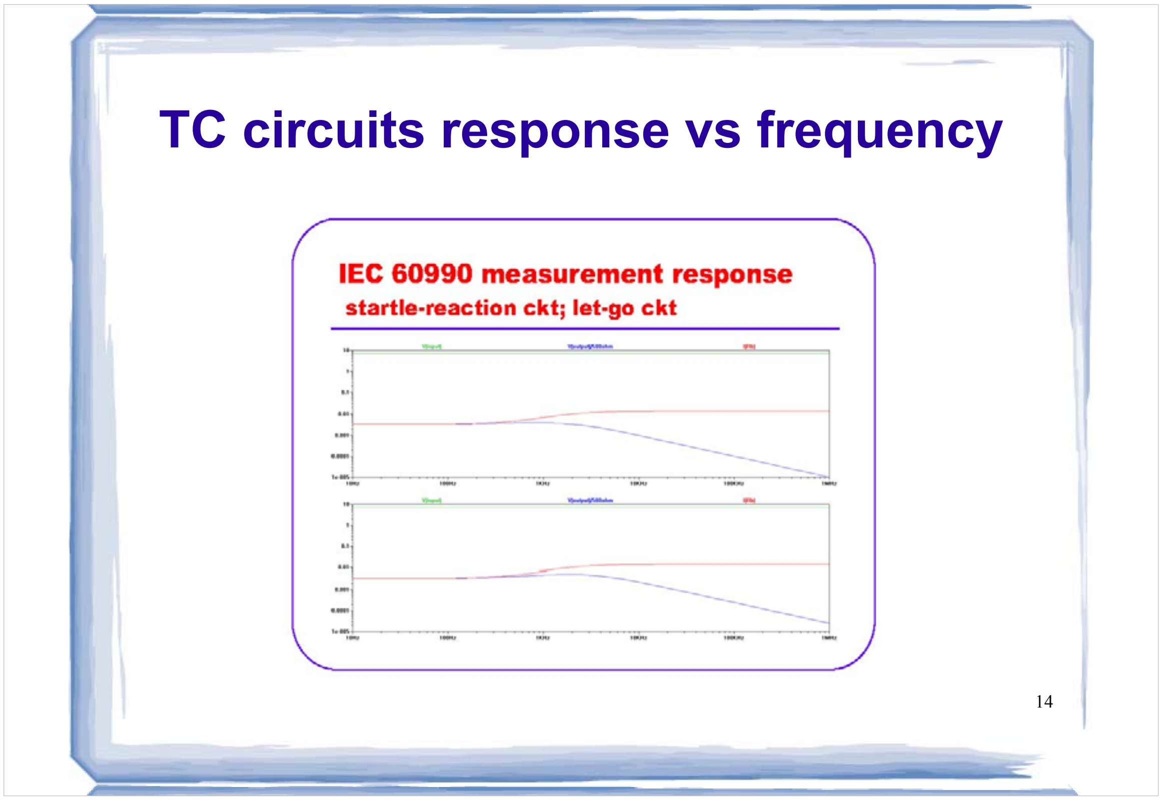
startle-reaction ckt; let-go ckt

The IEC 60990 Touch Current circuits are shown here.

Each circuit is made up of two sections. The IEC 60479 body model get the input from the circuit under test. This body model has been used within the IEC as the basis for TC measurements for more than 50 years.

The upper circuit is the startle-reaction circuit which includes the output filter circuit that provides the high frequency compensation. This compensation circuit modifies the traditional measurement taken across the 500 ohm resistor.

The lower circuit is the let-go circuit which has its own output filter circuit for the proper high frequency compensation for that effect. The compensation circuit is applied as described above.



TC circuits response vs frequency

IEC 60990 measurement response

startle-reaction ckt; let-go ckt

The IEC 60990 circuits performance[1] as a function of frequency are shown here.

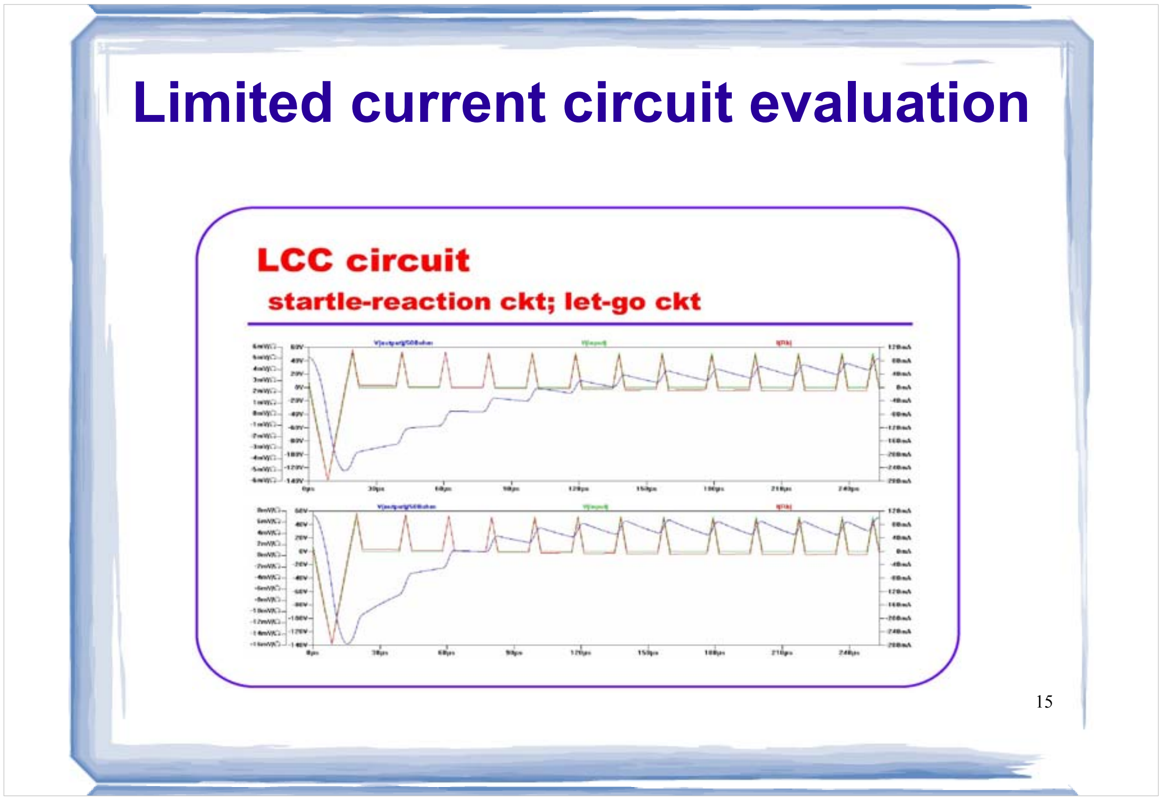
The input voltage is fixed across the frequency spectrum up to 1 MHz.

The input current rises, in this example, from the initial value of 3.5 mA (such as is allowed in IEC standards today) to 14 mA at high frequency.

The output is compensated according to the known frequency curve for the human body. This output falls off inversely to the frequency response curve to provide a constant meter reading (at the low frequency specification) which makes for easy determination of compliance – always 3.5mA for this case.

The s-r circuit is for cases where the limit is 2 mA or less and the l-g circuit is for cases above that.

[1] Touch Current measurement comparison: Looking at IEC 60990 measurement circuit performance; Perkins, IEEE PSES 2006



Limited current circuit evaluation

LCC circuit

startle-reaction ckt; let-go ckt

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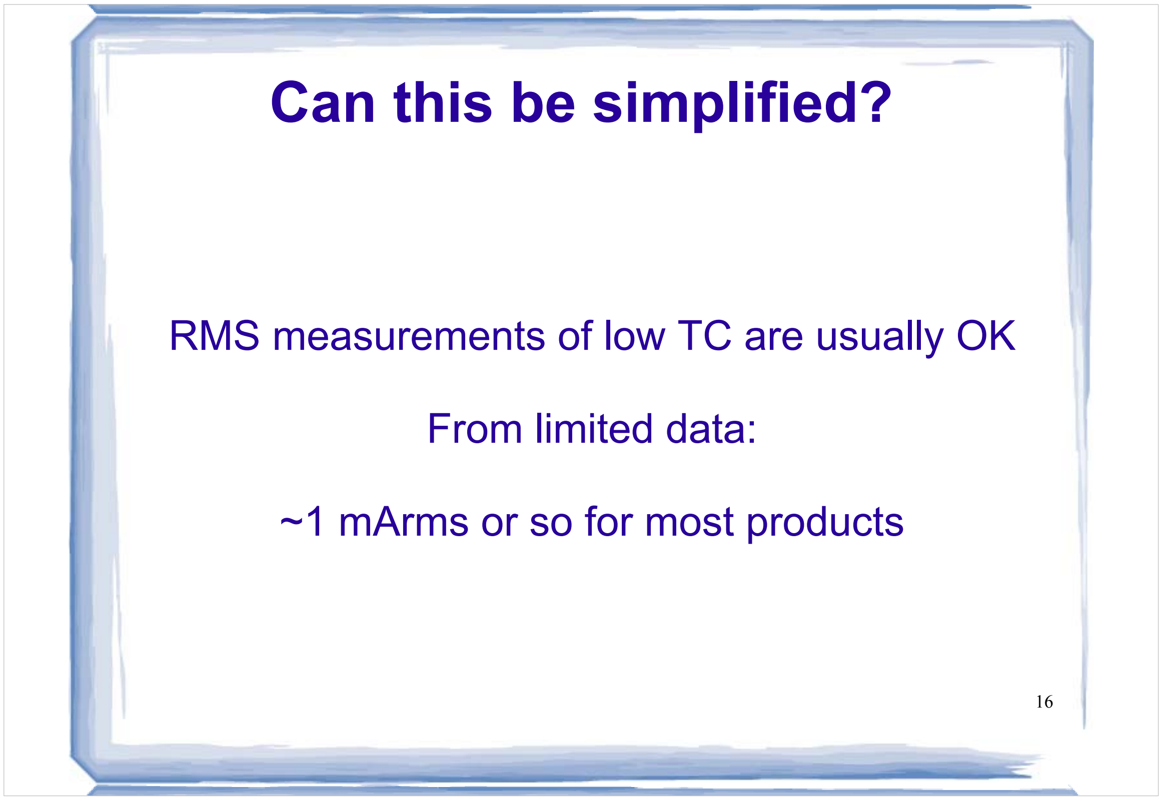
Standards, such as IEC 60950, allow access to circuits which will not be an electrical shock hazard.

The results shown here shows the detailed waveform for the Limited Current Circuit (LCC) current in this case, a backlight for a display.

This evaluation points out a real problem that must be looked at in waveform detail. Using the s-r circuit the rms tc value is 3.09 mA which is acceptable while the peak tc value is 5.07 mA which is above the limit.

Evaluating this waveform with the l-g circuit (per the HB-Std IEC 62368-1) the rms tc value is 5.9mA and the peak value is 11.5mA.

The peak value is the correct value here and the circuit is not a LCC.



Can this be simplified?

RMS measurements of low TC are usually OK

From limited data:

~1 mArms or so for most products

This seems more complicated in the test lab. Can a simple rule of thumb be developed?

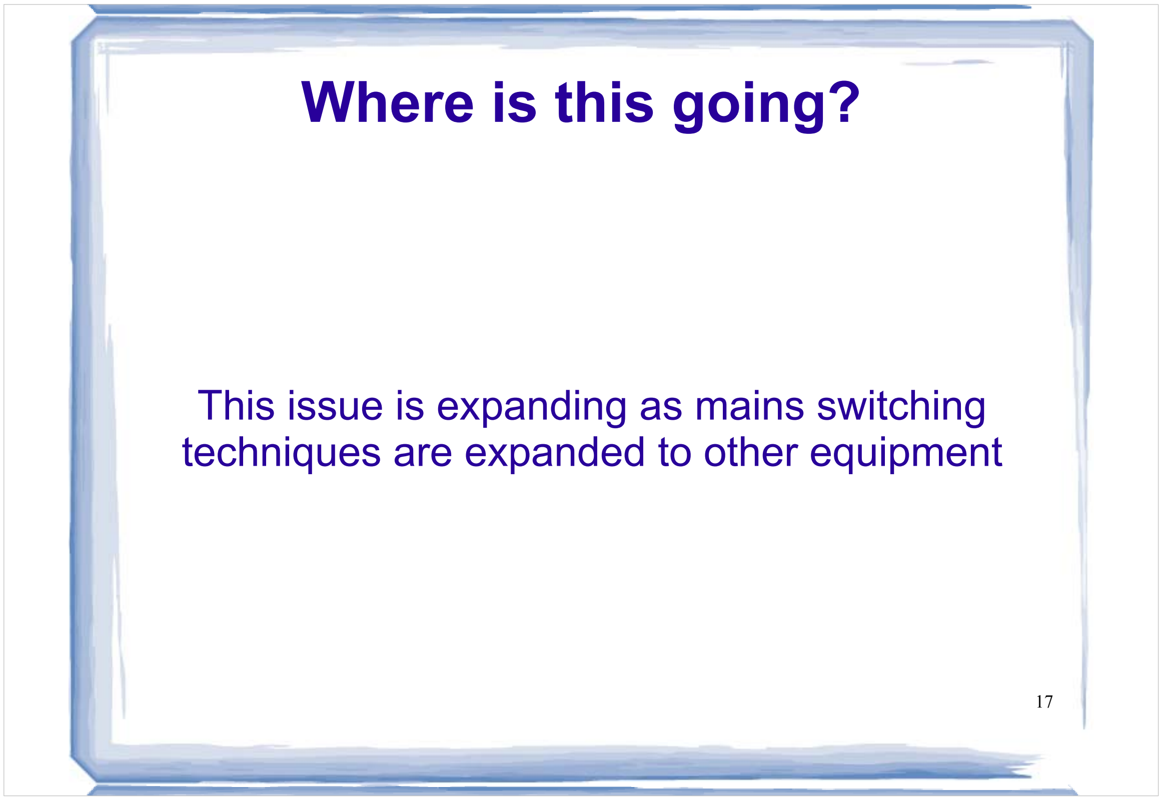
Based upon the limited data presented the calculation of a simple measurement using the traditional RMS setup seems to be adequate when the Touch Current is low. For the IEC 60950 IT products we can calculate: 5mApk / 3.25 max pk/rms ratio = 1.54 mArms or less.

From this small sample: for ~28% of the equipment tested a peak measurement should be made.

This is a smaller fraction of the examples presented than the 80% which had a peak/RMS ratio >1.6.

This needs to be checked with a larger data set; perhaps some cooperative effort between test houses.

This needs to be reconfirmed as the technology changes (e.g. adding energy efficiency switchers to SMPS) or as other types of equipment start using these techniques.

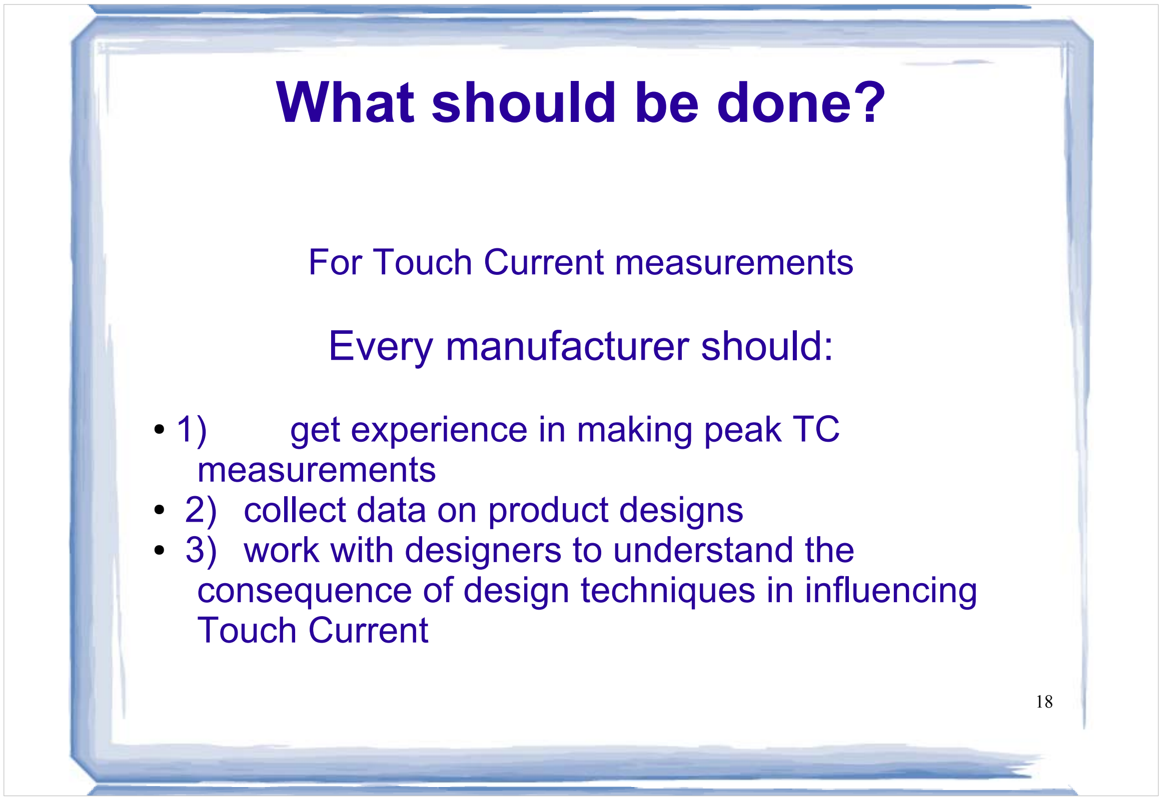


Where is this going?

This issue is expanding as mains switching techniques are expanded to other equipment

Complexity is being added to the present tc waveforms as energy efficiency requirements are being applied which necessitates the addition of another switching circuit to the product.

Mains switching techniques are being expanded to other classes of equipment to gain efficiency by the use of variable speed drives (or VFD's) on household appliances or higher efficiency lighting – LED's or CFL's which use switch mode power supplies (S-MPS) which have been shown to make touch current non-sinusoidal.



What should be done?

For Touch Current measurements

Every manufacturer should:

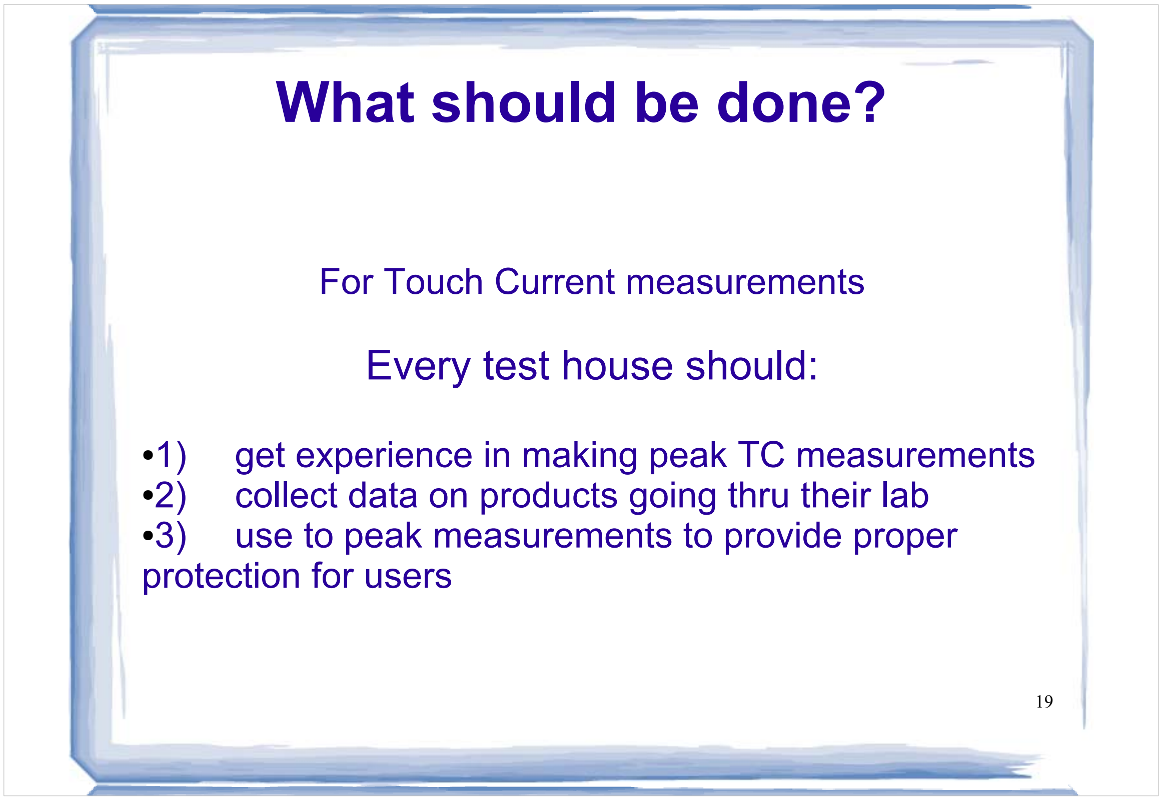
- 1) get experience in making peak TC measurements
- 2) collect data on product designs
- 3) work with designers to understand the consequence of design techniques in influencing Touch Current

The purpose of this presentation and paper is to help laboratories and manufacturers see the importance of peak Touch Current measurements specified in product standards.

These standards specify peak as well as RMS limits. It is wrong to make RMS measurements of non-sinusoidal waveforms.

Several references have been made to the influence of fast risetime pulses as they affect the product Touch Current.

Designers need to understand the influence of their design choices and not leave Touch Current as a residual effect to be discovered at the end of the design.



What should be done?

For Touch Current measurements

Every test house should:

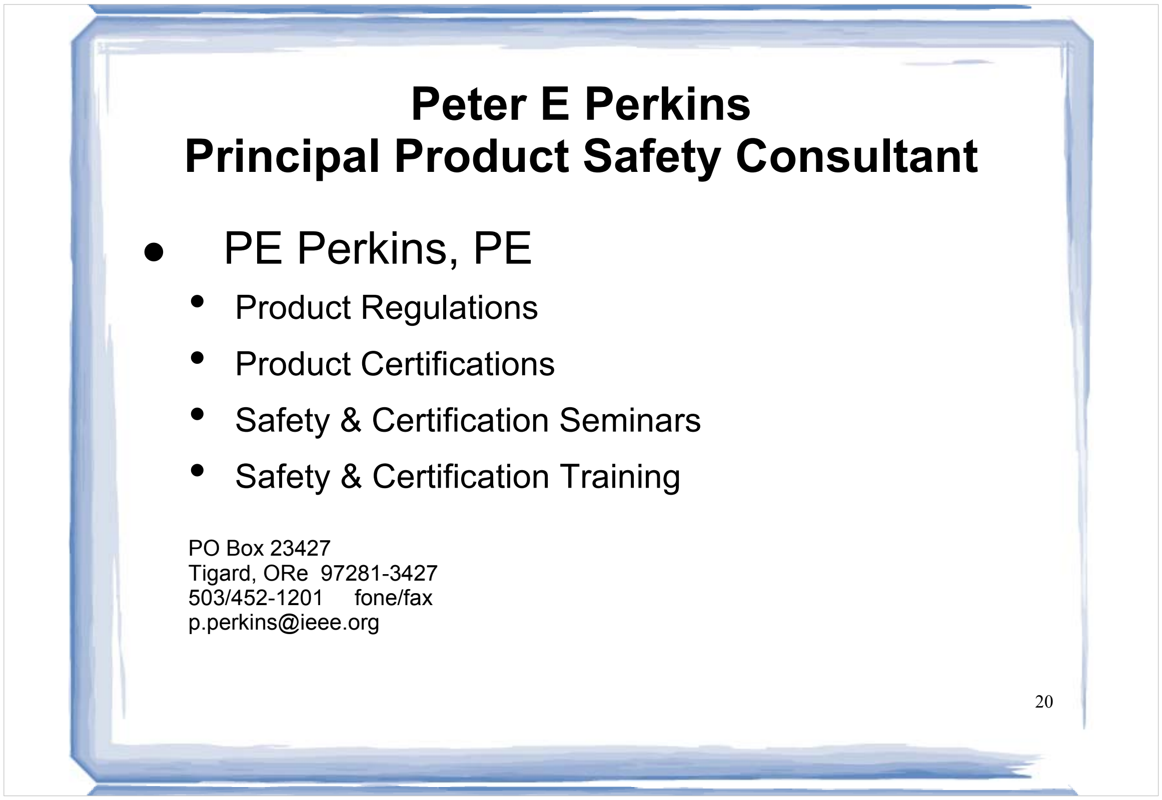
•1) get experience in making peak TC measurements
•2) collect data on products going thru their lab
•3) use to peak measurements to provide proper protection for users

Test houses need to make the proper interpretation of the measurements so that the desired protection is provided for users.

Investigation of technology changes is needed as progress is made.

The measurements are straightforward with proper equipment as part of the Touch Current metering setup.

It is time to move the measurement methods forward to meet the challenge of the application of technology in expanding use today.



Peter E Perkins
Principal Product Safety Consultant

- PE Perkins, PE
  - Product Regulations
  - Product Certifications
  - Safety & Certification Seminars
  - Safety & Certification Training

PO Box 23427
Tigard, ORe 97281-3427
503/452-1201 fone/fax
p.perkins@ieee.org

Mr. Peter E. Perkins, PE has more than 45 years of technical and practical experience. He was, for 17 years, manager in charge of Corporate Product Safety and Regulatory Affairs for an American MNC, a Fortune 500 electronics company. He has also worked in several engineering and managerial capacities within the Display Components Engineering Division of that company.

Mr. Perkins holds a MSEE degree and is a registered Professional Engineer, Electrical and a registered Professional Engineer, Quality in the USA. He is also a Certified Product Safety Manager.

Mr. Perkins is a holder of a display patent and the author of numerous papers. He has given numerous talks and training programs for companies all over the world plus the Univ of Wisconsin Extension course ‘Getting your CE marking’.

Mr. Perkins has an ongoing involvement in the development of technical safety standards. He currently sits on the following committees:

IEC TC64/wg4 – developer of IEC 60479, Effects of current passing thru the human body & IEC 61201, Guide for the use of conventional touch voltage limits.

IEC/TC108(74) - developer of IEC 60950, Safety Standard for IT Equipment, Safety of Information Technology Equipment and the new replacement IEC 62368-1 AV, IT & Communications Equipment Safety Requirements.

IEC/TC108/WG5 - Convenor of this working group that has developed IEC 60990, Methods of Measurement of Touch Current and Protective Conductor Current, a Pilot Safety committee within the IEC.

US/TAG-TC109 - the US Technical Advisory Group developing American input to IEC 60664, Insulation coordination for low voltage equipment

US/TAG-TC64 - the US Technical Advisory Group developing American input to IEC 60479 and IEC 61201.

US/TAG-TC66 - the US Technical Advisory Group developing American input to IEC 61010, Safety requirements for electrical equipment for measurement, control and laboratory use.

US/TAG-TC108 - the US Technical Advisory Group developing American input to IEC 60950, Safety of Information Technology Equipment and the new replacement IEC 62368-1 AV, IT & Communications Equipment Safety Requirements.

Mr. Perkins is currently working as an independent product safety and regulatory consultant for business in addition to offering seminars and training in the product safety and regulatory area.

IEC 60065 TC measurement analysis

Peter E Perkins, PE

This draft is a study paper to more clearly define the Touch Current measurement conditions as defined in IEC 60065. This is being shared with several experienced folks in order to get clarification and feedback on the application of these requirements. The finished paper will, hopefully, clearly define what is being measured by this evaluation.

This analysis looks at each electric shock determination made under IEC 60065 to show how the requirement treats applied waveforms under the conditions specified.

All of the commentary from this analysis is in this typeface; the original clauses from the standard are carried over in their original typefaces shown below.

From: 60065 © IEC:2001

9 Electric shock hazard under normal operating conditions

9.1 Testing on the outside

9.1.1 General

ACCESSIBLE parts shall not be HAZARDOUS LIVE.

NOTE 1 For interconnection with apparatus under the scope of other standards, circuits should comply with 9.1.1 and, depending upon the construction, with 8.5 or 8.6.

In addition, when not connected to another apparatus, inaccessible contacts of TERMINALS shall not be HAZARDOUS LIVE, with the following exceptions:

– contacts of signal output TERMINALS, if they have to be HAZARDOUS LIVE for functional reasons, provided the contacts are separated from the supply source as required according to clause 8 for ACCESSIBLE conductive parts.

NOTE 2 Inaccessible input TERMINALS, for example those of loudspeakers, are permitted to be HAZARDOUS LIVE when connected to such output TERMINALS.

NOTE 3 For the marking of such output TERMINALS, see 5.2 b).

— TERMINALS complying with 15.1.1 provided for connecting the apparatus to the MAINS, socket-outlets and contacts of connecting blocks for providing power to other apparatus.

The requirements to determine whether a HAZARDOUS LIVE part is ACCESSIBLE apply only to HAZARDOUS LIVE voltages not exceeding 1 000 V a.c. or 1 500 V d.c. For higher voltages, there shall be a CLEARANCE between the part at HAZARDOUS LIVE voltage and the test finger or the test pin as specified in 13.3.1 for BASIC INSULATION (see figure 3).

Compliance is checked by inspection and by measurements according to 9.1.1.1 and tests according to 9.1.1.2.

9.1.1.1 Determination of HAZARDOUS LIVE parts

In order to verify that a part or a contact of a TERMINAL is HAZARDOUS LIVE, the following measurements are carried out between any two parts or contacts, then between any part or contact and either pole of the supply source used during the test. Discharges shall be measured to the TERMINAL provided for connecting the apparatus to the supply source, immediately after the interruption of the supply.

NOTE 1 For discharges between the poles of the MAINS plug, see 9.1.6.

The part or contact of a TERMINAL is HAZARDOUS LIVE if

a) the open-circuit voltage exceeds

- *35 V (peak) a.c. or 60 V d.c.,*
- *for audio signals of PROFESSIONAL APPARATUS, 120 V r.m.s.,*
- *for audio signals of other than PROFESSIONAL APPARATUS, 71 V r.m.s.;*

The voltage setting on the Simpson 228 (0-300V AC or DC) will adequately measure these open circuit voltages.

If the voltage limits in a) are exceeded, provisions b) to d) apply.

b) the TOUCH CURRENT, expressed as the corresponding voltages U_1 and U_2, and measured in accordance with IEC 60990, with the measuring network described in annex D of this standard, exceeds the following values:

- *for a.c.: U_1 = 35 V (peak) and U_2 = 0,35 V (peak);*
- *for d.c.: U_1 = 1,0 V.*

NOTE 2 The limit values of U_2 = 0,35 V (peak) for a.c. and U_i = 1,0 V for d.c. correspond to the values 0,7 mA (peak) a.c. and 2,0 mA d.c.

I'd like some feedback as to how this voltage measurement of U_1 or U_2 is normally made. I use a Simpson 228 meter for TC measurements because it has the 990 measurement circuits internally and provides current values. It does not have any outputs for voltage measurements from the 990 TC circuits (although I know of one that has been modified with output jacks to make these measurements – is that common?)

U_1 corresponds to the output from the unweighted measuring network (Fig 3) of IEC 60990. It is usually specified for limiting electrical burns effects and the measurements are rms which better correspond to the heating then burning effects on the body.

IEC 60479-1 tells us that 'with currents of several amperes lasting several seconds, deep-seated burns or other serious injuries which can be internal, and even cause death, are likely to occur. (cl 5.6)'. 'Zone AC-4: additional effects including 'heavy burns may occur'. (Table 11). From Fig 14, 20-50 mA/mm^2 the skin will become brownish in color and blisters will develop, above 50 mA/mm^2 carbonization of the skin can occur.

DC currents above 100 mA are painful at the contact area and will cause burns up to 300 mA. (cl 6.4). 70 mArms is a common limit for burn current from apparatus; it is normally expected to be more of a problem above 10kHz or so.

The limit value U_1 = 35 V (peak) for a.c. corresponds to the value 70 mA (peak) a.c. for frequencies greater than 100 kHz.

U_1 ANALYSIS:

For an output limit of 35Vpeak an rms voltage of 24.75V would be the corresponding limit value to use for analysis in the frequency domain. It is used in this analysis below.

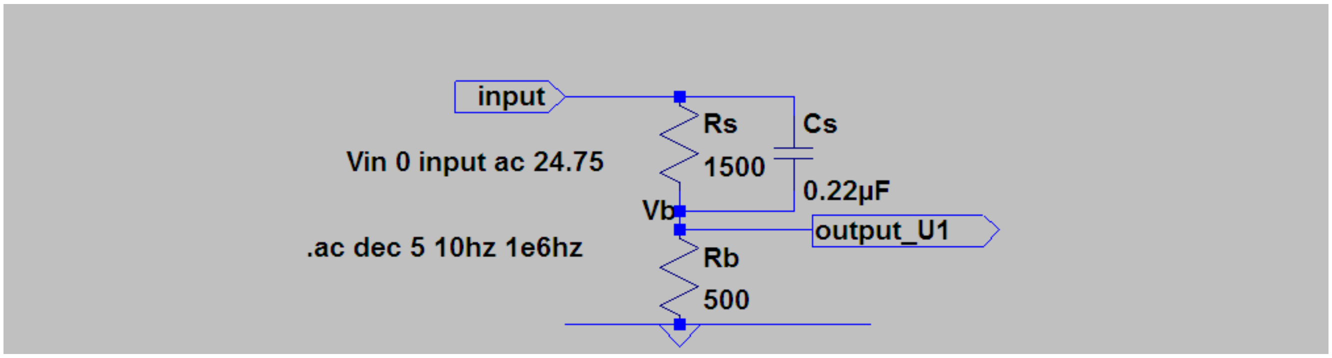


Figure 1: burn circuit for sine analysis

The description of the performance of this circuit as a function of frequency is shown below.

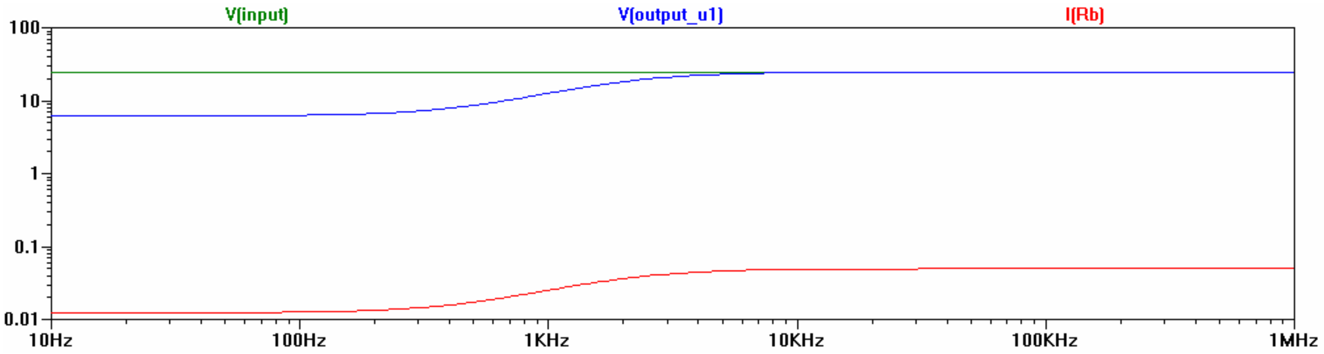


Figure 2: burn circuit analysis vs frequency

For a constant (35V(peak) =) 24.75Vacrms input the circuit shows 12.5mArms at 6.3Voutput_u1 at line frequency. This current increases to 49.5mArms (70mApeak) above 10kHz as the Voutput_u1 increases to 24.75V, changing as shown in the plot given here. The peak values are sqrt2*the rms values given. This change in current is due to the bypass capacitor which represents the capacitance of the skin.

If the input waveform is not sinusoidal then the evaluation must be done with an oscilloscope as the peak/rms ratio of the current is no longer sqrt2 = 1.414. As an example, for a 1ms(1kHz) pulsed waveform:

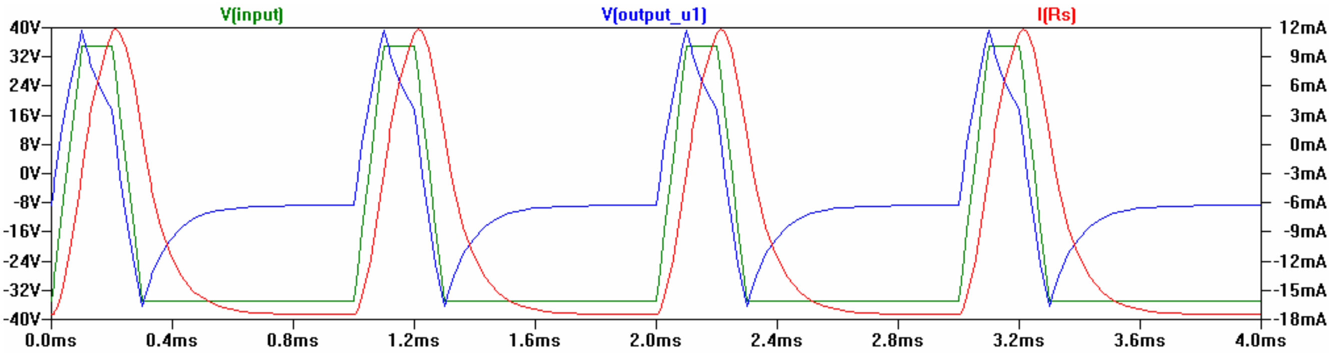


Figure 3: burn circuit pulse analysis - line frequency

Here the Voutput_u1 peak = (+39.3+|-36.7|)/2 = 38.0Vpeak, which is more than the 35Vpeak allowed. The current, however is only 14.2mArms, 15mApeak compared to the 70mArms which is allowed.

For a higher frequency pulse 0.1ms rep rate (10kHz) we see the following:

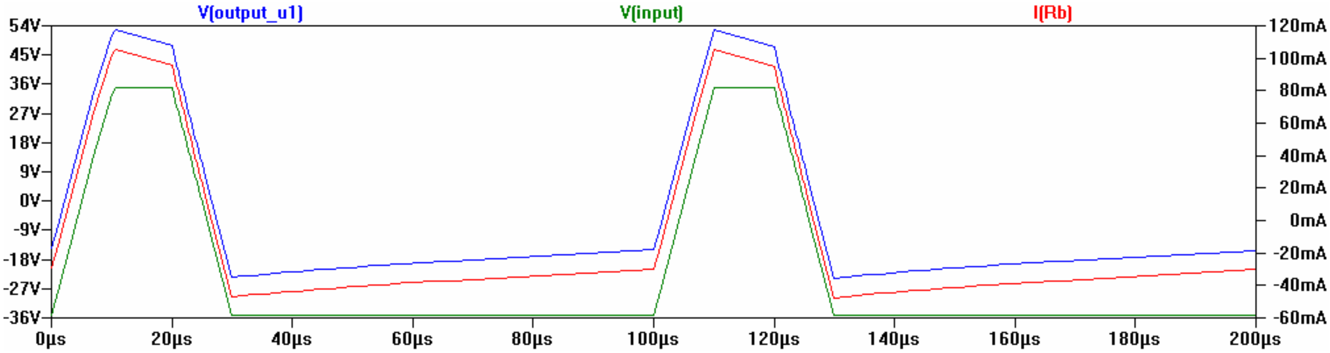


Figure 4: burn circuit analysis of 10kHz pulse waveform

In this case the Voutput_u1 peak = (+52.6+|-23.5|)/2 = 38.05Vpeak, higher than the allowed 35Vpeak. The current is now 50.5mArms or 76.2mApeak, above the 70mApeak allowed.

A more complicated waveform would have to be carefully analyzed (or measured) to determine if it complied.

U$_2$ ANALYSIS:

The voltage U$_2$ is the output voltage from the IEC 60990 Fig 4; measuring circuit, touch current weighted for perception or reaction. The effect of this is now being called startle reaction in IEC 60479 to more accurately characterize it.

For an open circuit voltage of 0.35V(peak) described as the 0.7U$_2$(peak)mA limit, applied to the network the following figure applies. An rms input voltage of 0.248V is applied to the measurement circuit to accurately represent this case in this analysis.

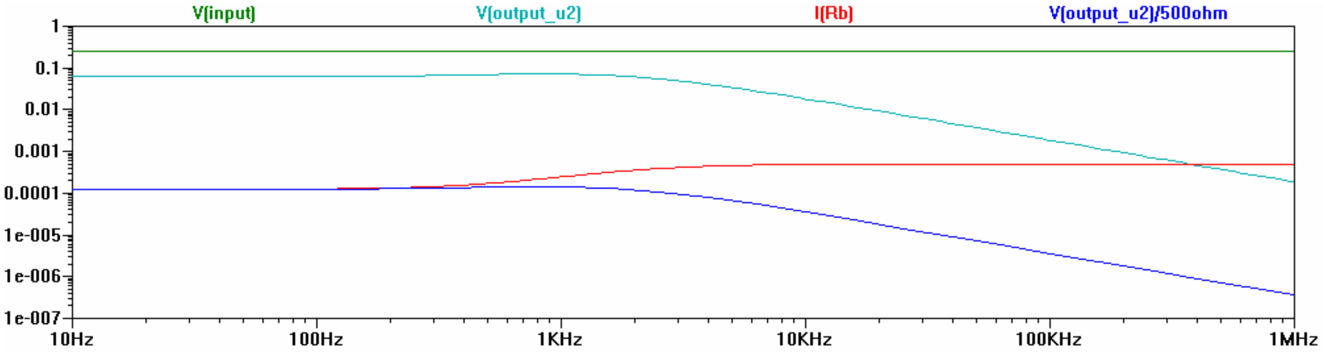


Figure 5: startle reaction circuit response vs frequency

The circuit response is summarized in the following table.

Frequency/response	Voutput_u2	I(Rb)	Actual TC = V(output_u2)/500ohm
Line frequency	0.062Vrms	0.125mArms	0.125mArms
10kHz	0.018Vrms	0.487mArms	0.035mArms
100kHz	0.002Vrms	0.496mArms	0.003mArms

Table 1: U2 performance

The I(Rb) at 100kHz of 0.496mArms corresponds to the specified limit of 0.7mA(peak) but the actual TC measured would only be 0.125mArms on a meter such as the Simpson 228.

What measurement is really wanted here? It would be of interest to see some waveforms of these measurements. Are they always sinusoidal? Audio outputs would usually be a complex mixture of various frequency sinusoids, but the resulting waveform itself may not be purely sinusoidal. Digital circuits would certainly not be sinusoidal. What is the influence of SMPS generated noise on these signals? Is it of significance?

and moreover

c) the charge exceeds 45 EC *for stored charges at voltages between 60 V d.c. and 15 kV d.c., or*

d) the energy of discharge exceeds 350 mJ for stored charges at voltages exceeding 15 kV d.c.

NOTE 3 It is recommended that for apparatus intended to be used in tropical climates, the values given in a) and b) above, be halved.

NOTE 4 To avoid unnecessarily high TOUCH CURRENTS when several apparatus are interconnected, it is recommended that the individual TOUCH CURRENT values are not higher than needed for functional reasons.

For CLASS I constructions the r.m.s. TOUCH-CURRENT to earth shall not be more than 3,5 mA. The measurement shall be carried out with the measurement network described in annex D of this standard and with the protective earthing connection disconnected.

For class I earthed equipment a sinusoidal waveform the following analysis applies.

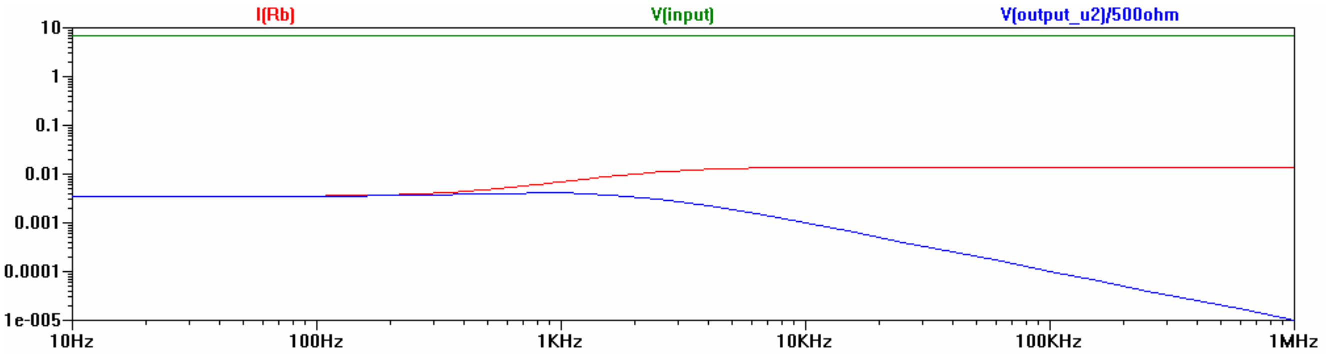


Figure 6: 3.5mA sinusoidal TC vs frequency

The TC is 3.5mA at line frequency and is discounted above 1 kHz to give the same reading for a sine wave at any particular frequency.

For equipment with SMPS the TC to earth is not sinusoidal[a]. A typical TC waveform looks like the figure below.

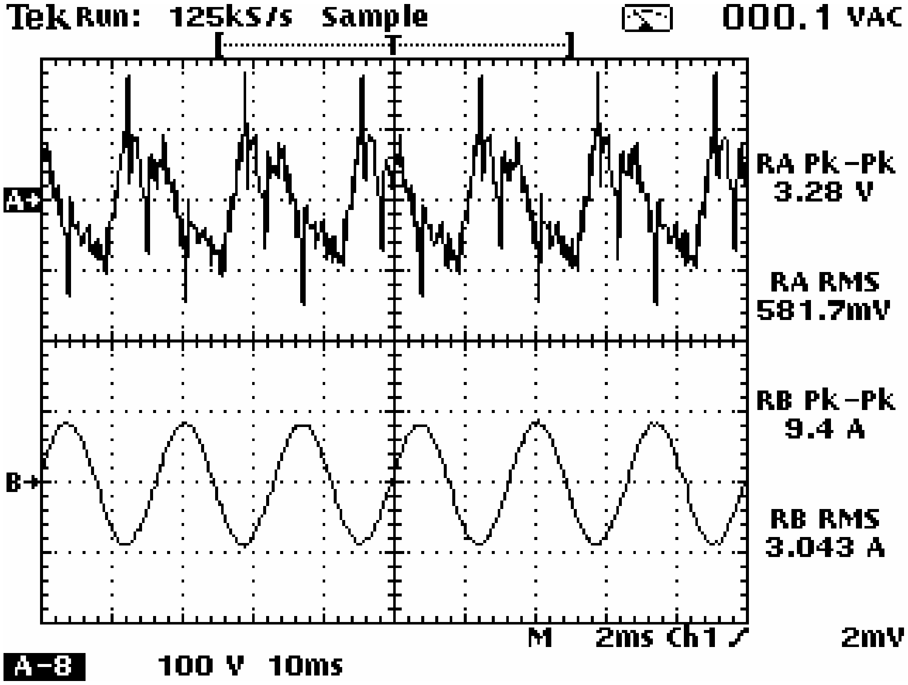


Figure7: Typical TC waveform (= A) for pfc corrected SMPS (B = input current)

The pk/rms ratio for this wave form is 2.82, twice that expected for a sinusoidal waveform. An rms measurement is inappropriate for this type of waveform.

Finally, what about interconnected equipment with the earth carried through the cabling even though the power cord is not earthed? Note 4 suggests that this TC should be minimized; how is it evaluated within this standard? What is the normal practice for showing compliance?

11 Fault conditions

NOTE To check compliance with the requirements of this clause, it may be necessary to repeat the dielectric strength tests. However, it is advisable to identify beforehand all the insulations to be tested with a higher test voltage in order to avoid more than one humidity treatment.

11.1 Electric shock hazard

Protection against electric shock shall still exist when the apparatus is operated under fault conditions.

Compliance is checked by the tests described in clause 9, modified as *specified below and under fault conditions.*

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[a] See the paper ‘Keeping up with proper Touch Current measurements’ by Peter E Perkins, PE given at the October 2005 IEEE PSES symposium in Chicago, IL USA.

For contacts of TERMINALS

– *the permissible values of 9.1.1.1 a) for other than audio signals, are increased to 70 V (peak) a. c. and 120 V d.c.,*

NOTE 1 The limits under normal operating conditions for audio signals should not be exceeded under fault conditions.

and

– *the permissible values of 9.1.1.1 b) are increased to* U_1 *= 70 V (peak) and* U_2 = *1,4 V (peak) for a. c. and to* U_1 *= 4 V for d.c.,*

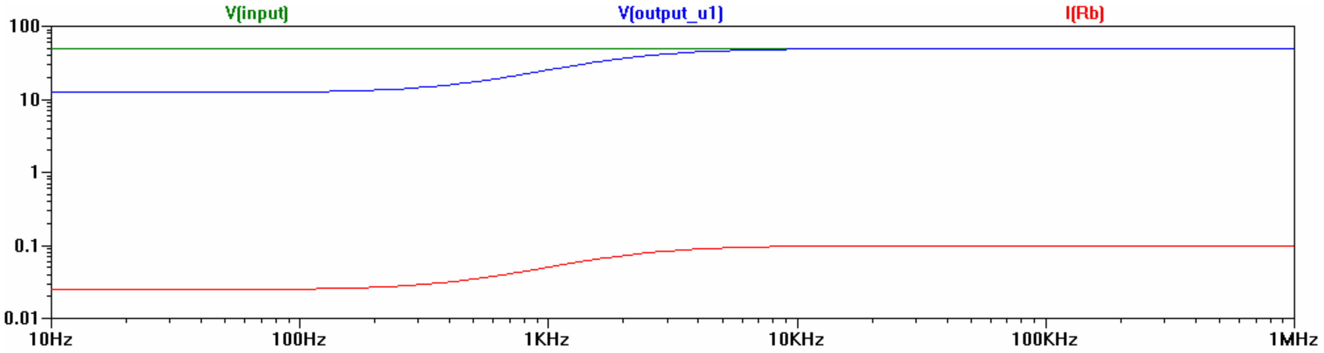


Figure 8: burn current under fault conditions

For the U_1 = 70V(peak) fault condition, which corresponds to 49.5Vrms, Fig 3 above provides the sinusoidal response of 25.2 mArms at line frequency and 99 mArms at 100 kHz.

For the U_2 = 1.4V(peak) fault condition, which corresponds to 0.99Vrms,

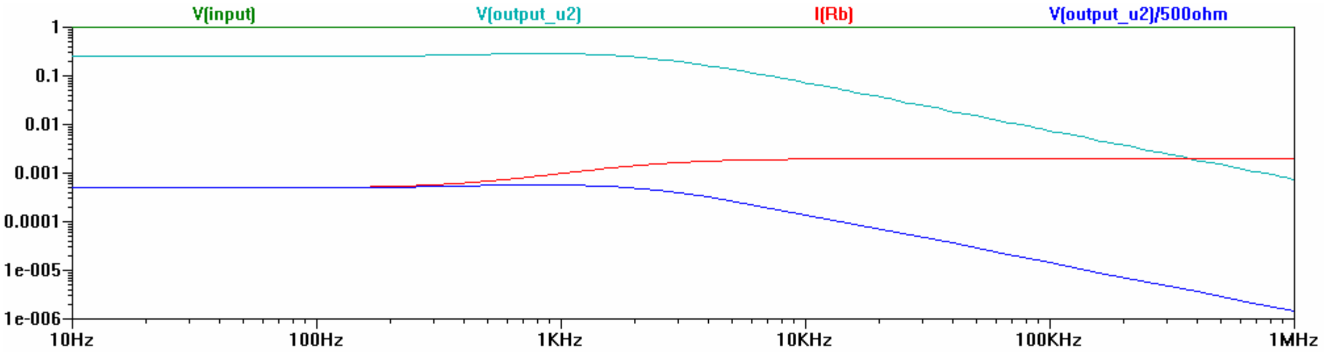


Figure 9: TC fault condition U2 analysis

Frequency/response	Voutput_u2	I(Rb)	Actual TC = V(output_u2)/500ohm
Line frequency	0.248Vrms	0.499mArms	0.497mArms
10kHz	0.071Vrms	1.94mArms	0.140mArms
100kHz	0.007Vrms	1.98mArms	0.014mArms

Table 2: U2 fault results

This case corresponds to a measured TC of 0.5mArms, which is a common limit for startle reaction – as would be shown on the Simpson 228 meter.

provided that the connectors for antenna and/or earth cannot be inserted into the TERMINAL *under test.*

NOTE 2 It is recommended that for apparatus intended to be used in tropical climates, the values given above be halved.

If short-circuiting or disconnecting a resistor, a capacitor, an RC-unit, an optocoupler or an inductor causes an infringement of the requirements, the apparatus is still deemed to be satisfactory if the component complies with the relevant requirements of clause 14 (see 4.3.4).

If, during the tests, an insulation mentioned in table 5 is subjected to a voltage exceeding the voltage occurring under normal operating conditions, and if this increase involves a higher test voltage according to 10.3, this insulation shall withstand a test for dielectric strength at the higher test voltage, unless the higher voltage is due to the short-circuiting or disconnection of a resistor, a capacitor, an RC-unit, an optocoupler or an inductor complying with the relevant requirements of clause 14.

This standard outlines a complicated TC measurement methodology which does not take into account all the waveforms or conditions routinely encountered and against which protection is needed. Feedback from the developers and users would be fruitful in this discussion.

Please provide your feedback to this draft paper directly to me… Pete

Touch current comparison data

First discussed at the IEC TC74/WG5 meeting June, 1997 in Melville, LI, NY, USA
additional waveforms have been included since that meeting
PE Perkins, Convenor IEC TC108/WG5

Measurements in this paper are for the purpose of reviewing some data on equipment to confirm the work of IEC TC 108 (was TC74) wg5: IEC60990, Measurement of Touch Current and Protective Conductor Current.

IEC60990 has proposed using peak value touch currents to properly account for the non-sinusoidal touch currents expected in modern equipment brought about by the continued introduction of direct power semiconductor devices and their application to equipment.

Dalziel, in his 1943 paper[i], clearly pointed out that "… the electric-shock value due to relatively small electric currents are controlled by the crest value of an a-c wave and not by its root-mean-square value …" properly relating the physiological effects to the peak value of current. This was reconfirmed by Hart[ii] in 1985. RMS measurements were normally used because most equipment traditionally had sinusoidal Touch Current waveforms plus non-sin measurements were considerably more difficult to make with older instrumentation. Therefore the traditional values for Touch Currents were taken by dividing the physiological peak value by the sqrt 2 to get the proper RMS value. In view of reversing this trend, the usual RMS Touch Current values should be multiplied by the sqrt 2 to get the proper peak value giving the same physiological effect.

Regarding the spike nature of the TC waveform, the broadband measurement of IEC 60990 properly accounts for the additional HF current that can be tolerated by the body; these impulses recur well under the approximately 1 sec. heart cycle needed to restore the heart's resistance to VF.

It is known that for modern switching power supplied equipment that the input current waveforms are non-sinusoidal for these equipments and it has been expected that the leakage current waveforms would also be non-sinusoidal. Unfortunately, there has been a dearth of direct measured data to show the current status of events. Further, there has been a great hue & cry that the measurements were not obtainable, for a variety of reasons. The measurement issue has disappeared with the introduction of digitizing measurement equipment.

These type test measurements shown here were gathered with commercially available test equipment. A Simpson 228 true RMS reading, with burn hazard, let-go and reaction response networks (as specified by IEC60990), leakage current meter was used as the basic measuring instrument for the TC; a Tektronix THS720P Digital scope was attached to the 1 volt full scale meter amplifier output at the jacks provided on the front of the Simpson to capture the waveforms shown here.

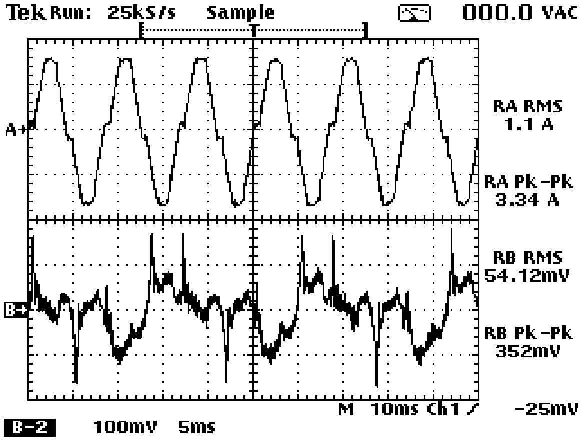
The TC measurements were made as the usual chassis-Neutral/Earth measurement, normal and reverse polarity and with switch OFF and ON including any other operator switches in each position. Input power measurements were also made on each equipment. The largest measured value is shown in each example.

Note that the use of power factor (harmonics) corrected power supplies is driving the touch current waveforms further away from the sinusoidal waveforms that had been experienced from AC driven equipment in the past. This further confirms the use of touch current peak measurements for equipment in order to properly show the electric shock effect of modern equipment.

Peak value TC measurements should always be made when non-sine TC's are present.

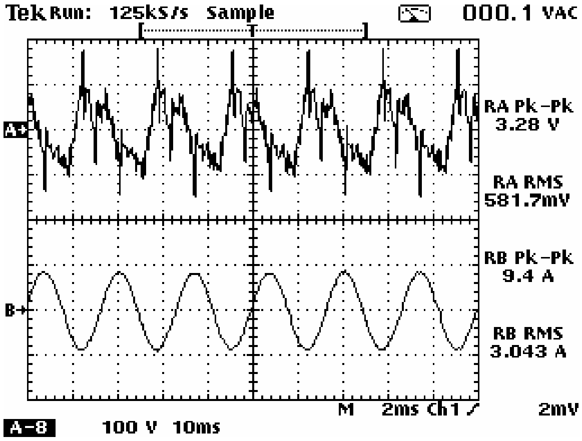
Additionally, the fundamental frequency for some TC waveforms is included.

)Portable projector C (with pfc power supply):
Input current and leakage current waveforms



max measured leakage current = 0.54 mArms or 1.755 mApk at 253V (60 Hz)
Itc peak/rms ratio: 0.352/0.054/2 = 3.250
input peak/rms ratio: 3.34/1.1/2=1.519

)Telecom equipment (w/pfc) in a cabinet:
Leakage current and input waveforms.

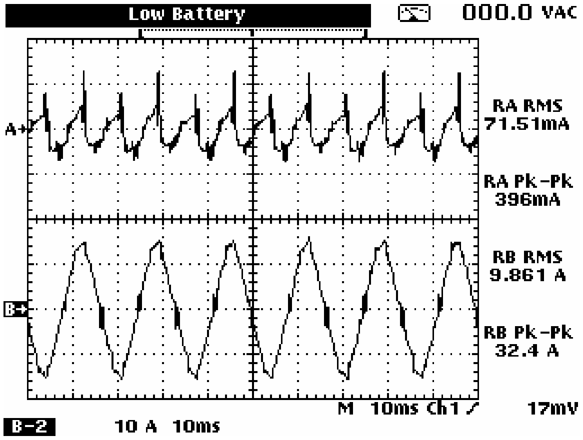


measured leakage current = 0.58mArms at 127.2V; expect 1.168mArms or 3.293mApeak at 253V.
Itc peak/rms ratio: 3.28/0.5817/2=2.819 (60 Hz)
input I peak/rms ratio: 9.4/3.043/2=1.545

Touch current comparison data

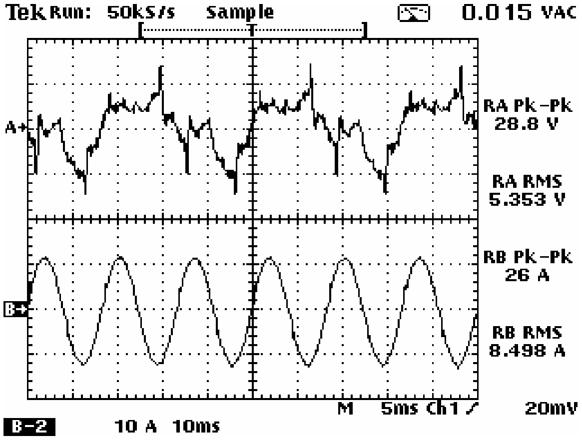
First discussed at the IEC TC74/WG5 meeting June, 1997 in Melville, LI, NY, USA
additional waveforms have been included since that meeting
PE Perkins, Convenor IEC TC108/WG5

)Industrial server A (with pfc power supply):
Leakage current and input current waveforms.



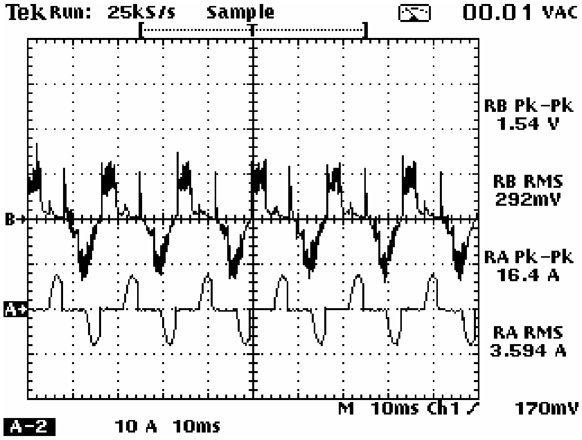
Measured leakage current = 0.0715mArms (center-tapped to earth) at 254V. (60 Hz)
Expect 0.143mArms at 254V line-to-ground.
Itc peak/rms ratio: 396/71.5/2 = 2.769
Input I peak/rms ratio: 32.4/9.861/2 = 1.643

)Telecom equipment B in a cabinet (with pfc power supply):
Leakage current and input current waveforms



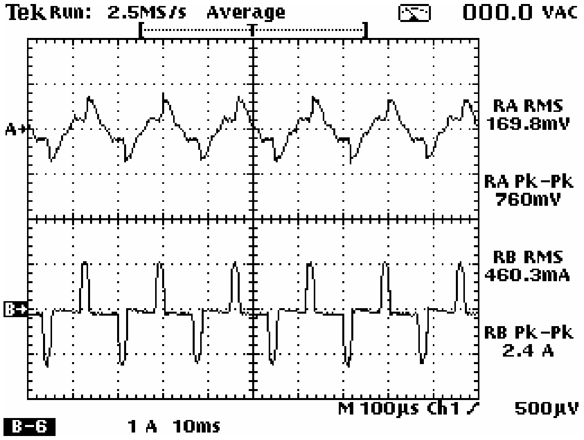
max measured leakage current =0.5353Arms at 127.2V; expect 1.065mArms or 2.865mApk at 253V.
Itc peak/rms ratio: 28.8/5.353/2 = 2.690 (60 Hz)
input peak/rms ratio: 26/8.498/2 = 1.530

)Variable speed drive exerciser: (running at half speed)
Leakage current and input current waveforms.



measured leakage current = 0.0876mArms at 120.5V; expect 0.184mArms or 0.485 mApk at 253V. (60 Hz)
Itc peak/rms ratio: 1.54/0.292/2=2.637
input I peak/rms ratio: 16.4/3.594/2=2.282

)Wall mounted telecom cabinet with external AC power brick:
Leakage current and input current waveforms.



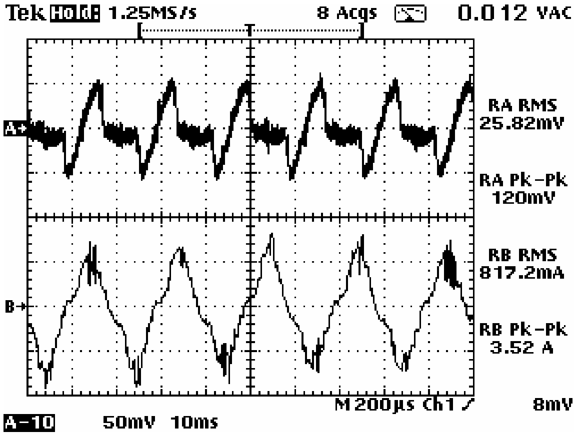
max measured leakage current =0.1698mArms at 123V; expect 0.345 mArms or 0.772 mApk at 253V.
Itc peak/rms ratio: 760/169.8/2 = 2.238
input peak/rms ratio: 2.4/0.4603/2 = 2.607

Touch current comparison data

First discussed at the IEC TC74/WG5 meeting June, 1997 in Melville, LI, NY, USA
additional waveforms have been included since that meeting

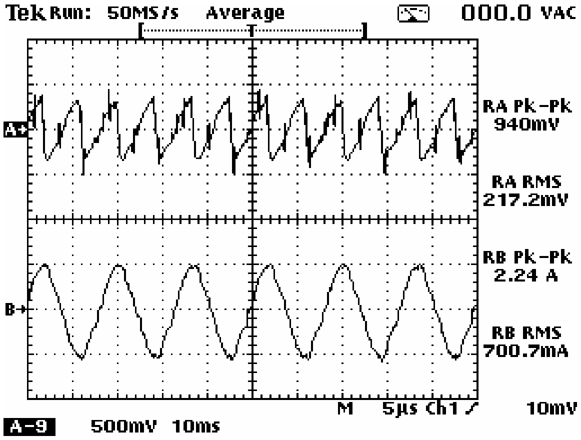
PE Perkins, Convenor IEC TC108/WG5

)Portable projector E:
Leakage current and input current waveforms.



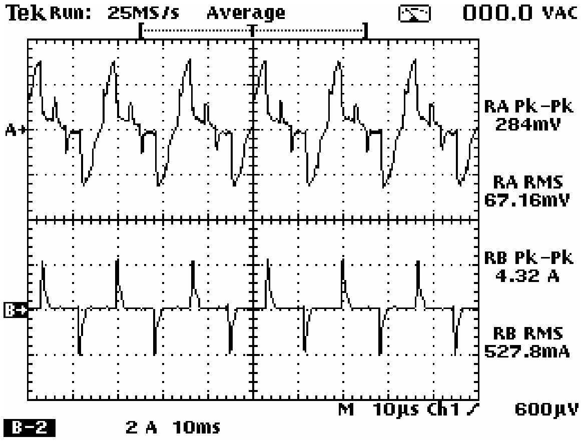
measured leakage current = 0.026mA at 253V.
Itc peak/rms ratio: 120/25.82/2 = 2.32 (60 Hz)
Input I peak/rms ratio: 3.52/0.8172/2 = 2.15

)Portable projector B:
Leakage current and input current waveforms.



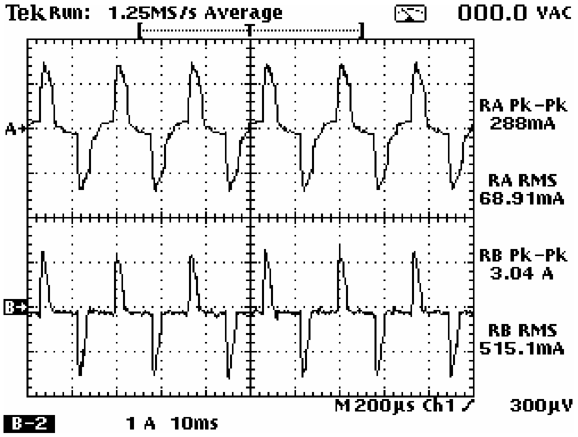
measured leakage current = 0.217mArms or 0.469mApk at 253V. (120 Hz)
Itc peak/rms ratio: 0.940/0.2172/2=2.166;
input I peak/rms ratio: 2.24/0.7007/2=1.598

)Laptop computer C with 3 wire mains plug
Leakage current and input current waveforms.



Max measured leakage current = 0.067mA at 120V
Expect 0.142mArms or 0.299mApk at 253V. (60 Hz)
Itc peak/rms ratio: 284/67316/2 = 2.114
Input I peak/rms ratio: 4320/527.8/2 = 4.092

)Laptop computer A with 3 wire mains plug
Leakage current and input current waveforms.



measured leakage current = 0.0681mA at 120.1V;
expect 0.145mArms or 0.303mApk at 253V.
Itc peak/rms ratio = 288/68.9/2 = 2.090
Input I peak/rms ratio = 3.04/0.5151/2 = 2.951

Touch current comparison data

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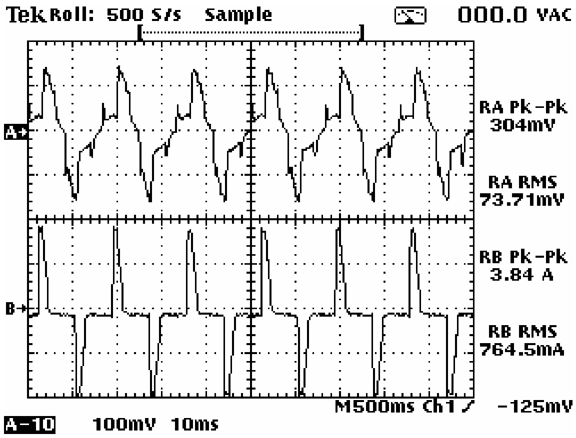
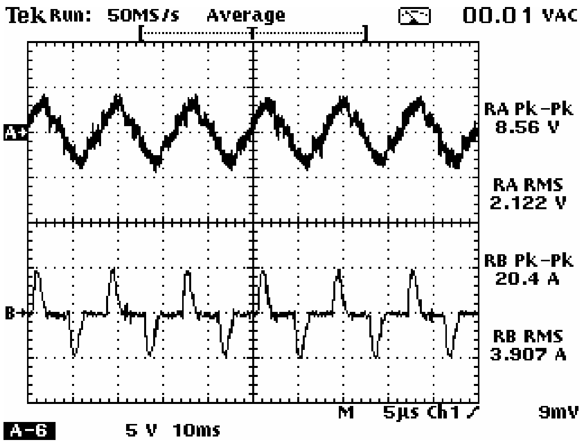
additional waveforms have been included since that meeting
PE Perkins, Convenor IEC TC108/WG5

)Laptop computer B with 3 wire mains plug:
Leakage current and input current waveforms.



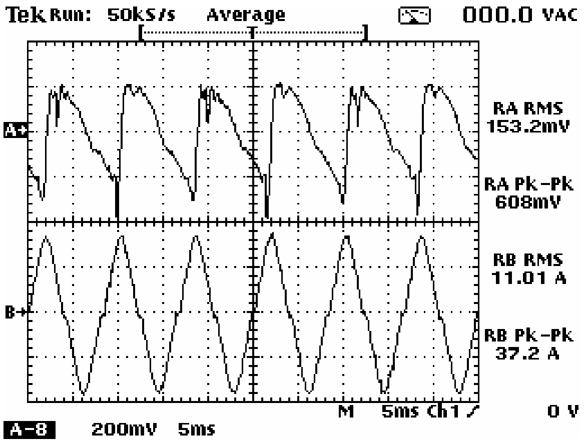
Max measured leakage current = 0.073mA at 121.9V
Expect 0.153mArms or 0.314mApk at 253V. (60 Hz)
Itc peak/rms ratio: 304/73.71/2 = 2.062
Input I peak/rms ratio: 3.84/0.7645/2 = 2.511

)Portable projector A:
Leakage current and input current waveforms.



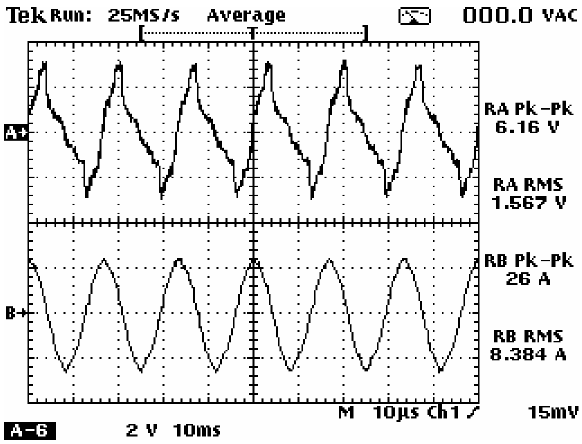
measured leakage current = 0.21mArms at 116V; expect 0.458mArms or 0.924mApk at 253V. (60 Hz)
Itc peak/rms ratio: 8.56/2.122/2=2.017;
input I peak/rms ratio: 20.4/3.907/2=2.611

)Industrial server B (with pfc power supply):
Leakage current and input current waveforms.



Measured leakage current = 0.1532 mArms at 253.8V
Itc peak/rms ratio: 608/153.2/2 = 1.984 (120 Hz)
Input I peak/rms ratio: 37.2/11.01/2 = 1.689

)Rackmounted computer system A (with pfc power supply):
Leakage current and input current waveforms.



max measured leakage current = 1.567mArms, 3.08mApk at 254V. (60 Hz)
Itc peak/rms ratio: 6.16/1.567/2=1.966
input I peak/rms ratio: 26/8.384/2=1.554

Touch current comparison data

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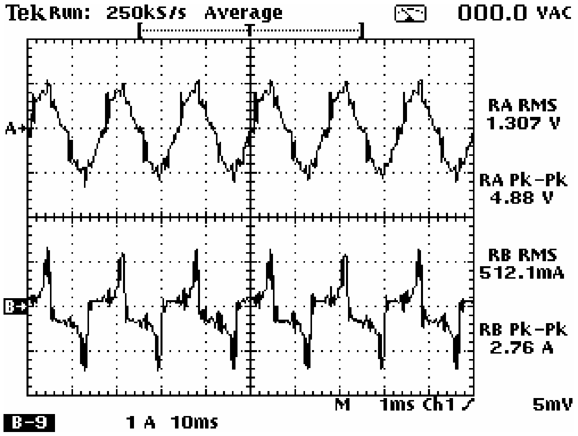
additional waveforms have been included since that meeting

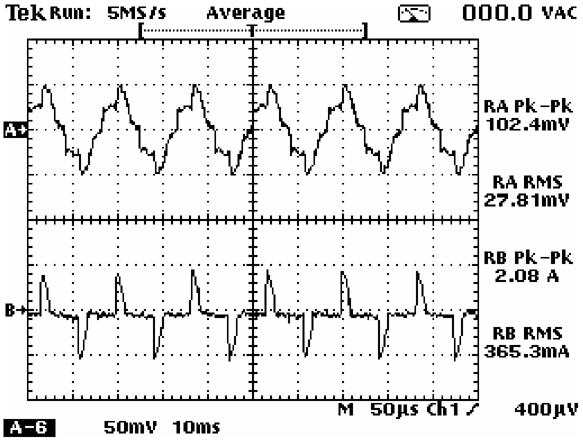
PE Perkins, Convenor IEC TC108/WG5

)Laboratory instrument – med:
leakage current and input current waveforms.



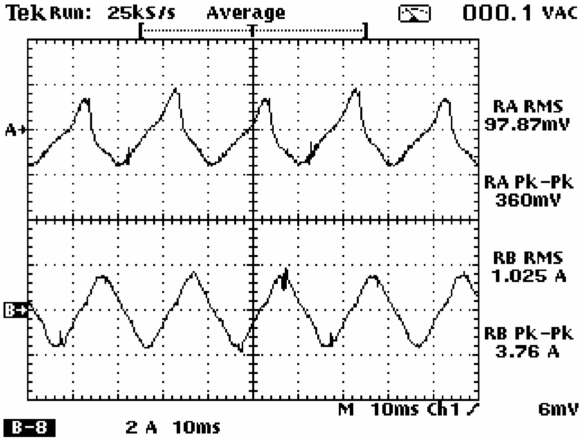
max measured leakage current = 1.307mArms, 4.88mApk-pk at 253V. (60 Hz)
Itc peak/rms ratio: 4.88/1.307/2 = 1.867
Input I peak/rms ratio: 2.76/0.5121/2 = 2.695

)Laptop computer D – 2 wire mains plug
Leakage current and input current waveforms



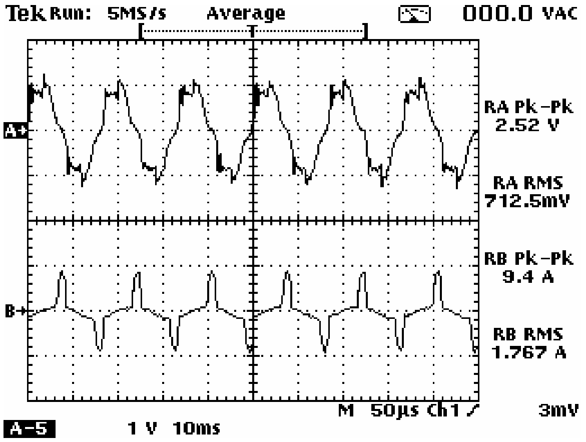
measured leakage current = 0.0.0278mArms at 120.8V; expect 0.058mArms or 0.107mApeak at 253V.
Itc peak/rms ratio: 102.4/27.81/2 = 1.841 (60 Hz)
input I peak/rms ratio: 2.080/365.3/2 = 2.848

)Portable projector D (w/ pfc):
Leakage current and input current waveforms



max measured leakage current = 0.098mArms, 0.180mApk at 253V. (111 Hz)
Itc peak/rms ratio: 360/97.87/2 = 1.839
input I peak/rms ratio: 3.76/1.025/2 = 1.834

)Small telecom system:
Leakage current and input current waveforms.



Measured leakage current=0.7125mArms, 2.52mApk-pk at 128V; expect 1.408mArms or 4.98mApk-pk at 253V. (60 Hz)
Itc peak/rms ratio: 2.52/0.7125/2 = 1.768
Input I peak/rms ratio: 9.4/1.767/2 = 2.660

Touch current comparison data

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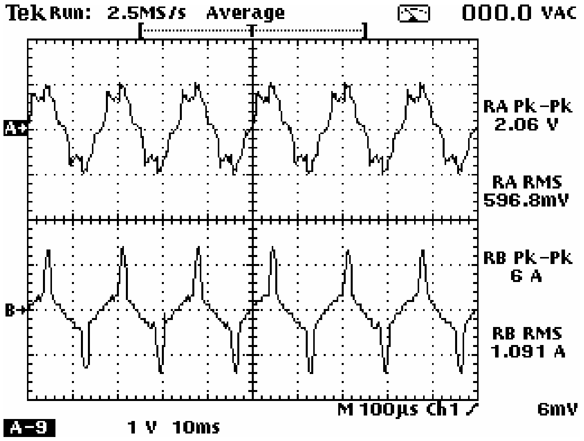
PE Perkins, Convenor IEC TC108/WG5

)Small telecom pedestal system:

Leakage current and input current waveforms.



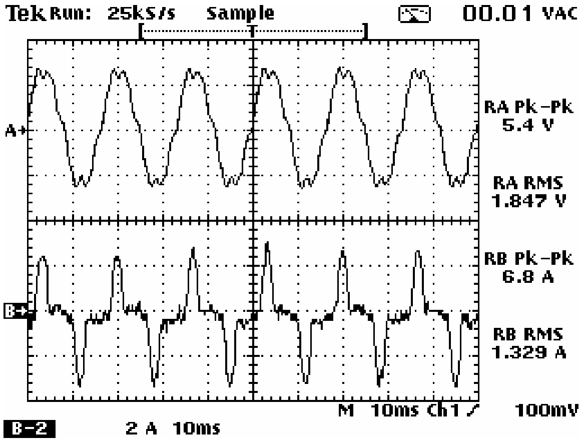
max measured leakage current = 0.597mArms, 1.03mApk at 253V. (60 Hz)

Itc peak/rms ratio: 2.06/0.5968/2 = 1.726

input I peak/rms ratio: 6/1.091/2 = 2.750

)Monolithic computer system:

Leakage current and input current waveforms.



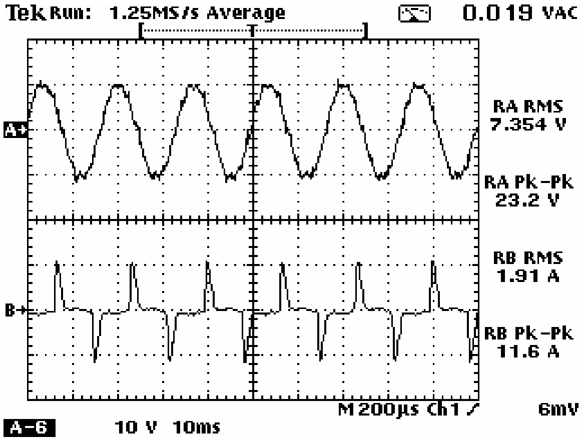
Measured leakage current = 0.055mArms at 126.1V; expect 0.110mArms or 0.161mApeak at 253V.

Itc peak/rms ratio: 5.4/1.847/2=1.7101 (60 Hz)

input I peak/rms ratio: 6.8/1.329/2=2.558

)SOHO computer system:

Leakage current and input current waveforms.



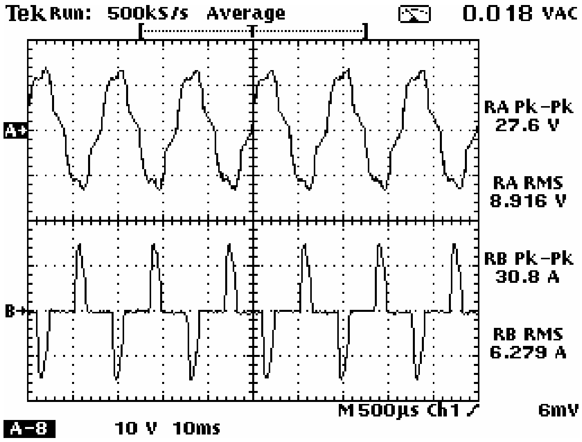
max measured leakage current = 0.75mArms at 120.4V; expect 1.545mArms or 2.436mApeak at 253V.

Itc peak/rms ratio: 23.2/7.354/2 = 1.577 (60 Hz)

input I peak/rms ratio: 11.6/1.91/2 = 3.037

)Projection display system A:

Leakage current and input current waveforms.



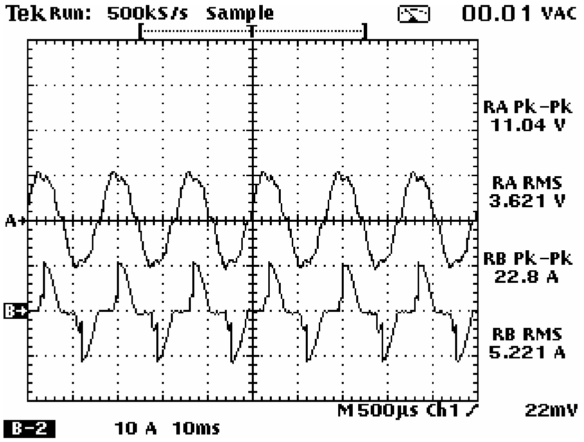
max measured leakage current=0.89mArms at 120.9V; expect 1.862mArms or 2.883mApeak at 253V.

Itc peak/rms ratio: 27.6/8.916/2=1.548 (60 Hz)

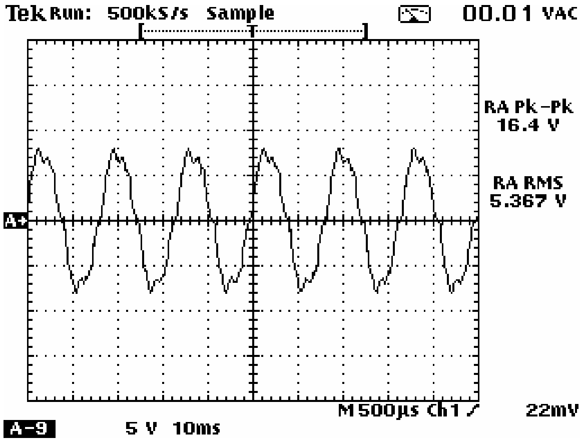
input I peak/rms ratio: 30.8/6.279/2=2.453

)Desktop copier:

Input current waveform (B)



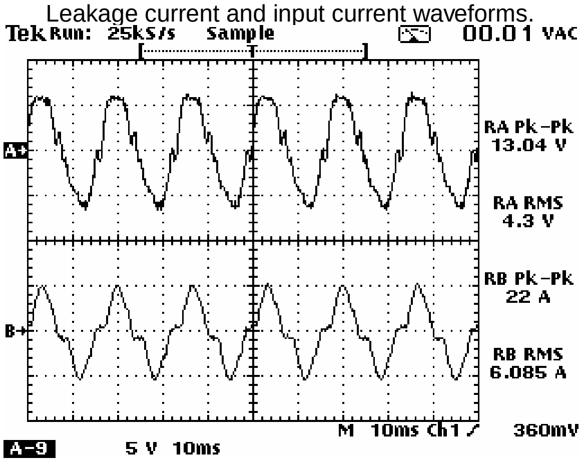
Leakage current waveform (A)



max measured leakage current=0.537mArms at 121V; expect 1.123mArms or 1.715mApeak at 253V.
Itc peak/rms ratio: 16.4/5.367/2=1.528 (60 Hz)
input I peak/rms ratio: 22.8/5.221/2=2.183

)Rackmounted computer system B (with pfc power supply):

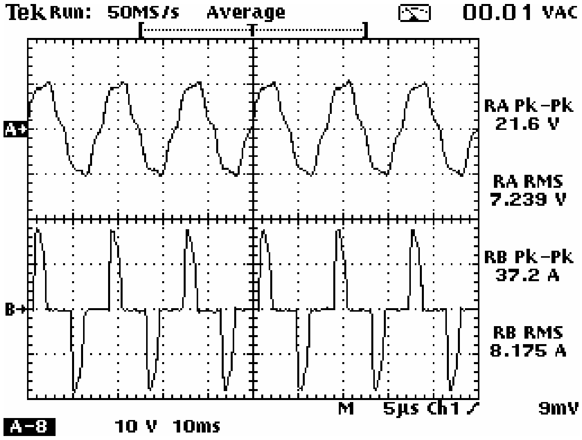
Leakage current and input current waveforms.



Measured leakage current=4.3mArms at 240V; expect 4.55mArms or 6.90mApeak at 254V. (60 Hz)
Itc peak/rms ratio: 13.04/4.3/2=1.516
input I peak/rms ratio: 22/6.08/2=1.808

)Projection display system B:

Leakage current and input current waveforms.



Measured leakage current = 0.72mArms at 119.7V; expect 1.521mArms or 2.269mApeak at 253V.
Itc peak/rms ratio: 21.6/7.239/2=1.492 (60 Hz)
input I peak/rms ratio: 37.2/8.175/2=2.275

Touch current comparison data

First discussed at the IEC TC74/WG5 meeting June, 1997 in Melville, LI, NY, USA
additional waveforms have been included since that meeting
PE Perkins, Convenor IEC TC108/WG5

Summarizing results.

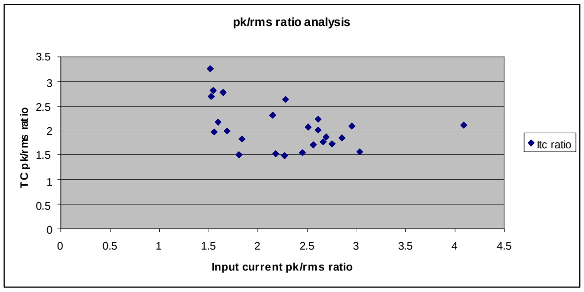


Figure 1: pk/rms ratio analysis

This data leads to my ongoing comment that pfc power supplies (Input ratio near sqrt 2) are pushing the TC pk to rms ratio higher – a more complex TC waveform. Review the waveforms at the beginning of the paper again.

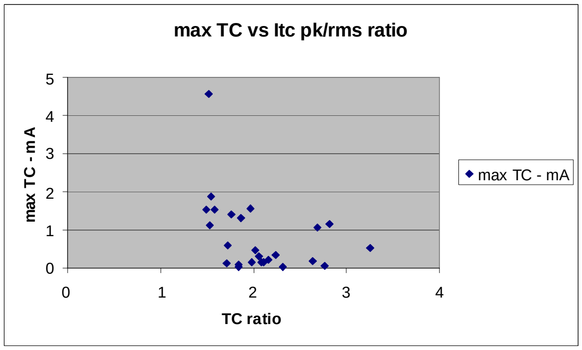


Figure 2: Max TC vs the TC pk/rms ratio

These figures compare the value of the current to the pk/rms ratio.

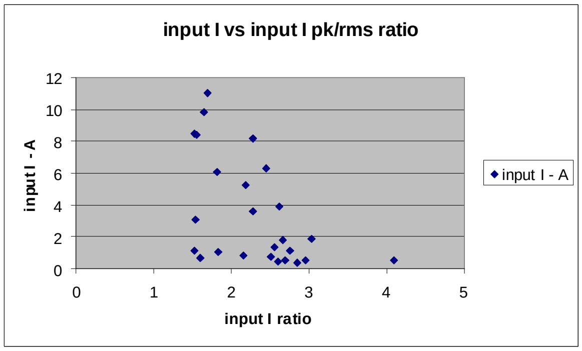


Figure 3: Input Current vs Input pk/rms ratio

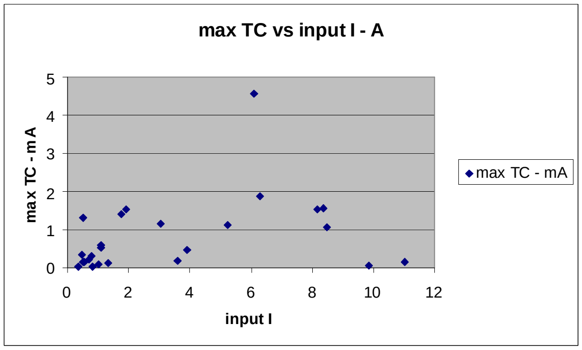


Figure 4: Max TC vs Input Current

In most of these cases the measured rms TC is below the 3.5mArms limit usually used. However several of these would not pass the 5mApk limit if the pk/rms ration was 3.250 (the first example). In this case the rms limit is 5/3.25 = 1.54mArms.

The fundamental frequency of the TC is line frequency in most cases with superimposed hi-frequency components, evidently from the mains switching circuits for both the power conversion and the power factor correction. One example is:

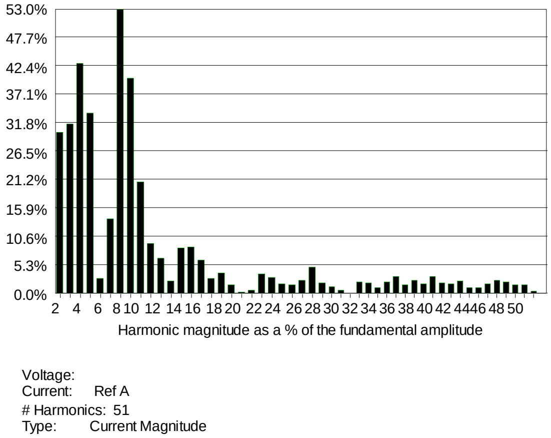


Figure 5: Industrial Server A TC harmonics

tcPK2RMScmp.doc
p.perkins@ieee.org

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[i] Effect of Wave Form on Let-Go Currents, Charles F Dalziel, AIEE Transactions in Electrical Engineering, Volume 62, December 1943.

[ii] Hart, W. F., A Five-Part Resistor-Capacitor Network for Measurement of Voltage and Current Levels Related to Electric Shock and Burns, in J. E. Bridges, G. L. Ford, I. A. Sherman, and M. Vainberg (eds.) Electrical Shock Safety Criteria, 1985, Pergamon Press, New York, pp.183-192.

Touch Current measurement comparison:
Looking at IEC 60990 measurement circuit performance

Peter Perkins
PE Perkins, PE
p.perkins@ieee.org

Abstract- **This paper will examine in some detail the performance of the IEC 60990 circuits considering specific conditions or waveforms.**

Conditions of electric burn (eBurn) plus Touch Current response by these circuits will be shown.

The examples are intended to show a range of waveforms and their calculated response.

The discussion is divided into two parts. Electric burn (eBurn) then Touch Current comparisons across the two circuits – startle-reaction circuit and let-go circuit.

These results will be compared to a TC waveform to show a comparison to modern electronic equipment.

This paper continues to confirm the need for peak measurements for TC waveforms from electronic equipment.

I. ELECTRIC BURN

- Product safety standards commonly give limits for electric burn from HF sources
- HF applies somewhere above 30kHz (as commonly believed)
- Measurement specifies the use of unweighted (IEC 60990 fig 3) circuits
- Sinusoidal waveforms are assumed
- RMS measurements are specified

Figure 1: Historic Electric Burn summary

The purpose of an eBurn specification is to limit the burn to a person touching such a circuit.

Earlier workers had been concerned with contact with HF circuits – wires, screwheads or connectors – which would primarily be finger contacts. Contact with wires – either end-on (wire diameter) or along the wire (very narrow width by 3 mm to 10 mm long) – is a very small area. Larger finger contacts in the range of 3 mm to 10 mm across seem to be the right order of magnitude. For a circle or a square contact this area is in the range of 7 to 100 mm^2; more generally this is on the order of tens of mm^2.

A small black burn spot from a quick contact with a small wire diameter is very acceptable; a narrow line burn seems similarly acceptable. Larger burns, e.g. from a screw connector or the like, is more of a problem. Even larger area contact & burn can be available on a circuit board. A dinner plate sized reddened area eBurn doesn't seem acceptable. Large carbonized areas are not acceptable.

IEC 60065:	70 mA pk > 100kHz
IEC 61010:	70mA (normal limit)
IEC 61010:	500 mA rms (fault limit)
IEC 60950:	70 mA rms
prIEC 62368:	50mA @ 100kHz (ES1)
prIEC 62368:	100mA @ 100kHz (ES2)

Figure 2: Some product standard electric Burn limits

From the product standard limits shown in Fig.2 it is shown that IEC 60065 specifies 70 mA pk AC using the unweighted TC measuring network. This applies to frequencies above 100 kHz.

IEC 61010 specifies 70 mA rms normal limit and 500 mA rms fault limit which relates to possible burns at higher frequency.

IEC 60950 specifies for LCC: 0.7 mA pk < 1kHz; 0.7*freq(kHz) ~ 70ma (cl 2.4.2).

The new, proposed prIEC 62368 specifies AC (1 kHz up to 100 kHz) current: ES1 limit ≤ 0.5 mA rms x f in kHz [= 50 mA rms at 100 kHz] and ES2 limit ≤ 5 mA rms + 0.95 x f in kHz [= 100 mA at 100 kHz].

The unweighted measurement circuit shown in Fig. 3a is also a basic part of each weighted measurement circuit shown in IEC 60990.

This fundamental body model circuit has been used for the last 50 years or so in electric shock evaluations.

The Fig. 3b example shows the increase in current with frequency due to the bypass capacitor in the model. This increase is about a factor of 4 from LF to HF and the transition occurs in the region of about 0.5 kHz to 5 kHz or so.

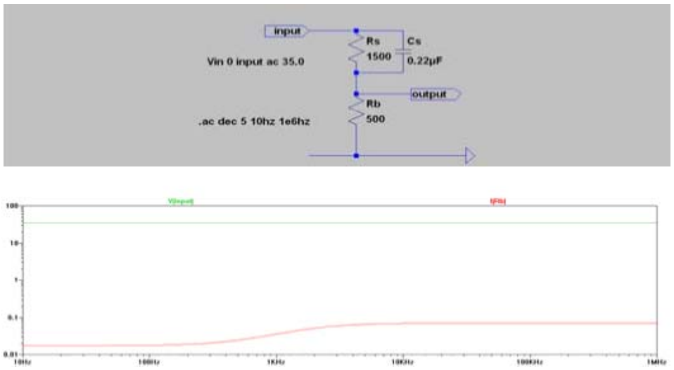


Figure 3: Unweighted measurement circuit (a) & current (b); IEC 60990, fig 3

Current / Std	LF current	HF current
IEC 60065	12.5 mA rms	50 mA rms
IEC 60950	17.5 mA rms	70 mA rms
IEC 61010	17.5mArrms, 126 mA rms	70 mA rms, 500 mA rms
prIEC 62368	12.5 mA rms, 25 mA rms	50 mA rms, 100 mA rms

Figure 4: eBurn data summary

This example in Fig. 3 shows 70 mA rms HF current which corresponds to some of the values used in the standards shown in Fig. 2.

The shape of the curve is the same for any sinusoidal input signal; the LF & HF current values change as the input changes.

Fig. 4 summarizes the calculated results of the SPICE analysis for the several eBurn limits given in the standards discussed.

Note that IEC 60065 specifies a peak limit but, since eBurn only applies to sinusoidal waveforms, this has been converted to rms values for this analysis.

The Low Frequency (LF) values are noted as they provide a basis for starting the discussion which is frequency dependant, as was shown.

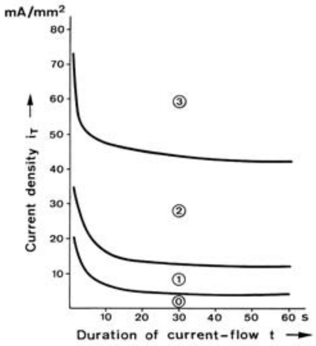
From Fig. 5 it is generally understood that a short term RF burn, reddening the skin, occurs at about 20 mA/mm^2 in a second or so – the shortest time a person can pull away by reaction. For a finger contact of 100 mm^2 this is 2000 mA (2 Amps) – a large current to which to subject a person. Fig. 5 shows these relationships.

Leaving current marks occurs at about 35 ma/mm^2 – 3500 mA (3.5 Amps).

Carbonization of the skin occurs at about 75 mA/mm^2 – 7500 mA (7.5 Amps). Longer term effects, 10's of seconds, are lower.

The Fig 5 data from IEC 60479-1 does not show frequency dependence for eBurn.

Combining the data from the current density curve with the contact areas expected provides the Fig. 6 table of expected currents.



Reddening the skin occurs at about 20 mA/mm^2 in a second or so – the shortest time a person can pull away by reaction. For finger contact of 100 mm^2 = 2000 mA (2 Amps).

Leaving current marks occurs at about 35 ma/mm^2 – 3500 mA (3.5 Amps).

Carbonization of the skin occurs at about 75 mA/mm^2 – 7500 mA (7.5 Amps). Longer term effects, tens of seconds, are lower.

Figure 5: skin eBurn effects (IEC 60479-1 fig 14)

Area, mm^2	20 mA/mm^2, mA rms	35 mA/mm^2, mA rms	75 mA/mm^2, mA rms
7	140	245	575
10	200	350	750
20	400	700	1500
50	1000	1750	3750
100	2000	3500	7500

Figure 6: eBurn currents vs. area

Note that the highest value considered here is 7.5 Amps over a 10 cm by 10 cm area.

The LF currents calculated ranged from 12.5 mA to 126 mA.

Fig. 7 (from IEC 60479-1) shows that a one second contact at 50 mA will produce ventricular fibrillation (VF).

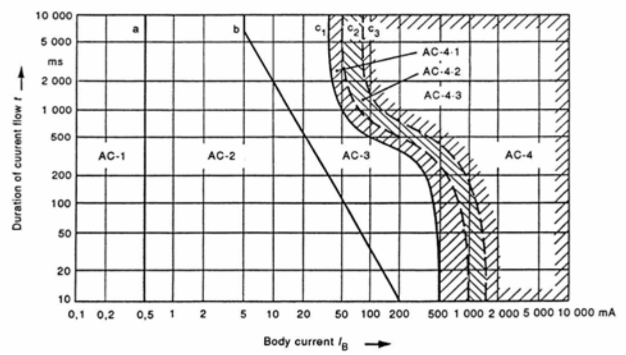


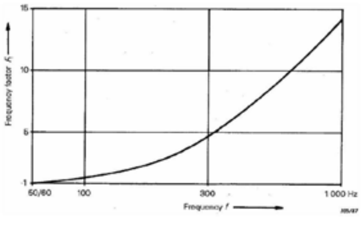
Figure 7: LF AC duration vs. body current; (IEC 60479-1, fig 20)

The body can withstand more current at high frequency for the same effect. The frequency factor curve for VF in IEC 60479 is shown in Fig. 8. This curve can be extended to HF as has been done for the similar curves in IEC 60990.

The current shown above is about 8.5 times higher than the threshold for let-go at the same frequency. This means that slightly below this value one would be protected from VF but would not be able to let-go of the circuit.

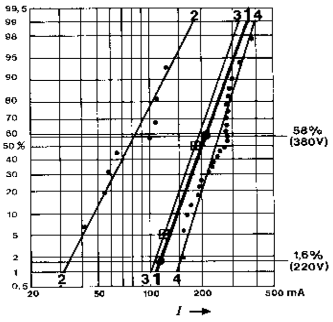
No frequency compensating circuit has been developed in IEC 60990 for this curve since it is expected that products would not drive performance up against this limit.

Certainly one would not want to put a person into VF upon contact with any eBurn current. Curve C1 (the 5% VF curve, protecting 95% of the population) would be the absolute upper limit without any margin for safety.



Freq factor for VF; waveforms > heart cycle, longitudinal thru the body (IEC 60479-2, Fig 3)

Figure 8: Frequency factor for Ventricular Fibrillation



0.5% VF @ 100mA
IEC 60479-1, fig 19

Figure 9: Comparative VF statistics

The 1984 version of IEC 60479 had a footnote: 'The point 500 mA/100 ms corresponds to a fibrillation probability in the order of 0.14%'. (This note appears to be the basis for choosing 500 mA as a limit.) This note has not been carried forward in the revision of the standard.

The latest version of the standard provides Fig. 9 which is a comparative curve of Fibrillation data that provides a curve calculated from line voltage and frequency accidents showing 0.5% VF at 100 mA.

The purpose of an eBurn specification is to limit the burn to a person touching such a circuit; but burns are not the only effect that needs to be considered. Coming in contact with such a circuit could lead to inability to let-go at levels well below those that would set off VF. Inability to let-go is defined by the b-curve body current levels of IEC 60479 'conventional time/current zones of effects of ac currents'.

From this point forward we will examine these traditional eBurn current values along with determining the frequency at which they fall below the let-go curve, curve b.

Using this frequency as a lower limit assures that any contact with the circuit will not result in inability to let-go (including its effect at high frequency, see Fig. 10 example).

In Fig. 11 a summary of the results of these SPICE calculations adding the let-go lower limit frequency is shown.

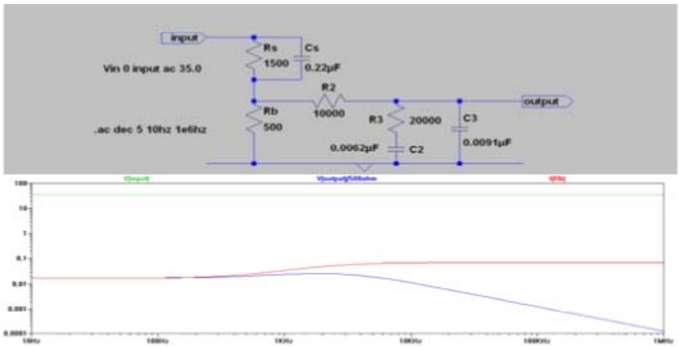


Figure 10: eBurn current from let-go weighted circuit

Current / product std	LF current	HF current	5 mA Let-go freq
IEC 60065	12.5 mA rms	50 mA rms	> 22kHz
IEC 60950	17.5 mA rms	70 mA rms	> 25 kHz
IEC 61010	17.5 mA rms,126 mA rms	70 mA rms, 500 mA rms	> 25kHz, > 180Khz
prIEC 62368	12.5 mA rms, 25 mA rms	50 mA rms, 100 mA rms	> 22kHz > 36kHz

Figure 11: eBurn data summary plus let-go frequency limit

These limits should always be specified above the frequency shown.

The plot shown in Fig. 12 summarizes the eBurn 5 mA let-go lower frequency point calculated for Fig. 11.

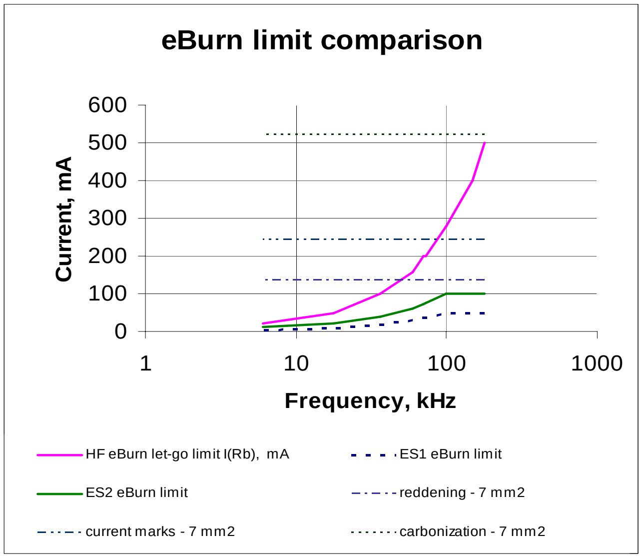


Figure 12: eBurn current comparison

Skin effects (reddening, current marks and carbonization, as shown in Fig. 5) lines are shown for a small contact area.

Operating below (and to the right of) the HF eBurn let-go curve always insures being below curve b of Fig. 7 to ensure let-go from allowable eBurn currents.

Operating above (and to the left of) the curve is forbidden under these conditions.

Each of these effects must be taken into account in setting a limit.

- Sinusoidal signals only
- Small, finger tip contact
- Reaction contact
- Adjusted for experience or training
- Always below let-go limit
- For all accessible circuits

Figure 13: eBurn limit conditions summary

Summarizing eBurn:

The eBurn limit only applies to sinusoidal signals.

The area of contact should be limited to small, finger tip contact to HF circuits.

The time of contact should be specified as being limited to reaction (< 1 sec).

The allowable limit should be specified for each type of person covered in the standard (ordinary normal user, supervised user or trained serviceman). Why would we subject ordinary users to an eBurn?

The allowable limit should ensure that the hazard never exceeds the let-go limit vs. frequency curve above.

These requirements should apply to accessible circuits which can be contacted at both poles. This includes all grounded secondary circuits and any isolated circuits where both contacts are easily available to touch.

II. TOUCH CURRENT

IEC 60990 provides circuits for measurement of Touch Current for:

- Startle-reaction conditions
- Let-go conditions

Figure 14: IEC 60990 TC conditions

IEC 60990 provides 2 Touch Current measurement circuits which meet the frequency factor curves of IEC 60479 under the following conditions.

A circuit weighted for startle-reaction (formerly called perception-reaction) – fig 4) – which is called s-r in this paper

A circuit weighted for let-go – fig 5 – called l-g here.

From Fig. 15, Startle-reaction is defined by curve a (the 0.5 mA line).

Let-go is defined by curve b (which is 5mA under steady state conditions but can go much higher under short time contact.

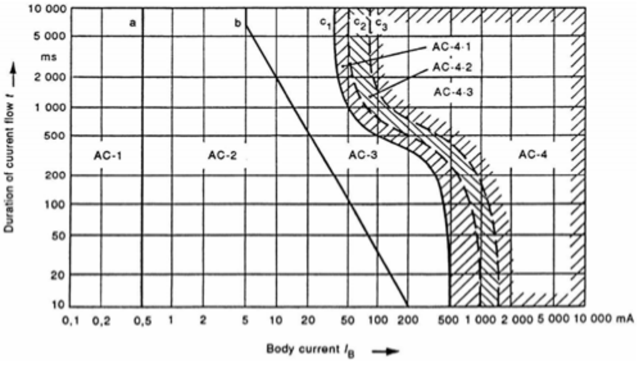


Figure 15: LF AC duration vs. body current; (IEC 60479-1, fig 20)

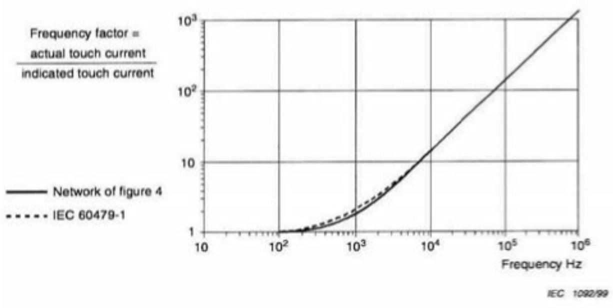


Figure F.2 – Frequency factor for perception or reaction

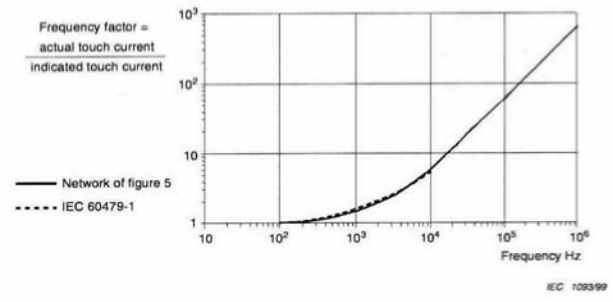


Figure F.3 – Frequency factor for let-go

Figure 16: TC freq factor curves; startle-reaction ckt (a); let-go ckt (b)

The c curves identify the region of ventricular fibrillation (VF) which is fatal, if not quickly reversed.

The human body can take more current at higher frequency for the same effect.

The curves of Fig. 16 are from IEC 60990 and show the frequency factor for startle-reaction (F.2 and let-go (F.3) as well as show the adequacy of the IEC 60990 circuits in adjusting the high frequency components according to this curve.

In Fig 17 gives a comparison of the frequency factor curves for startle-reaction and let-go circuits directly.

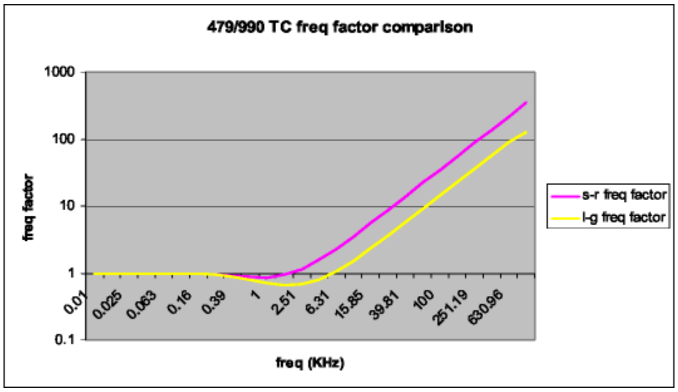


Figure 17: Touch Current frequency factor comparison

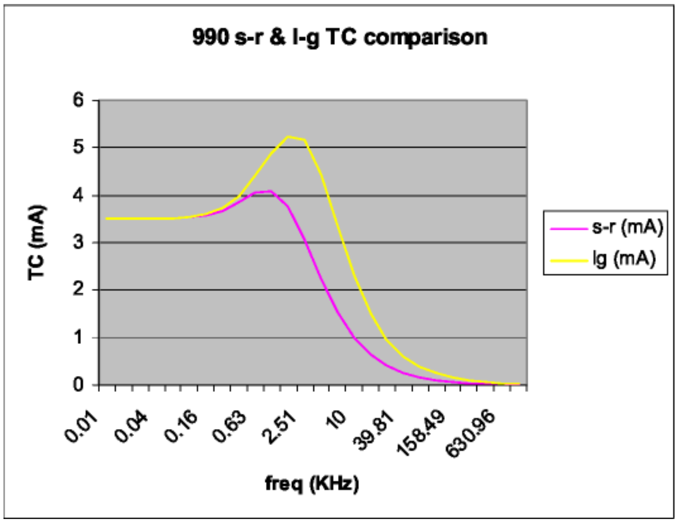


Figure 18: TC comparison

The TC comparison is shown in Fig 18 for the same input conditions.

A. Sinusoidal waveforms

The IEC 60990 circuits meeting the frequency factor curves just described are shown in Fig. 19. In each circuit the basic body model has a high frequency filter attached to meet the appropriate requirements.

The performance of each circuit is shown in Fig. 20 for the specific case chosen.

For this discussion, the case of 3.5 mA touch current has been selected. This case pushes the startle-reaction situation beyond the 0.5 mA expected, but has been commonly used in IEC standards such as IEC 60950 and IEC 61010.

Note that the touch current curve (the V(output)/500ohm - blue curve) is falling. The circuit has been designed to be the inverse of the frequency factor curve so that the same value can be read from the meter and compared to the limit irrespective of the frequency of the TC signal.

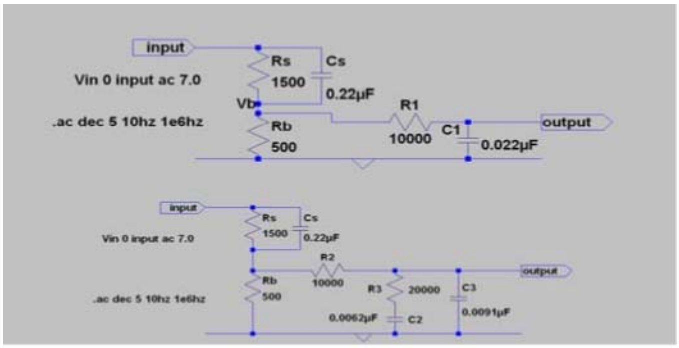


Figure 19: IEC 60990 TC circuits: startle-reaction ckt (a); let-go ckt (b)

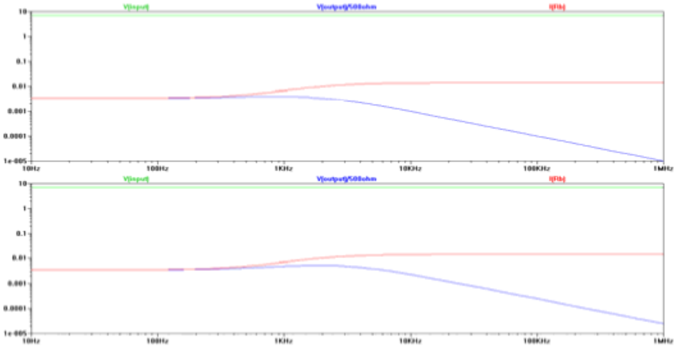


Figure 20: IEC 60990 measurement response; startle-reaction ckt (a); let-go ckt (b)

In this case we expect the rms TC to be 3.5 mA and the peak value to be square root of 2 * rms = 5 ma. The peak to rms ratio should them be the square root of 2 as shown in Fig. 21.

The startle-reaction (s-r) curve should be used for cases where the TC limit is 2 mA or less and the let-go (l-g) circuit above that. This will ensure that children will be able to let-go of the circuit when touched.

In all of the cases examined here, there will be an emphasis on peak measurement as the body responds to peak values of current for electric shock, not rms values.

Current	Peak	RMS	Pk/rms ratio
s-r cktTC = I(V(output)/500ohm)	4.94 mA	3.49 mA	1.415
l-g cktTC = I(V(output)/500ohm)	4.96 mA	3.50 mA	1.417

Figure 21: 50 Hz sine wave TC: startle-reaction ckt; let-go ckt

In each case shown in Fig. 22 we see the 50 Hz fundamental and no harmonics.

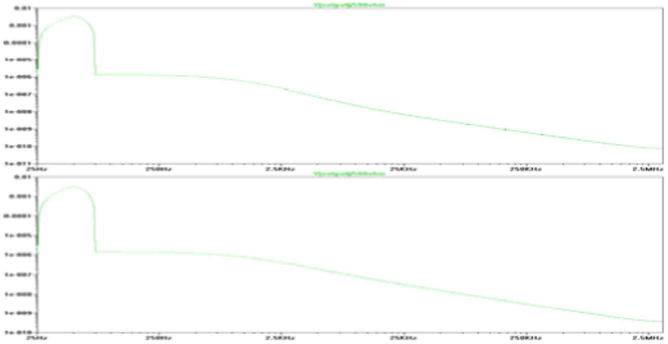


Figure 22: 50 Hz sine wave FFT: startle-reaction ckt (a); let-go ckt (b)

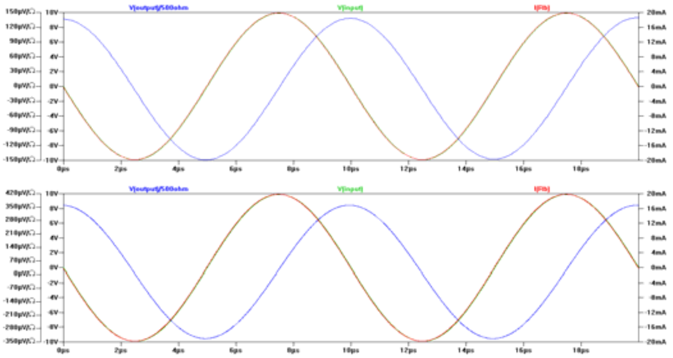


Figure 23:100kHz sin wave response; startle-reaction ckt(a); let-go ckt(b)

Fig. 23 looks at a 100 kHz sin wave input to each circuit. Comparing the peak and rms values for each circuit as before.

Current	Peak	RMS	Pk/rms ratio
s-r cktTC = I(V(output)/500ohm)	0.143 mA	0.101mA	1.416
l-g cktTC = I(V(output)/500ohm)	0.346 mA	0.245 mA	1.412

Figure 24: 100kHz sin wave TC

The frequency factor circuit reduces the TC value as expected at this frequency as shown in Fig. 24.

Each circuit treats the value in a different way – the TC is higher for the let-go measurement. The increased current starting with the middle frequencies increases the total current.

The peak/rms ratio is still square root of 2.

Again, only the fundamental frequency appears in the FFT as shown in Fig. 25.

B. Triangular waveforms

The triangular waveform might be considered a 'stretched out' sin wave, see Fig. 26.

Triangular waveforms have been seen in some equipment drawing substantial regulated power for heaters or similar loads.

For this case the rms TC is lower than the 3.5mA that would be allowed while the peak value is higher – about 5mA, one value below and one above as shown in Fig. 27.

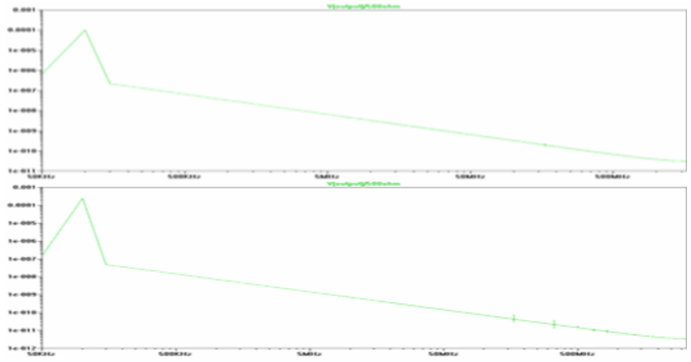


Figure 25: 100kHz sin wave FFT;startle-reaction ckt (a); let-go ckt (b)

Current	Peak	RMS	Pk/rms ratio
s-r cktTC = I(V(output)/500ohm)	4.98 mA	2.868 mA	1.736
l-g cktTC = I(V(output)/500ohm)	5.05 mA	2.869 mA	1.760

Figure 26: Triangular waveform response; 20 ms (50Hz) period

The peak/rms ratio is no longer square root of 2.

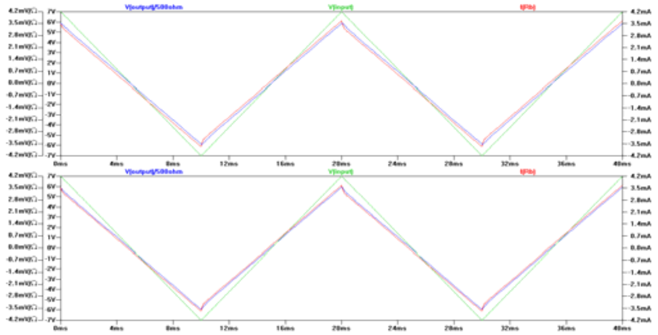


Figure 27: Triangular wave TC; s-r (a); l-g (b)

Somewhat to our surprise, Fig. 28 shows that there are considerable harmonics associated with the triangular waveform.

The filter circuit component of the TC circuits properly acts on these high frequency components of each waveform.

C. Square waves

The response to a line frequency square wave is shown here in Fig 29.

The differences in the TC response (blue curve) between these circuits is easily distinguishable here. This square wave has a 1% risetime – a very short portion of the pulse.

There are enough high frequency components here that the circuits treat them differently.

Although the rms values are about the same, the peak values are quite different.

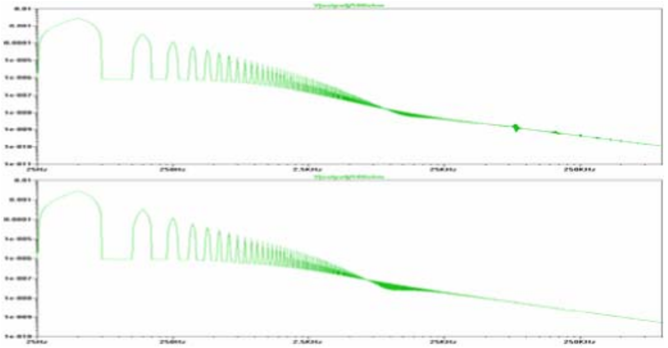


Figure 28: Triangular wave FFT; startle-reaction ckt (a); let-go ckt (b)

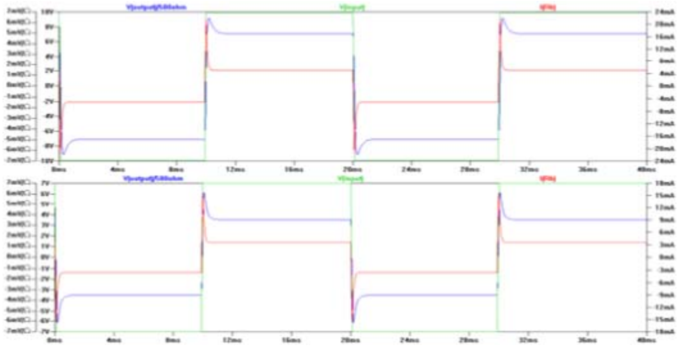


Figure 29: 20ms (50Hz) Sq Wave response; s-r ckt (a); l-g ckt (b)

Because of these differences the peak/rms ratios are quite different.

Current	Peak	RMS	Pk/rms Ratio
s-r cktTC = I(V(output)/500ohm)	6.39 mA	4.991 mA	1.280
l-g cktTC = I(V(output)/500ohm)	8.758 mA	5.054 mA	1.733

Figure 30: 20ms (50Hz) sq Wave TC

The peak values are the important measurement here and the values are given in Fig 30.

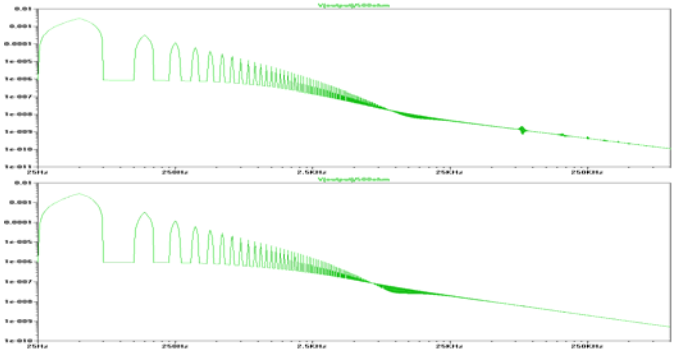


Figure 31: 20ms (50Hz) Sq Wave FFT; s-r ckt (a); l-g ckt (b)

Some high frequency differences can be seen in comparing these two FFTs of the circuit response to this waveform as shown in Fig. 31.

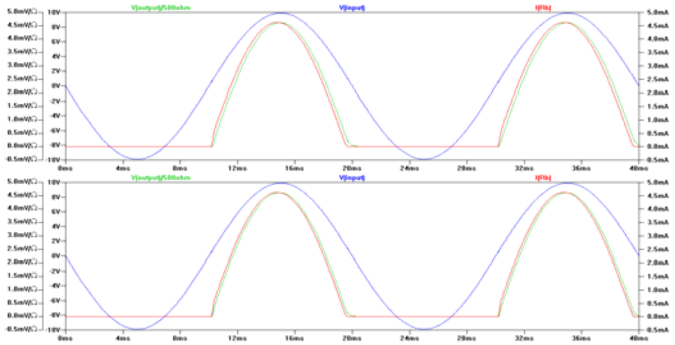


Figure 32: Half-wave rectified line-frequency sine wave response; s-r ckt (a); l-g ckt (b)

D. Rectified sin wave

Fig. 32 begins the discussion of rectification of line voltage which is an essential part of utilization of electric energy in equipment today.

As we might begin to suspect, Fig. 33 shown that the rms values are lower than our sinusoidal base case but the peak values are proportionally higher.

The peak/rms ratio is over 2.

Current	Peak	RMS	Pk/rms Ratio
s-r cktTC = I(V(output)/500ohm)	4.61 mA	2.264 mA	2.036
l-g cktTC = I(V(output)/500ohm)	4.62 mA	2.265 mA	2.036

Figure 33: Half-wave rectified line-frequency sin wave TC

The high frequency differences appear above 25kHz and up as shown in Fig. 34.

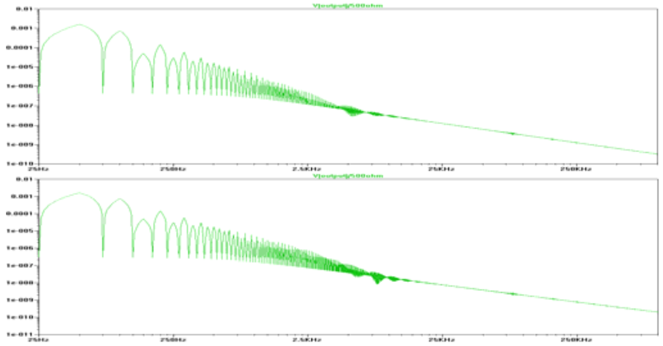


Figure 34: Half-wave rectified line-frequency sin wave FFT; s-r ckt (a); l-g ckt (b)

E. 1 ms square wave response

100 ms pulse, 1 sec rep rate (within the heart cycle), 1ms (1%) risetime shown in Fig. 35.

This calculation was looking for a TC below 14 mA pk to prevent VF for the particulars of this case.

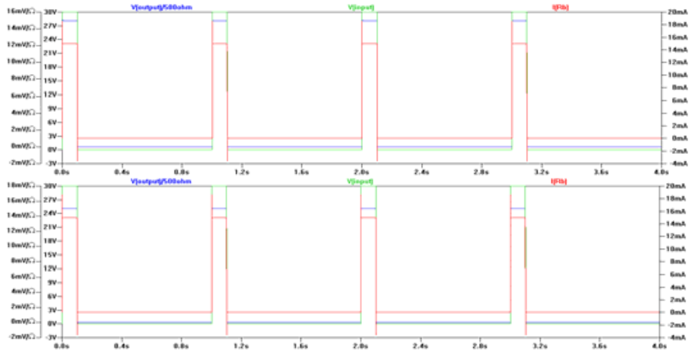


Figure 35:1 ms risetime pulse response: s-r ckt (a); l-g ckt (b)

Current	Peak	RMS	Pk/rms Ratio
s-r cktTC = I(V(output)/500ohm)	8.319 mA	4.761 Ma	1.747
l-g cktTC = I(V(output)/500ohm)	8.917 mA	4.762 mA	1.873

Figure 36: 1ms risetime pulse TC

With this risetime there is only a slight difference in the circuit responses between circuits as shown in Fig 36.

The pk/rms ratio is not sqrt 2, however.

The higher frequency components show as slight differences here as seen in Fig 37.

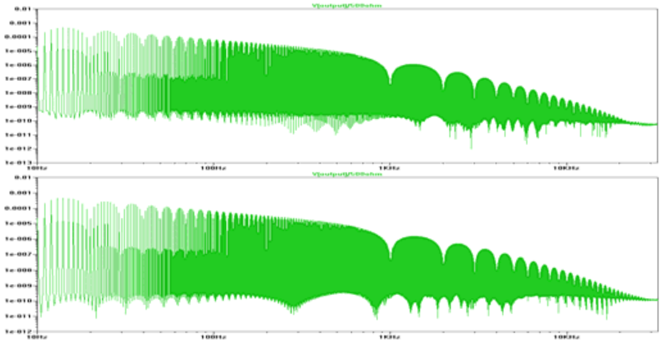


Figure 37: 1ms risetime pulse FFT; s-r-ckt (a); l-g ckt (b)

Looking at Fig. 38, at the slow risetimes the TC is about 7.5 mA in each case.

At the fast risetimes the TC is almost 10 mA for the s-r case and almost 14 mA for the l-g case.

The control of risetime is the key to using impulse circuits in applications where TC approaches the limit.

Although the FFT waveforms seem similar here in Fig. 39, the TC magnitude differs as we saw in the last slide.

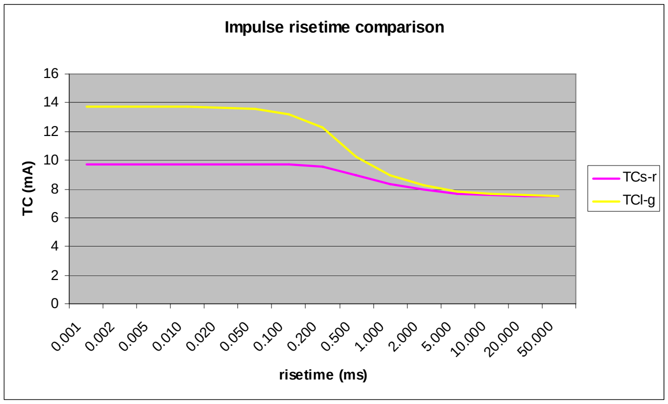


Figure 38: Impulse risetime comparison: s-r ckt; l-g ckt

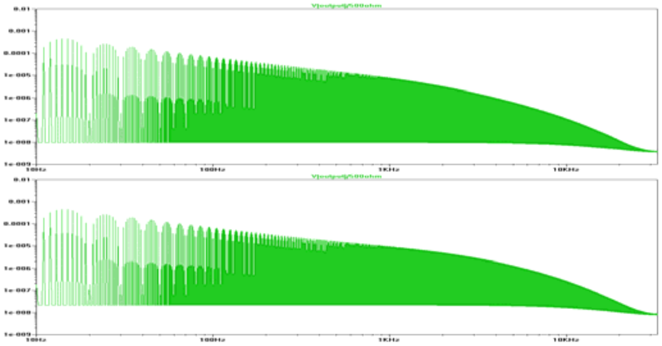


Figure 39: 0.01ms risetime pulse FFT; s-r ckt (a); l-g ckt (b)

Both the magnitude and the pk/rms ratio are different for a fast RT when filtered by each TC circuit as shown in Fig 40.

Current	Peak	RMS	Pk/rms Ratio
s-r cktTC = I(V(output)/500ohm)	9.732 mA	4.746 mA	2.051
l-g cktTC = I(V(output)/500ohm)	13.687 mA	4.749 mA	2.882

Figure 40: 0.01ms risttime pulse TC

F. Limited current Circuit analysis

Limited Current Circuit evaluation described in Fig. 41 replicates a real world case.

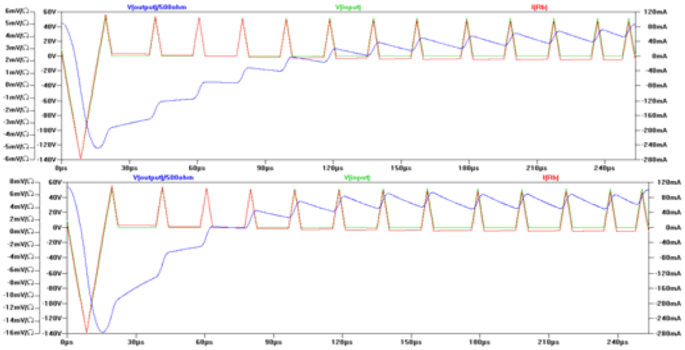


Figure 41: LCC circuit; s-r ckt (a); l-g ckt (b)

IEC 60950 allows access to circuits which will not be an electrical shock hazard.

This specific waveform was submitted for analysis because of its characteristics.

When reviewing the LCC waveform using the s-r circuit it shows the peculiar characteristic of being less than 3.5 mA rms but more than 5 mA pk (IEC 60950 limits), see Fig 42.

Again, reviewing this LCC waveform using the l-g circuit the values are substantially larger and the pk/rms ratio is also larger.

Current	Peak	RMS	Pk/rms Ratio
s-r cktTC = I(V(output)/500ohm)	5.070 mA	3.090 mA	1.641
l-g cktTC = I(V(output)/500ohm)	11.536 mA	5.645 mA	2.044

Figure 42: LCC TC comparison; s-r ckt; l-g ckt

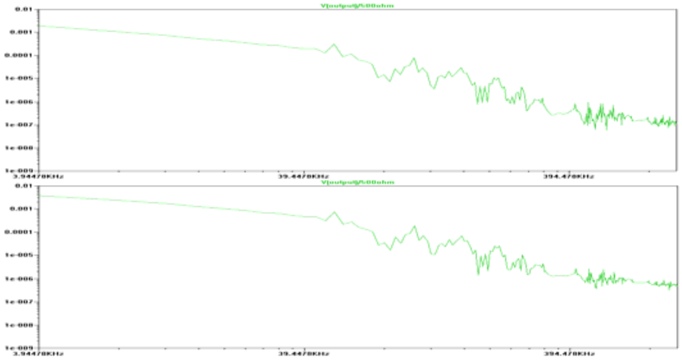


Figure 43: LLC circuit FFT: s-r ckt (a); l-g ckt (b)

Comparing these FFT's in Fig. 43 (which appear quite similar and contain harmonics starting about 40kHz.

This complex waveform cannot be evaluated by simply consulting the frequency factor curves.

The use of peak measurement is the only way to evaluate this complex waveform.

G. *TC Conclusions*

This paper compares the performance of the IEC 60990 eBurn, startle-reaction and let-go circuits against basic waveforms.

This leads to a better understanding as to the action of TC waveforms and encourages the proper evaluation of TC waveforms in equipment.

The simple waveforms shown here are not yet representative of the TC waveforms for modern equipment using mains switching techniques.

Switching electronics is used in switch mode power supplies and variable speed drives in equipment today. This technology is spreading to many other types of equipment – commercial, industrial and residential.

Peak measurements are needed for the s-r and l-g cases; these are specified in many standards but not uniformly applied today.

- From the review of these examples, we see the following:
    1) Both of these circuits evaluate LF waveforms in a similar way – properly accounting for HF components.
    2) Moving to the use of the let-go circuit (for limits approaching the l-g limit curve) requires a more conservative design to meet the limits.
    3) The general use of peak TC measurements is needed for today's complex TC waveforms.

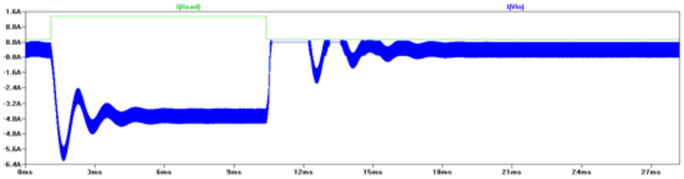
Figure 44: TC conclusions

III. EXPLORING FURTHER

How did we get there and what can we say about real SMPS?

Power supply manufacturers tout the performance of their modules in meeting the needed performance criteria for the applications they support.

Note from the fig 45 example, however, that the input current is never a fixed value, it oscillates over a small range (ooo 1amp or so in this case) to maintain the output regulation needed.



Input and load currents as the supply is switched on then off

Figure 45: Proto DC-DC power supply I/O currents

This current oscillation is capacitively coupled to earth and contributes to the TC for the product.

Many products use a multiplicity of these DC-DC converters for the distribution of power in the product; each of these will contribute to the TC for the product in their own way. The measured TC will, of course, sum these sources.

Note that both the output and the input show a continuous harmonic spectrum for this power supply as shown in Fig. 46.

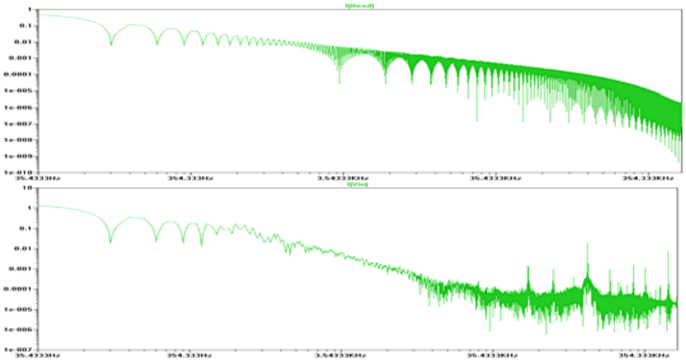


Figure 46: Proto DC-DC converter I/O FFT's

The measured Touch Current for a pfcSMPS in a product is shown in Fig 47 (top waveform) along with the pfc input current waveform (bottom waveform), see Fig. 47.

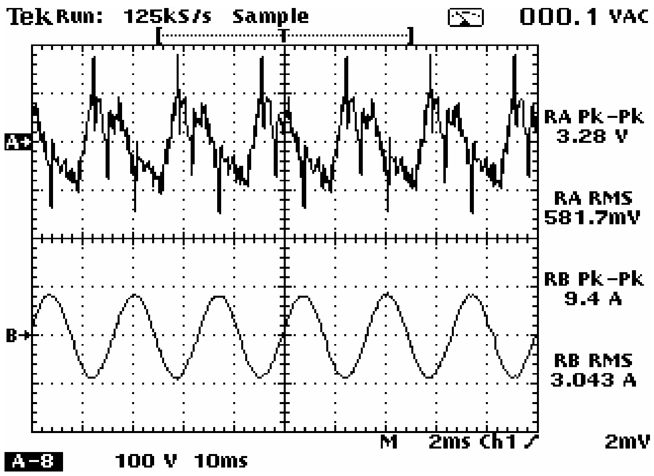


Figure 47: pfcSMPS Touch Current waveform (top)

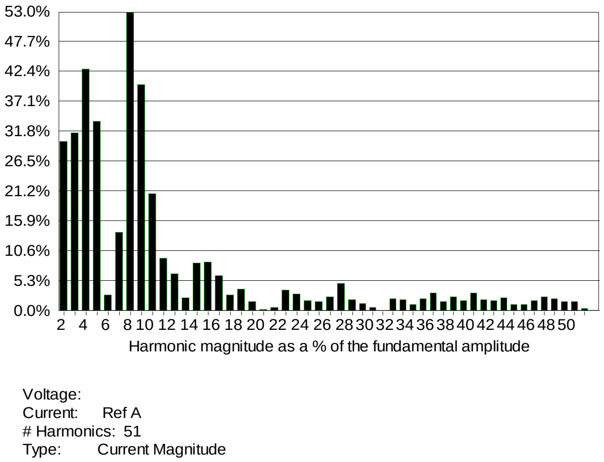


Figure 48: Measured Frequency Spectrum for pfcSMPS TC

The measured harmonics for a pfcSMPS Touch Current waveform shown above are shown in Fig 48.

This oscilloscope analysis shows lots of harmonics near the fundamental as we've seen in many of the non-sinusoidal examples (triangular, square wave, rectified sine wave & pulse). The scope analysis is limited to the first 50 harmonics (2.5 - 3 kHz); the SPICE analysis includes these first 50 harmonics and then goes to higher frequencies.

This paper clearly shows the need to move to peak measurements for Touch Current in all electronic products.

This paper also forms a solid basis for further understanding of the effect of system generated waveforms on the TC results for any product which can be more complex than the simple waveforms used as examples here.

Touch Currents have become the low frequency counterpart to EMC currents – a residual of the design process and not clearly controlled.

REFERENCES

[1] IEC 60479 Effects of electric current on the human body and animals; -1 General; -2 Special aspects

[2] IEC 60990 Measurement of touch current and protective conductor current.