Asian Power Electronics Journal, Vol. 13, No. 2, October 2019

Human Impedance Characteristic Investigation by Low Voltage Square Wave Excitation

Xu C. D[1] Cheng K. W. E[2] Wang D. H[3]

Abstract–In order to obtain the characteristic of the human impedance [1][2], A square wave electric signal is proposed to apply to the human beings. The peak current when a human is in initial contact of an electrical signal is examined. The use of square wave is a better method for human detection as it gives an exponential current that is unique as compared to another electrical appliance. The result provides a critical judgment for smart electric socket which could identify human being from another appliance.

The whole research is based on the human model in the standard of IEC 479[3]. Considering the instant effect in the first charging moment by the step pulse, the human model is simplified to an RC circuit.

Keywords–Human impedance, square wave excitation, safety

I. INTRODUCTION

Traditional safety product cannot identify the human body from the other electric load because of the overtime and complication of the human body impedance data [4]. To reduce the human body risk against the shock and touch current, the human body impedance test is carried on providing the updated data based on the international standard human impedance model in standard of IEC 479.

As shown in Fig. 1. The human impedance consists of skin resistor R_1 and R_2 paralleled with capacitor C_1 and C_2 connected with internal resistor.

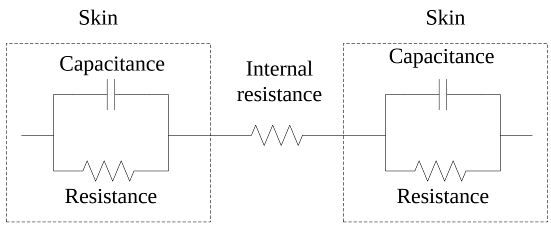


Fig. 1: The model of human body

As mentioned in the standard, the skin resistance R_1 and R_2 are around several hundred k ohm, the internal resistance is around 500-1000 ohm. From the experimental results, the skin capacitance C_1, C_2 are few pF.

In the proposed method, the human impedance is obtained by applying a square wave low voltage power source to the human body. For square waveform [5], the rise time of square waveform is very fast and is about 100-200ns in ESIC circuit. When the human capacitance starts being charged, there is current flowing through the whole body. The value of R1 and R2 is several hundred k ohm from IEC 479, the current flowing through R_1 and R_2 is very small that is about 60 uA for square waveform of 24V and R_1 and R_2 assumed to be 200k ohm. Meanwhile, the peak current flowing human is generally higher than 10mA from experiment data. The current flowing through R_1 and R_2 is 0.6% of peak current, that is, most current flows through C_1, R_0 and C_2. Therefore, the human model could be simplified into a RC model at the step pulse moment as shown in Fig. 2.

Fig. 2: Simplified RC model

From the up and down edge of the wave, the internal resistor and the charging time could be obtained. In order to identify human body from other electric load, analysis and conclusion is made. Human body could be identified by the peak current and the pulse time.

From the experiments result, human impedance is very stable with a fixed internal resistor connected with a changing capacitor.

II. TEST APPARATUS AND TEST PROCEDURE

The equipment like Signal Generator (AFG3021B), Power Amplifier, Digital Storage Oscilloscope (DSO-X 3024A), AC/DC Current Probe (Tektronix TCPA300) are used in the test. The whole test procedure is based on report 5. The pressure of 500g on the skin and the contact area 100mm2 and 10mm2 are designed in the test to obtain more accurate results.

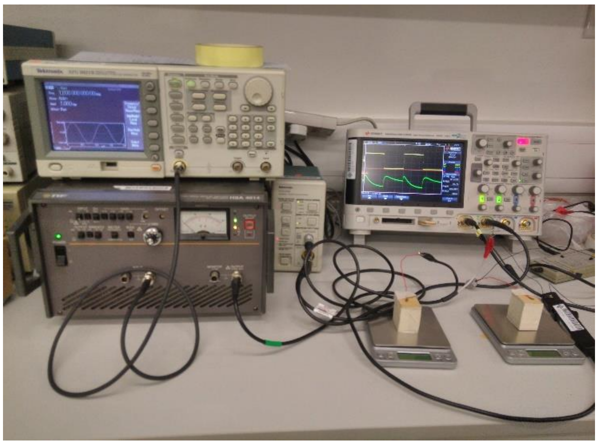


Fig. 3: Test platform

The signal generator and power amplifier are to generate and amplify the signal to obtain the low voltage square wave excitation power source. The digital storage oscilloscope is to measure the voltage and current by using the voltage probe and AC/DC current probe.

The power source for the test is set up as RMS a.c. voltages of 10Vac, 18Vac and 25Vac, Square wave, and nine fixed frequency from 50Hz to 20 kHz. The positive and negative of the power source connect with the line and neutral poles of devices, respectively. The peak value of

Power Electronics Research Centre, Department of Electrical Engineering, The Hong Kong Polytechnic University, Hong Kong
E-mail: 10902353r@connect.polyu.hk
E-mail: eric-cheng.cheng@polyu.edu.hk

test current and pulse time of test current will be measured and recorded. This measured wavefom will be analysed and compared to verify the detection criteria. The test platform is shown in Fig. 3.

III. THE HUMAN IMPEDANCE MODEL ANALYSIS

1. Theoretical analysis

The following analysis would be based on the human model in IEC standard as shown in Fig.1. when the square wave power source is charging the human, especially on the rising edge, the two skin capacitance has been by passed and the current is going through the resistor directly, which has been discribed in the first section.

Therefore, $R_{\text{int}} = \dfrac{V}{I_{\max}}$.

when the applied voltage is different, the relative maximum current is different, but the human body's internal impedance is very stable which is close to 1.5 k ohm.

Take XuCD as an example. When the contact area is 100mm^2

$$R_{\text{int}} = \frac{\triangle v}{\triangle i} = \frac{v}{I_{\max}} ,$$

When v=10V, i=6.65mA, when the frequency is 50 Hz. So as the other frequency.

Therefore, when the frequency is at 100, 200, 500, 1k, 2k, 5k, 10k, 20k, the internal resistance is 1.52k, 1.52k, 1.52k, 1.50k, 1.54k, 1.52k, 1.54k, 1.60k, respectively.

The internal resistance of XuCD at all the applied voltages has been illustrated in the Table1.

When the contact area is 10mm^2, the internal resistance could be calculated based on the above analysis as shown in Table 2.

The pulse time is determined by the RC constance, the time is chosen by falling to 90% of the maximum current which is close to 2.3 τ .

Therefore, the total skink capacitance could be calculated by 2.3 τ =pulse time.

Take XuCD as an example. When the contact area is 100mm^2

τ = Rint x C0, in seconds, where R is the value of the internal resistor in ohms and C is the value of the sum of two skin capacitors in Farads. This then forms the basis of an RC pulse time 2.3τ can also be thought of as "2.3 x $R_{\text{int}}C_0$".

2.3 x $R_{\text{int}}C_0$=20.13us, when at frequency of 50 Hz, and the contact area is 100mm^2, and the applied voltage is 10V.

It could be seen in the above analysis, the internal resistance could be solved as 1.5 k ohm, therefore, the skin capacitance could be calculated as

C_0=20.13us/(2.3× R_{int})=5.8202 nF, So as the other frequency.

Therefore, when the frequency is at 100, 200, 500, 1k, 2k, 5k, 10k, 20k, the skin capacitance is shown in Table 3.

The skin capacitance of XuCD at all the applied voltages has been illustrated in the Table1 when the contact area is 100mm^2. As shown in Table 4

When the contact area is 10mm^2, the skin capacitance could be calculated based on the above analysis and shown in Table. 5

As we can see, the data is very stable.

2. Simulation results

The simplified model of human being will be as shown in Fig. 4

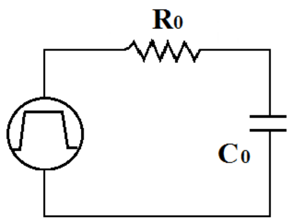


Fig. 4: The simplified model of human being

where R_0=R_{int}.

Taking XuCD as an example, when the contact area is 100mm^2, the average resistance is around 1.54k Ohm.

When the applied voltage is 10V, frequency is 1k, the capacitance is around 5.46nF.

the simulation result will be shown in Fig. 5.

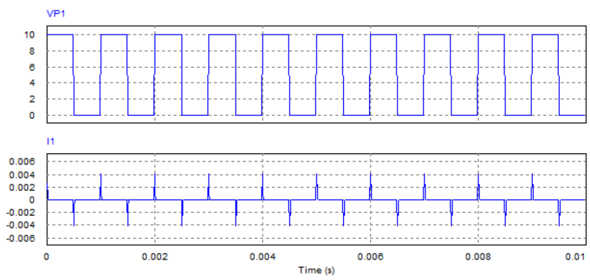


Fig. 5(a): Time response of the square wave source and the input current (simulation result)

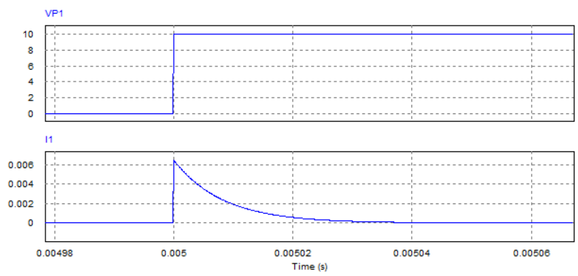


Fig. 5(b): Zoom in of time response of the square wave source and the input current with R=1.54k Ohm, Vin=10V, f=1k Hz, C=5.46nF(simulation result)

Table 1: Internal resistance with 100mm^2 contact area

Frequency Hz	50	100	200	500	1k	2k	5k	10k	20k
10V	1.503759	1.52207	1.52207	1.52207	1.503759	1.540832	1.52207	1.540832	1.642036
18V	1.607143	1.636364	1.607143	1.607143	1.607143	1.607143	1.607143	1.607143	1.698113
25V	1.506024	1.52439	1.436782	1.428571	1.428571	1.436782	1.54321	1.582278	1.666667

Table 2: Internal resistance with 10mm^2 contact area

Frequency Hz	50	100	200	500	1k	2k	5k	10k	20k
10V	2.016129	2.083333	2.118644	2.016129	2.083333	2.016129	2.04918	2.083333	1.953125
18V	1.969365	2.097902	2.200489	2.117647	2.179177	2.137767	2.200489	2.117647	2.158273
25V	2.083333	2.04918	2.118644	2.118644	2.155172	2.155172	2.04918	2.04918	2.192982

Table 3: The skin capacitance

Frequency Hz	50	100	200	500	1k	2k	5k	10k	20k
	5.820196	5.92157	5.9787	5.92157	5.935848	5.680161	5.753035	5.623726	5.014983

Table 4: Skin capacitance with 100mm^2 contact area

Frequency Hz	50	100	200	500	1k	2k	5k	10k	20k
10V	5.820196	5.92157	5.9787	5.92157	5.935848	5.680161	5.753035	5.623726	5.014983
18V	5.007536	5.024396	5.115749	5.061643	5.010242	5.007536	4.73971	4.577391	4.152947
25V	6.091478	6.594226	7.232348	6.482609	6.668261	6.324522	6.282783	5.85287	5.191304

Table 5: Skin capacitance with 10mm^2 contact area

Frequency Hz	50	100	200	500	1k	2k	5k	10k	20k
10V	1.043757	0.989217	0.952209	1.000626	0.951652	1.004939	0.965391	0.930783	1.119722
18V	1.371	1.251768	1.248734	1.299638	1.207077	1.204019	1.189459	1.225725	1.188551
25V	1.235478	1.213635	1.155374	1.112278	0.932035	0.992557	1.239096	1.251826	1.173704

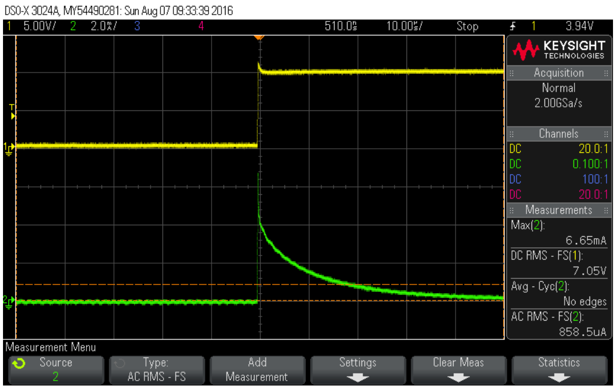


Fig.5(c): Zoom in of time response of the square wave source and the input current (experimental result)

Compare the simulation result with experimental data from the following Table 6., the peak current is 6.57mA and the pulse time is 20.73µs, the two results agree very well with each other, which strongly support the test result of the human impedance and also support that the simplified human model doesn't affect the result.

3. Comparison with IEC standard

The unique of the experiment presented is the applied voltage to the human bodies which is square wavefom and is different with the standard which is sinewave. Therefore, the standard data could only be the reference.

Table 6: The experiment results for 8 frequencies of test

	contact area=10mm2							
Peak current (mA) / Applied voltage (V)	50 Hz	100 Hz	200 Hz	500 Hz	1k Hz	2k Hz	5k Hz	10k Hz
10	6.65	6.57	6.57	6.57	6.65	6.49	6.57	6.49
18	11.2	11	11.2	11.2	11.2	11.2	11.2	11.2
25	16.6	16.4	17.4	17.5	17.5	17.4	16.2	15.8
Pulse time (us) / Applied voltage(V)	contact area=100mm2							
10	20.13	20.73	20.93	20.73	20.53	20.13	20.14	19.93
18	18.51	18.91	18.91	18.71	18.52	18.51	17.52	16.92
25	21.1	23.12	23.9	21.3	21.91	20.9	22.3	21.3

As we can see from the standard as shown in below figure, the human impedance is around 3.2k ohm when the applied voltage is 25V 50 Hz sinewave with large contact area. When the frequency is increased to 2k, the human impedance is close to the internal resistance which is around 600 ohm as shown in figure below. In the experimental results, the human impedance is around 1.5k ohm with 100mm^2. With large contact area, the human impedance could be even smaller based on the research. Therefore, the human impedance is smaller than the 3.2k ohm in the standard which verified that the experiment result is consistent with the standard data.

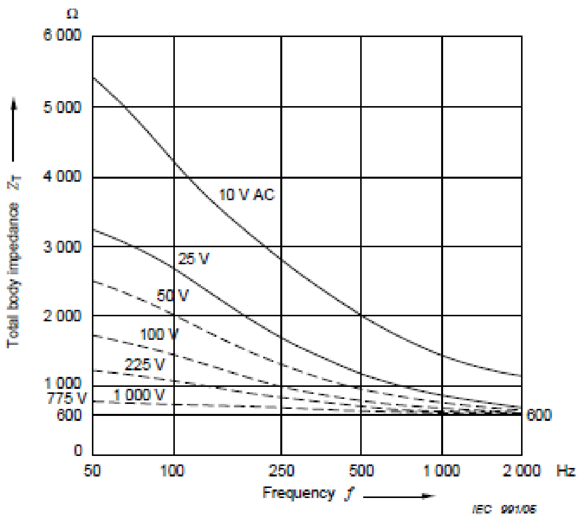


Fig. 6: Frequency dependence of the total body impedance ZT of a population for a percentile rank of 50 % for touch voltages from 10 V to 1 000 V and a frequency range from 50 Hz to 2 kHz for a current path hand to hand or hand to foot, large surface areas of contact in dry conditions

As compared with Fig.6 and 7 in the standard, the human impedance with applied 25V 50 Hz sinewave voltage and 10mm^2 and 100mm^2 are 200k and 2000k ohm respectively, otherwise in the presented experiment is around 1.5k and 3k ohm respectively. The reason is that in the standard, the applied voltage is low frequency sinewave, the skin

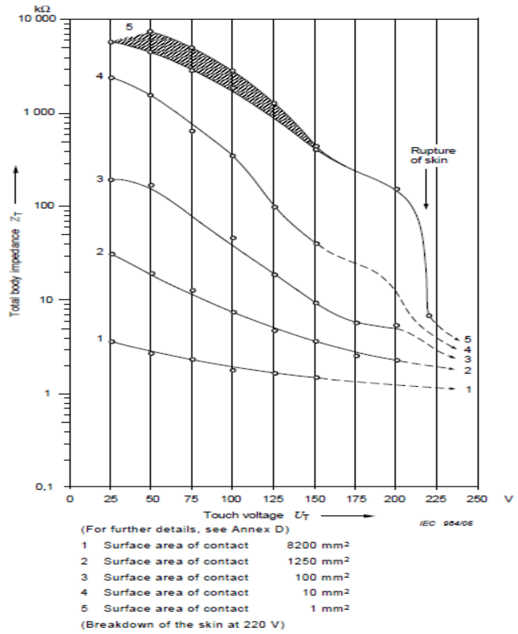


Fig. 7: Dependence of the total impedance ZT of one living person on the surface area of contact in dry condition and at touch voltage (50 Hz)

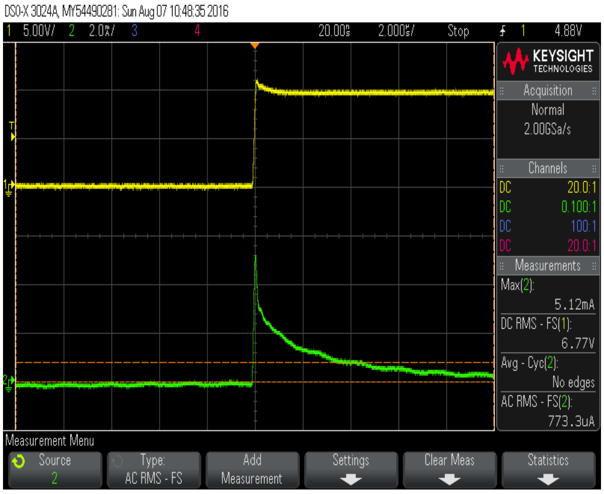
capacitance could not be bypassed, therefore, the skin impedance accounts for most of the human impedance and which is much larger than the internal impedance of the human body.

IV. Experimental Results

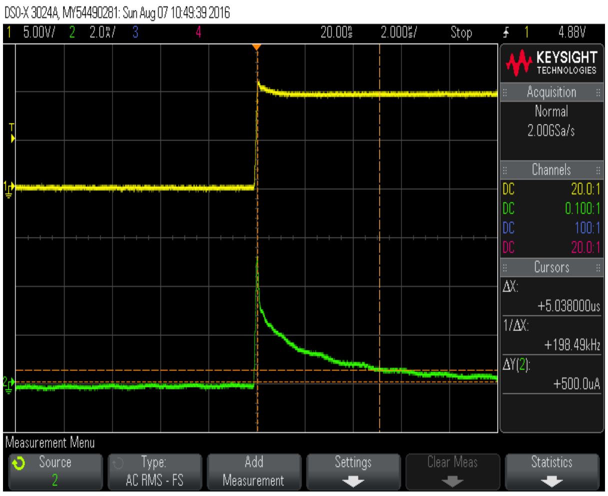
One human being's experimental data would be used to support that simplified RC model could be effectively analyse the data but doesn't affect the result.

In the experiment, the excitation power source is square wave, the voltage level is 10V, 18V and 25V, and frequency is from 50Hz to 20kHz. The pressure applied on the skin is 500g. The contact area is 100mm^2 and 10mm2. Fig. 8 Shows the peak current and discharging time of two human bodies are under 10V&50Hz excitation and 10mm^2

contact area. The definition of discharging time is when the current from maximum falling to the 90%. The peak current and pulse time has been collected and proceeded with different excitation voltage and frequency. as shown in Fig. 9. The internal resistance and capacitance have been calculated and shown in Fig. 10.

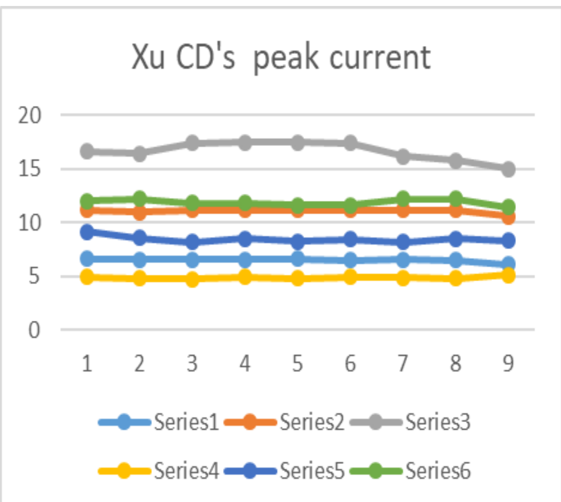


(a) Peak current of Xu CD

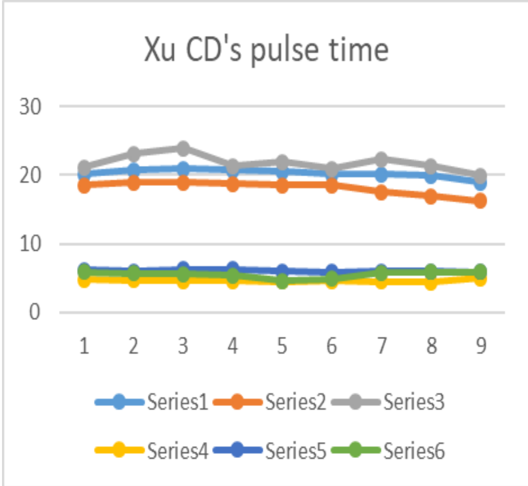


(b) charging time of Xu CD

Fig. 8: Peak current and charging time of XuCD

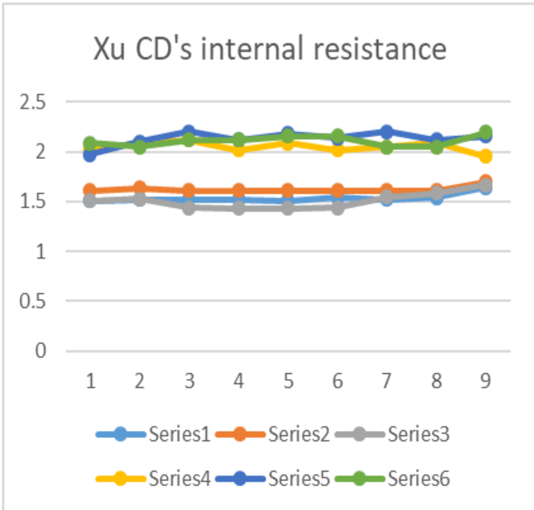


(a)Peak current of Xu CD

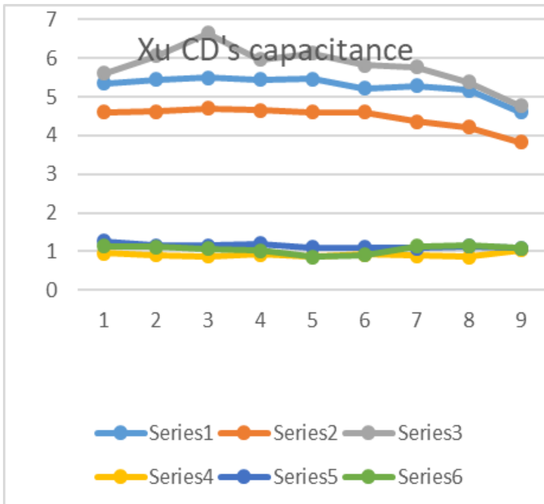


(b) charging time of Xu CD

Fig. 9: Peak current and charging time of XuCD with different excitation voltage and frequency.



(a)Internal resistance of Xu CD



(b)Capacitance of Xu CD

Fig. 10: Internal resistance and the capacitance of human body (nF and x-axis is the frequency changing with 50, 100, 200,500, 1k, 2k, 5k, 10k, 20k Hz)

1. Peak current and internal resistance

The peak current is stable for human body for differenct frequency. From a simplified human model, the internal resistor could be calculated and shown in Fig. 10 from ip=V/R_{int}, as ip is stable in the different frequencies, Rint is a constanct value and range from 1.4k ohm to 2.2 k ohm. The internal resistance is steady around 1.5k ohm when the contact area is 100mm^2. When the contact area is 10mm^2, the internal resistance is steady around 2.0 k ohm with diffrennt frequency, which increase with the contact area decreasing.

2. The pulse time and capacitance

The pulse time of the human body are also shown in Fig. 10. The pulse time is constant when the contact area is 10mm^2. The capacitance could be calculated and shown in Fig. 10. As shown in Fig. 10, the human body's capacitance is increase with the contact area. And when the contact area is 10 mm^2, most of human body's capacitance is around 1 nF.

V. Conclusion

A simplified human model was analysed based on IEC standard. By testing 11 human subjects, the relative human body model and parameters could be find. As we can see from the testing result from Fig.9-11, we can know that the internal resistance and capacitance is very stable.

The internal resistance decreases with the contact area increasing, while the capacitance increases with the contact area increasing. Meanwhile, the resistance and capacitance of all human bodies are from 1.2k Ohm to 3.2k Ohm. And in order to obtain an internal resistance close to the real value, voltage with fast step up transient have to be chosen to apply the human body. Therefore, low voltage square wave was applied to human beings. Test results has reviewed human characteristics. Therefore, human can be identified from the other loads by the research.

References

[1] C Gabriel, A Peyman and E H Grant, "Electrical conductivity of tissue at frequencies below 1 MHz", Phys. Med. Biol. 54 , 2009, 4863–4878.

[2] A. van Boxtel, "Skin resistance during square-wave electrical pulsed of 1 to 10 mA", Med. & Biol. Eng. & Comput., 1977, 15, 679-687.

[3] Geojy Mathew, white paper, "Medical Devices Isolation- "How safe is safe enough".

[4] IEC standard TS 60479-1, Effects of current on human beings and livestock –Part 1: General aspects

[5] David T. Lykkem, "Square-wave analysis of skin impedance", Psychophysiology, Vol. No. 2, Sep, 1970, pp262-275.