A Novel Electric Shock Protection System Based on Contact Currents on Skin Surface

Ashutosh Saxena, Supratim Ray, and Rajiv K. Varma

Abstract—**A novel method for Electric Shock Protection by automatic disconnection of supply is presented. Contact currents, which occur when a person touches a conducting surface at higher potential, are used to detect if the person is receiving a shock. In case of shock, contact currents flow through various paths in the body including the skin surface, creating a potential difference on the skin surface.**

The circuit presented here, to be worn on human body just like a wristwatch, monitors this potential difference and signals another circuit through wireless communication to disconnect the power supply thus saving the person's life. It also provides protection when the person touches both the power conductors simultaneously, the case where GFCI fails. It performs satisfactorily for electrical shocks both with ac and dc power supplies.

Index Terms—**Contact Currents, Electric Shock, human body, Safety.**

I. INTRODUCTION

THE standard power supply used in homes and laboratories is 120V, 60Hz sinusoidal system in the United States and 220V, 50 Hz in India. An electrical contact with ungrounded conductor or with exposed conductive parts of electrical equipment as a result of fault in basic insulation (fig. 1) would result in an electric shock to the person. It could cause physical injury or death due to effects like ventricular fibrillation and respiratory arrest [1-4].

The protective methods [2,3] include equipment grounding, double insulation and methods based on automatic disconnection of supply. Following devices are known to provide protection by automatic disconnection of power supply, in event of ground faults resulting from insulation breakdowns or contact with ungrounded supply conductor:

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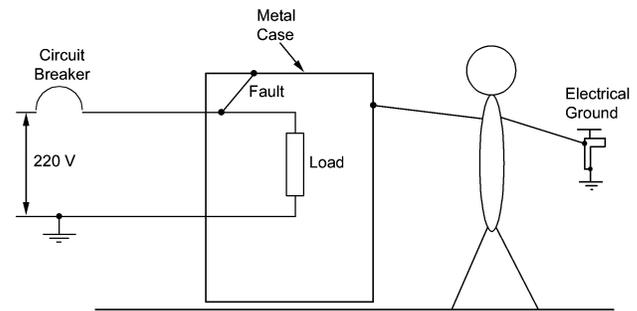

Fig. 1. Typical Electric Shock accident

A. Overcurrent protective devices [4]

The conductors are protected against overload by overcurrent devices such as fuses or circuit breakers (fig. 1). This circuit protection primarily protects wire insulation from overheating because of excess current. They offer no protection against electrocution where lethal current is about 100 mA [4].

B. Ground Fault Circuit Interrupter (GFCI) [3,4]

The difference in the current flowing between the power conductors (usually phase and neutral) serving a load is monitored. If the difference exceeds a predetermined level, it is assumed that the difference in current could be the current flowing through a person's body, and a circuit interrupter rapidly trips. They have the following limitations [3,5]:

1) Most GFCI's work only with alternating current supplies.
2) It cannot provide protection when the person touches both the power conductors simultaneously (fig. 2). In this situation, the current flows from one power conductor to another through victim's body; creating no difference in the current between two power lines. Thus, GFCI will not operate even if a large current passes through the victim's body.
3) They can be installed only in those electrical installations, which have two power conductors (usually the phase and the neutral). In some installations, neutral wire is either damaged or not installed. Here, only phase-line is connected, and the circuit is completed through ground-path. GFCI cannot work in these electrical installations.
4) There are problems due to nuisance tripping [5,6]. A
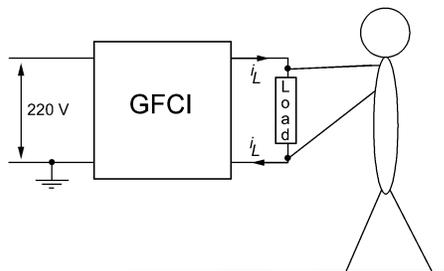
typical value for which the GFCI is set to trip is 6 mA.

Fig. 2. A situation when GFCI fails to operate.

Fig. 3. The proposed electric shock protection system

All the existing devices operate by observing the current flowing in the power conductors. Overload or imbalance in the current flowing in power conductors may or may not be directly related with the victim receiving electric shock. However, current flowing in the human body due to shock is a sure indication that the person is a victim of electric shock.

In this paper, we propose a novel method for electric shock protection (fig. 3). The circuit described in this paper, to be worn on human body, detects if the person is receiving an electric shock by observing the *current flowing on the surface of the skin*. This design can work in those installations also where only one power conductor is installed, the other being connected to ground. It works satisfactorily when shocks are caused by either alternating or direct current supplies. It further provides protection when the person touches both the power conductors simultaneously (fig. 2), the case when GFCI fails.

In case of electric shock, contact currents [1,7] flow through the human body. These currents flow through various paths like bone marrow, skin surface, etc. Current flowing through the skin surface produces a potential difference due to the impedance of the skin surface. This potential difference generated on skin surface is used to detect if the person is receiving a shock or not.

The Electric Shock Protection system consists of two parts-
1) Electric Shock Detector Circuit (E-lifebelt): This has to be worn on human body at a place like arm. This device is of the size of a wristwatch and does not give discomfort to the user.
2) Circuit to disconnect power supply: This is a conventional circuit breaker which opens the power circuit when signaled by E-lifebelt gadget.

This gadget is a personal protection system. After wearing the gadget 1) and installing 2), the supply will be disconnected automatically in case the wearer receives a shock. It can be installed as a personal safety gadget in a household, or can be used as a safety gadget for electricians who have a high risk of getting electric shocks.
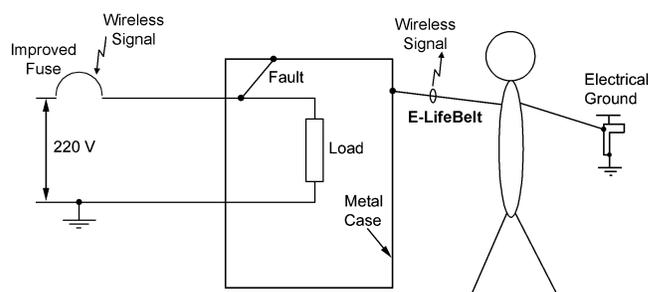
II. CONTACT CURRENTS IN HUMAN BODY

Contact currents [1] occur when a person touches conductive surfaces at different potentials and completes a path for current flow through the body. Depending on the magnitude of the current flowing and its frequency [4], the current can be lethal. Detailed studies have been done on current flow in human body [7,8] and sophisticated models of current flow have been developed [1]. From these investigations for 50/60 Hz currents on human body, current levels have been determined which cover the range of effects from the threshold of perception, let-go-current, ventricular fibrillation, and cardiac asystole [4]. It is generally agreed that it is the magnitude and time duration of the current passing through the body that causes a given effect. The touch voltage is only important insofar as it will produce a given current depending on the impedance in the circuit path. Death at voltages, like 120/220 V, can usually be attributed to ventricular fibrillation.

The threshold of perception for a finger-tapping contact is approximately 0.2 mA. The maximum allowed leakage current for appliances is 0.5 mA. Currents above 6 mA are considered as Let-Go current level [14]. This level is important because for currents above this level, the victim can be involuntarily held by his or her own muscles to the energized conductor and cannot let go. If a person is once frozen to a circuit, either he or she will get off and live; or he or she will not get off—the contact resistance may decrease and increase the current to a lethal level resulting in ultimately death. By extrapolation from experiments on animals [4], the safe current limit for victim to survive is 500 mA for shock of 0.2 seconds in duration and 50 mA for shocks longer than 2 seconds.

The flow of current in human body follows a very complex current density distribution depending on the properties of various body tissues. For understanding the working principle of the proposed device, consider a simplified model of current flow in human body as shown in fig. 4. In the E-lifebelt, three metal electrodes are placed along the direction of current flow in contact with skin surface. The elements shown in fig. 4 are defined as:

Z_s surface impedance of the skin between the electrodes.

Z_h　the impedance of the internal part of the hand (constituted by bone marrow, blood vessels, etc.) in parallel with skin surface impedance Z_s.

Z_b　human body impedance along with contact impedance.

V　supply voltage

I_B　current passing through the human body

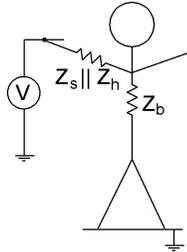V_S　potential difference sensed between the electrodes.

Fig. 4. A simplified model of current flow in human body.

The quantities are related as

$$I_B = V \left/ \left(\frac{Z_s Z_h}{Z_s + Z_h} + Z_b \right) \right. \qquad (1)$$

$$V_S = V Z_s Z_h / (Z_s Z_h + Z_h Z_b + Z_b Z_s) \qquad (2)$$

The electrical resistance (Z_b) of the body is made up of the internal body resistance (which is low), the skin resistance (which is usually high but varies greatly from person to person), and the contact resistance (which depends on the type and pressure of contact, humidity and the state of the surface of the skin: sweaty, wet). The typical values of surface impedance of skin between electrodes were between 30 kΩ and 2 MΩ. The minimum value of overall body resistance for a current path between hand and foot is generally accepted as being roughly 500Ω [5]. The experimentally measured potential between the two electrodes for AC shocks with 24 V (peak-to-peak) supply, was found to vary from 100 mV to 800mV (peak-to-peak)

This model suggests that the proposed device will work only for electric shocks in which electric current passes through hand on which gadget is worn. But owing to the complex flow of current in human body, some amount of current will be observed in every part of body, wherever the point of injection of the current is. The phenomenon that potential is observed in opposite hand, when shock is administered in other hand (with feet grounded), can be explained by making complicated computer models [1]. For understanding, consider the human body as a sphere with concentric layers having different conductivity. In such a case, potential gradients will be observed everywhere on surface of the sphere irrespective of the location of the two points of contact.

III. Design

The shock protection system consists of two parts:

1. Circuit to detect if the person is receiving an electric shock and emit wireless signals in case the person is receiving an electric shock.
2. A circuit breaker which receives the wireless signal and disconnects the power supply in case of shock. The signal receiver drives a relay that disconnects the power supply. This part of the system is called "Improved Fuse" and has to be installed in the main power supply.

The block diagram of the design is shown in fig. 7. The waveforms at various points in the gadget obtained for a typical experiment with ac shock are shown in fig. 6. The circuit for detecting the shock is depicted in fig. 8 and consists of the following components:

A. Electrodes

The electrodes (fig. 5) are in the base of E-lifebelt. They are in direct contact with skin surface. They are formed from three Copper tracks (each of area = 9*1.5 mm^2) on an etched Printed Circuit Board at a distance of 3 mm from each other. E_1 and E_2 provide input to the Differential Amplifier, while the third electrode G is connected to the ground of the circuit.

To ensure a proper electrical contact with the skin surface, the surface area of electrodes should be above a minimum value. As the separation between the electrodes is decreased, the amplitude of signal between the electrodes also decreases. Local skin effects (like sweat) may decrease this value further. A minimum separation between electrodes is required to keep the signal values reasonably above noise originating due to skin potential responses. Experimentally, the separation value of 3 mm was found to be suitable.
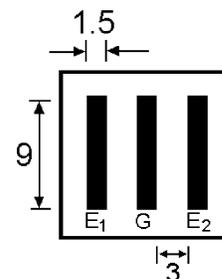

Fig. 5. The electrodes in direct contact with the skin surface. The black portions are the three Copper electrodes. All dimensions are in mm.

B. Buffers

The input from the electrodes is buffered to provide high input impedance. High input impedance is required because the impedance of the surface of the skin is itself very high.

C. Differential Amplifier

It is used to reject common mode signal between the two electrodes. Three electrodes are required because the amplifier is not an isolation amplifier. An isolation amplifier would have obviated the need of three electrodes; and the circuit could have a floating ground.

D. Filter

For shocks due to AC current, only the signal in the 50 Hz range is important. A shock due to DC current is in the form of a distorted step voltage, which has a 50 Hz component also. The filter consists of a bandpass filter at 50 Hz in parallel with a proportionate gain for DC shocks. The signal on the skin surface is contaminated with EMG (electromyogram) signals and other noise. The value of EMG signals is low in comparison to voltages due to electric shocks. Even though the filter rejects most of the out-band EMG signals and noise, placing the E-Lifebelt directly above a large muscle should be avoided.

E. Full Wave Rectifier and Local Peak Detector

The signal is full wave rectified to convert the bipolar signal to its absolute value. A local peak detector circuit, which detects local peaks in the waveforms, is used to smoothen the waveform (fig. 6). The output holds its voltage level at a peak until next peak arrives.

F. Threshold Detector and Signal Transmitter

Threshold Detector compares the output of the previous stage with an adjustable preset threshold voltage V_{th}. If the output of the Peak Detector Circuit is greater than threshold V_{th}, then it implies that the person is receiving a shock. In such a case a signal transmitter is activated to signal the improved fuse, so that the power supply is turned off to save the person's life. The signal transmission and reception was done by using a commercially available Frequency Modulated (FM) transmitter-receiver circuit. However, in actual installation, it may be required to license a frequency band depending on local regulations.

The values of the circuit elements are as follows:

$R_1 = 18k$	$R_2 = 180k$	$R_3 = 3.9k$
$R_4 = R_5 = 15k$	$R_6 = 1k$	$R_7 = R_9 = 39k$
$R_8 = 6.9k$	$R_{10} = R_{11} = 2.2k$	$R_{12} = 440k$
$C_1 = C_2 = 0.474\ \mu F$	$C_3 = 0.01\ \mu F$	D_1, D_2: Diodes
$X_1 - X_7$: OpAmp (LM324)		

The Improved Fuse consists of the signal receiver which drives the electro-mechanical power relay. The contact arrangement in the relay used (Matsushita JQ1AP-12V) is Normally Open (NO) and single pole single throw (SPST) with contact rating of 5A for 220V.
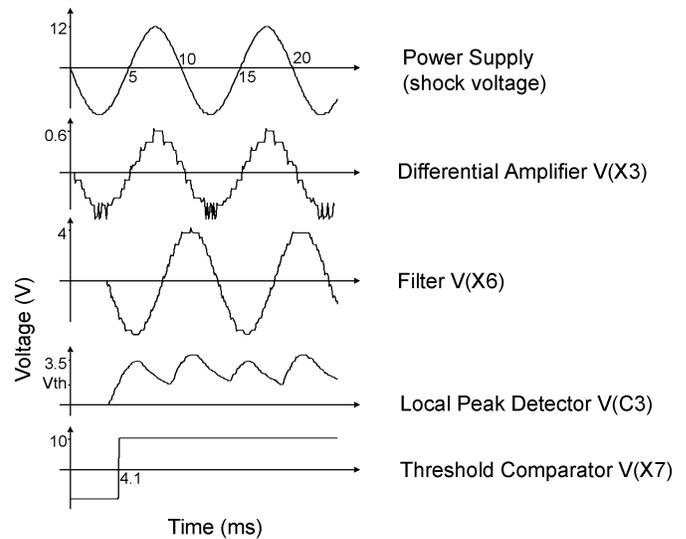

Fig. 6. Waveforms obtained for a typical experiment for AC shock at various points in the E-Lifebelt gadget. Path of contact current was B with gadget worn in left hand.
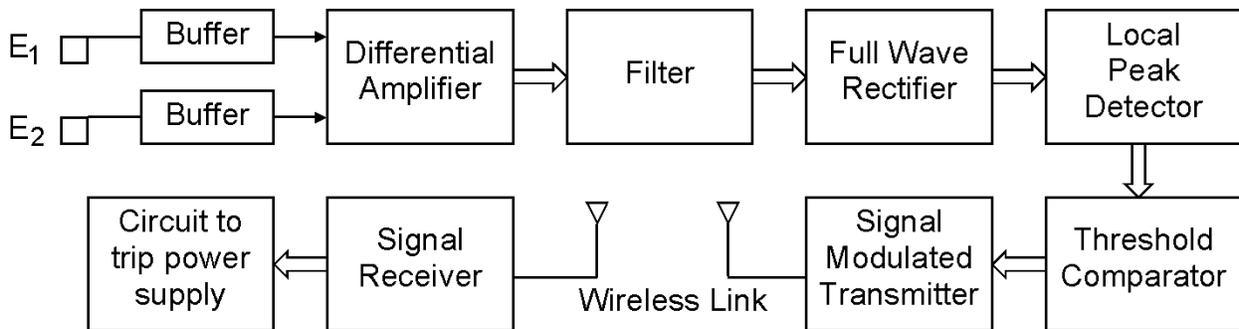

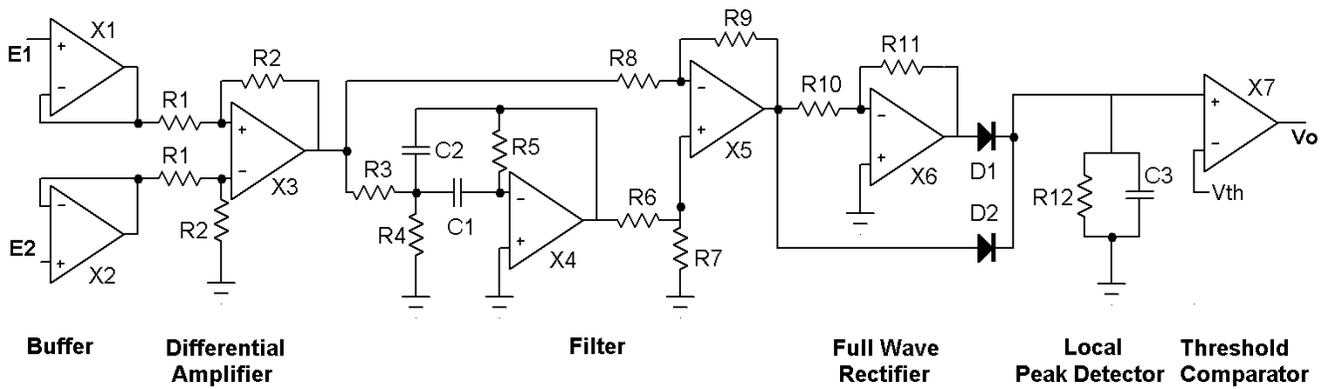Fig. 7. Block Diagram of the proposed electric shock protection system.

Fig. 8. Circuit Diagram of the E-Lifebelt gadget.

I. RESULTS

The tests were conducted on four subjects (Age: 19, 21, 26, 23; and Sex: M, M, M, F respectively) who voluntarily agreed for the tests and experience electrical shocks. The E-lifebelt gadget was worn either on left arm or on right arm. Experiments were performed for the following paths (fig. 9) of contact currents:

A. Hand to both feet
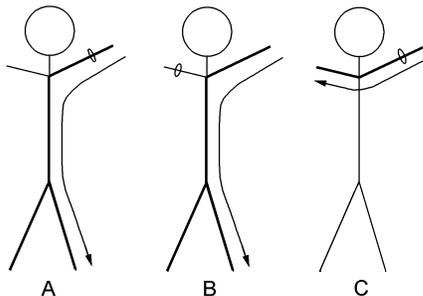B. Opposite hand to feet
C. Hand to opposite hand

Fig. 9. The three paths of contact currents considered

The experimental setup is shown in fig. 10. One power conductor is connected with fingers of the hand. For paths A and B, the subject stands on a conducting plate connected to the other conductor. For path C, the subject stands on insulator and touches the other conductor with his second hand. For alternating currents, shocks were received at 24V (peak-to-peak) through a step-down transformer. Shocks from direct current were obtained with 30V power supply. To administer electric shock the switch S is closed.
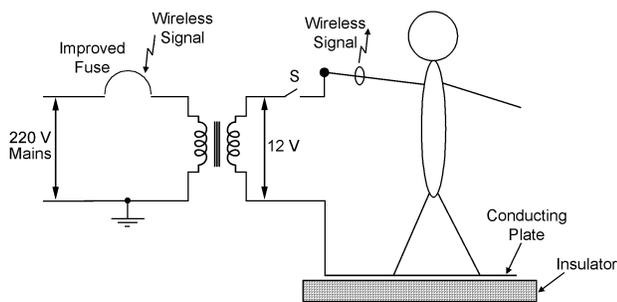

Fig. 10. The experimental setup (for shocks from AC power supply).

The total time taken by the system to trip the power supply consists of:
1) Delay in current transmission in the body from contact point to the place where gadget is worn.
2) The delay by the circuit to detect the shock.
3) Signal transmission time T_T from E-lifebelt gadget to the Improved Fuse.
4) Time T_R taken by the relay to trip the power supply.

The Detection time T_D is defined as the time of the activation of the signal transmitter after switch S is closed to administer the shock. This time T_D consists of delays in 1) and 2). Thus the total tripping time of the system can be symbolically expressed as

$$T = T_D + T_T + T_R \qquad (3)$$

The time delay T_T due to signal transmission is negligible. The time T_R taken by relay depends on the relay used. The maximum release time of the relay used was stated to be 4 ms.

The typical detection and tripping times obtained for AC shocks are shown in Table 1. The contact currents observed in these experiments were of the order of 0.5 mA. The probability distribution of the detection time T_D and the total tripping time T is shown in fig. 11 for AC shocks and in fig. 12 for DC shocks. The E-lifebelt gadget was worn alternately on left lower arm or right lower arm. Total 50 shock experiments were conducted each for AC and DC supply. Effect of moisture (sweat) on the skin was studied. The amplitude of the signal (at the electrodes) decreases for moist skin; and detection time increases slightly. The amplitude of the signal was more for Path C as compared to other paths A and B.

For AC shocks, the total tripping time T is 7 ms (average value), and 11 ms (worst case value). For DC shocks, tripping time is 4 ms (average value) and 7 ms (worst case value). The limits according to IEC 364-4-41 [2] are satisfied by this system.

TABLE 1
SHOCK DETECTION TIMES FOR AC CURRENT (TYPICAL VALUES)

S.N.	Subject	Path	Gadget Position	State of skin	T_D (ms)	T (ms)	Remarks
1	1	A	Left	Normal	2.8	7.6	-
2	1	B	Left	Normal	3.5	7.2	-
3	1	C	Left	Normal	2.2	5.8	Amplitude high
4	1	A	Right	Normal	2.9	6.3	-
5	1	B	Right	Normal	3.3	6.5	-
6	1	C	Right	Normal	2.3	6.3	Amplitude high
7	1	A	Left	Moist[1]	3.3	7.4	Amplitude low
8	1	B	Left	Moist[1]	3.1	7.4	Amplitude low
9	1	B	Right	Moist[1]	4.4	7.3	Amplitude low
10	2	A	Left	Normal	2.7	6.6	-
11	2	B	Left	Normal	3.1	8.8	-
12	2	A	Left	Moist[1]	3.2	5.8	-
13	2	B	Left	Moist[1]	4.2	8.1	-
14	3	A	Left	Dry	1.9	5.3	Amplitude high
15	3	B	Left	Dry	2.9	6.0	
16	3	C	Left	Dry	2.4	6.2	Amplitude high
17	4	A	Right	Normal	2.9	7.7	-
18	4	B	Right	Normal	3.3	7.4	-
19	4	C	Right	Moist[1]	2.7	6.4	-
20	4	B	Left	Moist[1]	2.8	5.7	-

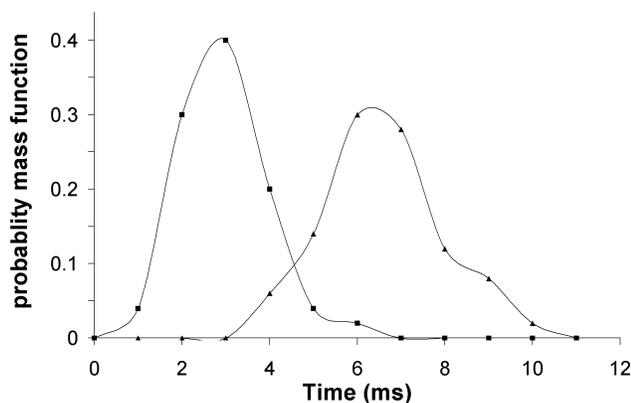[1]Moist only in the electrode region

Fig. 11. Probability distribution of Detection (■) and Tripping (▲) time for 50 experiments on AC shocks with 24 V (pp) supply.
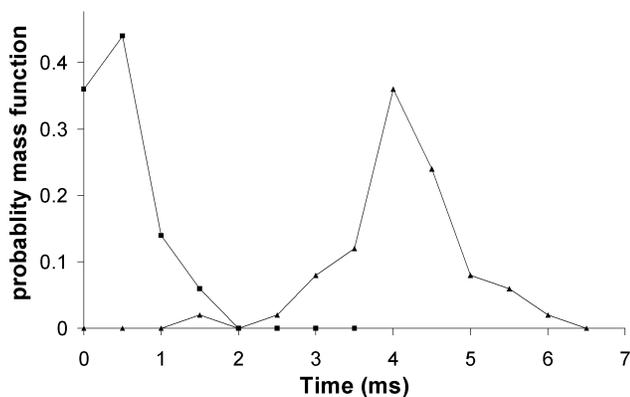
Fig. 12. Probability distribution of of Detection (■) and Tripping (▲) time for 50 experiments on DC shocks with 30 V supply.

II. DISCUSSIONS

The designed circuit detects the electric shock in one-fourth time of a complete AC cycle. The total tripping time of the system satisfies the limits according to IEC 364-4-41 [2]. The path of the current flowing through the body has a minor effect on the tripping time. Experiments were carried out with various states of the skin like oily, dry and wet; the device

functioning in each case. It performs satisfactorily for electrical shocks both with AC and DC power supplies. No interference was found to occur because of EMF in normal home and laboratory environments.

The tests are carried out at 30V for DC and 24V for AC and the device has been found to perform satisfactorily. The device will work whenever sufficient voltage is produced between the two electrodes. Extrapolating the present results, the device is also expected to work reliably at higher voltages, which are normally utilized in power distribution systems.

III. CONCLUSIONS

An elegant fast-acting wrist-worn shock detection device is proposed and tested for both AC and DC voltages. The device is found to work reliably thus ensuring the safety of the individual wearing the device. It is expected to be of value to technicians who work in electrically hazardous environments.

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