

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 in this paper. Contact currents, which occur when a person touches a conducting surface at higher potential, can be 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. This design also works in places where only one power conductor is installed, the other being connected to ground. It also provides protection when the person touches both the power conductors simultaneously. It performs satisfactorily for electrical shocks both with ac and dc power supplies.

Index Terms—Contact Currents, Electric Shock Protection, Safety

I. INTRODUCTION

AN electrical contact, whether directly with live parts in normal service or indirectly with exposed conductive parts of electrical equipment as a result of fault in basic insulation, could cause physical injury or other harm to persons [1-4]. The 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:

A. Overcurrent protective devices [4]

The ungrounded and grounded conductors are protected against overload by overcurrent devices such as fuses or circuit breakers in the ungrounded conductor. They offer no protection against electrocution where lethal current is about 0.1 amperes.

Ashutosh Saxena is a junior undergraduate in Department of Electrical Engineering, Indian Institute of Technology, Kanpur, India (e-mail: ashusax@iitk.ac.in).

Supratim Ray was a senior undergraduate in Department of Electrical Engineering, Indian Institute of Technology, Kanpur, India. He is now with the Biomedical Engineering Department, John Hopkins University, Baltimore, MD 21205 USA (e-mail: sray@bme.jhu.edu).

Rajiv K. Varma was with Department of Electrical Engineering, Indian Institute of Technology, Kanpur, India. He is now Associate Professor in the Electrical and Computer Engineering Department, University of Western Ontario, London, Ontario, N6A 5B9 Canada (e-mail: rkvarma@engga.uwo.ca).

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. GFCI works only with alternating current supplies.
2. It cannot provide protection when the person touches both the power conductors simultaneously.
3. They can be installed only in electrical installations, which have two power conductors (usually the phase and the neutral). In some installations, neutral wire is either damaged or not installed. In these, only phase-line is connected, the other one being connected to ground. GFCI cannot work in these electrical installations.
4. There are problems due to nuisance tripping [5,6].

In this paper, a novel design for electric shock protection by automatic disconnection of supply is presented. 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 also works in those installations where only one power conductor is installed. 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.

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 gadget): 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 (Improved Fuse): This is a conventional circuit breaker with a signal receiver built-in.

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

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 have been developed [1,9].

The simplified model of current flow in human body is shown in Fig. 1. In the E-lifebelt, two metal electrodes 8 mm apart along the direction of current flow are put in contact with skin surface. The elements shown in Fig. 1 are defined as:

- Z_1 the surface impedance of the skin between the electrodes.
- Z_2 the impedance of the internal part of the hand (constituted by bone marrow, blood vessels, etc.) in parallel with skin surface impedance Z_1 .
- Z_3 the human body impedance along with contact impedance.
- V Supply Voltage
- I_B Current passing through the human body
- V_S Potential difference between the electrodes.

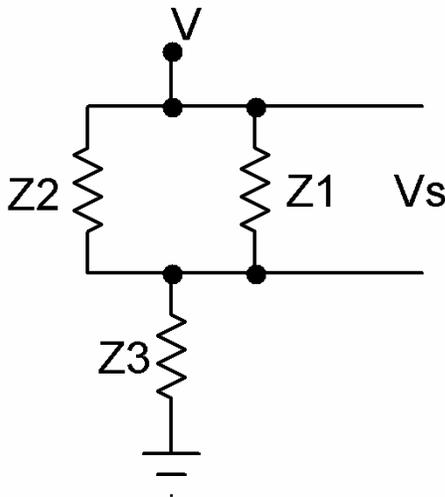


Fig. 1. The simplified impedance model of human body.

The quantities are related as

$$I_B = V / \left(\frac{Z_1 Z_2}{Z_1 + Z_2} + Z_3 \right) \tag{1}$$

$$V_S = V Z_1 Z_2 / (Z_1 Z_2 + Z_2 Z_3 + Z_3 Z_1) \tag{2}$$

The electrical resistance (Z_3) 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 12 V supply, was found to vary from 300 mV to 1V.

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. The potentials on the skin surface are contaminated with EMG (electromyogram) signals and other noise.
2. Circuit to receive the wireless signal and to disconnect the power supply in case a wireless signal is received. The output from the signal receiver circuit is used to drive a relay that disconnects the power supply. This part of the circuit is called “Improved Fuse” and has to be installed in the main power supply.

The block diagram of the design is shown in Fig. 3. The signal transmission and reception was done by using a Frequency Modulated (FM) transmitter-receiver circuit.

The design must ensure that –

1. It detects the shock in a minimum time.
2. It must be able to detect low amplitudes above noise.
3. It must not be false-triggered by noise.

The circuit for detecting the shock is depicted in Fig. 4 and consists of the following components:

1) Electrodes

The electrodes are in the base of E-lifebelt. They are in direct contact with skin surface. They are formed from two Copper tracks (area 9 mm * 1.5 mm) on an etched Printed Circuit Board at a distance of 8 mm from each other. They provide input to the Differential Amplifier.

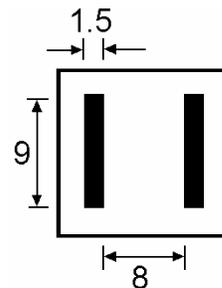


Fig. 2. The electrodes in direct contact with skin surface. The black portions are the two Copper electrodes. All dimensions are in mm.

2) Buffers

The input from the electrodes is buffered to provide high input impedance.

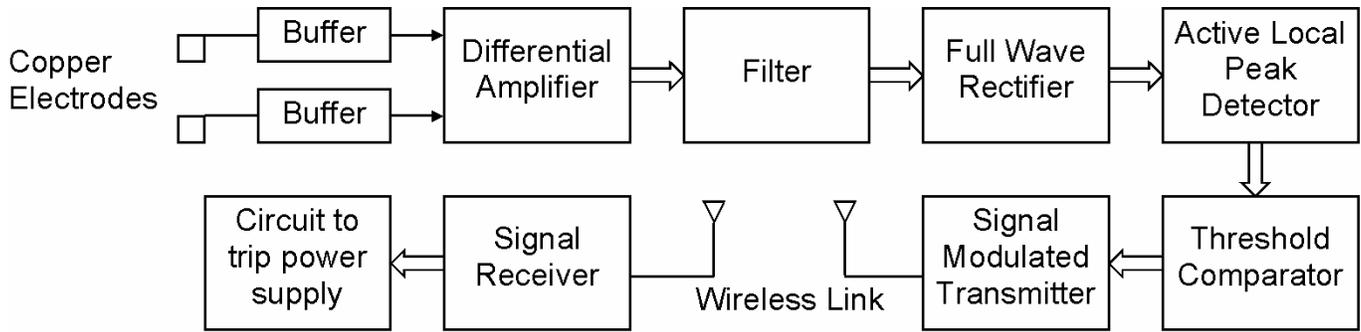


Fig. 3. Block Diagram of the Design.

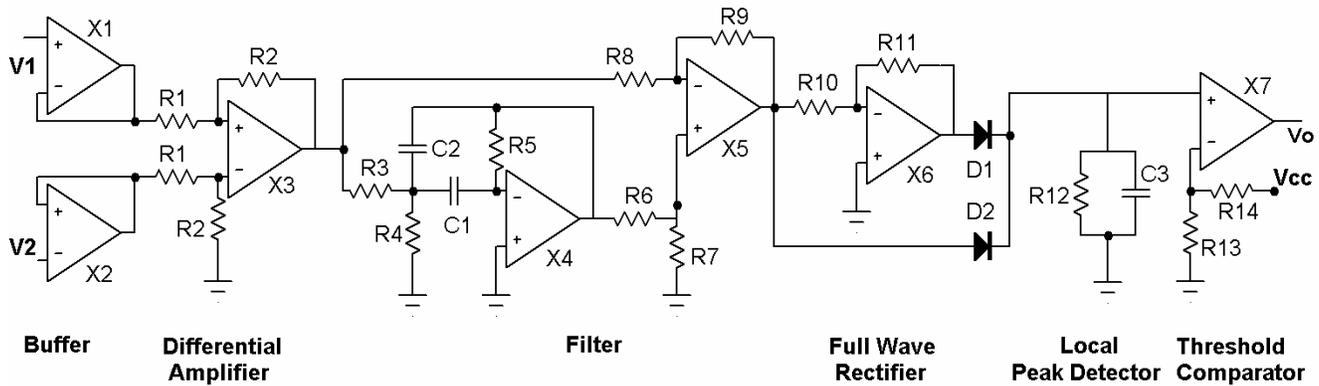


Fig. 4. Circuit diagram of E-lifebelt Gadget.

3) Differential Amplifier

It is used to reject common mode signal between the two electrodes.

4) 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 EMG signals developed that act as a noise for this system are rejected by this filter.

5) Full Wave Rectifier

The signal is full wave rectified so that circuit can operate in the negative cycle of AC current. The voltage drop due to diode does not matter; therefore, the circuit does not compensate for it to reduce component count.

6) Local Peak Detector

To smoothen the waveform, a Local Peak Detector circuit, which detects local peaks in the waveforms, is used. The output holds its voltage level at a peak until next peak arrives.

7) Threshold Detector and Signal Transmitter

Threshold Detector compares the output of Active Local Peak Detector with a preset threshold voltage. If the output of the Active Peak Detector Circuit is greater than threshold level, then it implies that the person is receiving a shock. In such a case a signal generator is activated to signal the improved fuse, so that the power supply is turned off to save the person's life.

The Improved Fuse consists of the signal receiver, the relay and the circuit to drive the relay to disconnect power supply.

IV. RESULTS

The tests were conducted on four subjects who voluntarily agreed for the tests and experience electrical shocks. The E-lifebelt gadget was worn on places like left/right lower arm. Shocks from Direct Current were obtained with 30V power supply. For alternating currents, shocks were received with 12V 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 at which output V_O of the threshold comparator is high after the shock is received. This time T_D consists of delays in 1) and 2). Thus the total tripping time of the system can be symbolically expressed as

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

The time delay T_T due to signal transmission is negligible. The time T_R taken by relay depends on the relay used. Solid-state relays of tripping time less than 1 ms are available. The

relay used in our experiments was a solid-state relay with a worst case tripping time of 2 ms.

The probability distribution of the detection time T_D is shown in Fig. 5 for AC shocks and in Fig. 6 for DC shocks. Experiments were performed for the following paths of contact currents:

1. Hand to both feet
2. Hand to opposite hand
3. Opposite hand to feet

The E-lifebelt gadget was worn alternately on left lower arm or right lower arm. A total of 50 shock experiments were conducted with each 12 volt ac supply and 30 volt dc supply.

For AC shocks, the total tripping time T is 5 ms (average value), and 9 ms (worst case value). For DC shocks, tripping time is 2 ms (average value) and 3 ms (worst case value). The limits according to IEC 364-4-41 [2] are satisfied by this system.

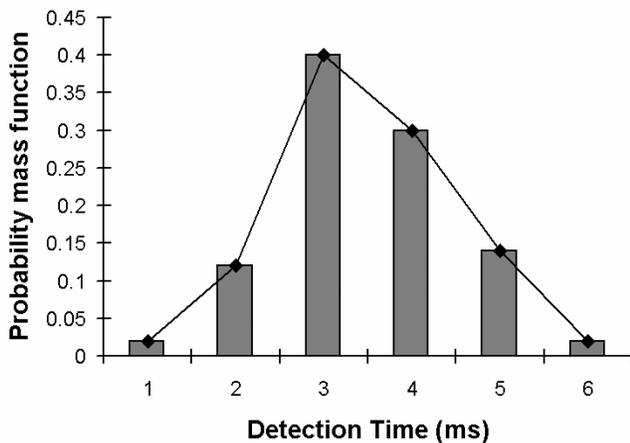


Fig. 5. Probability distribution of Detection Time (ms) for 50 experiments on AC shocks with 12 V supply.

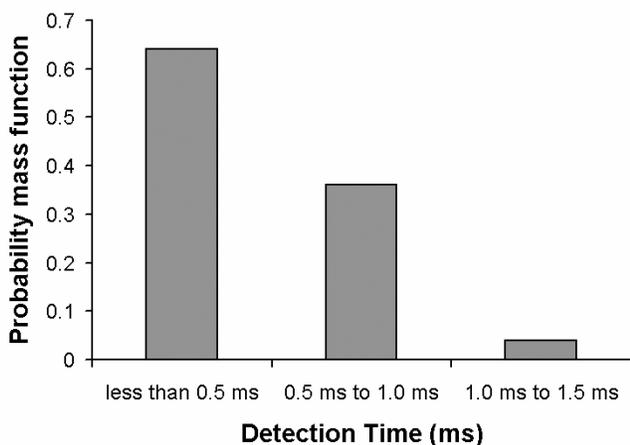


Fig. 6. Probability distribution of Detection Time (ms) for 50 experiments on DC shocks with 30 V supply.

V. 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.

The tests are carried out at 30V for DC and 12V 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.

VI. 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.

VII. REFERENCES

- [1] Trevor W. Dawson, Krys Caputa, Maria A. Stuchly, and R. Kavet, "Electric Fields in the Human Body Resulting From 60-Hz Contact Currents", *IEEE Transactions of Biomedical Engineering*, vol. 48, no. 9, September 2001.
- [2] Giuseppe Parise, "A Summary of IEC Protection Against Electric Shock", *IEEE Transactions on Industry Applications*, vol. 34, no. 5, September 1998.
- [3] LaRocca, R.L., "Personnel Protection devices for use on appliances", *IEEE Transactions on Industry Applications*, vol. 28, issue 1, part 1, Jan.-Feb. 1992.
- [4] Theodore Bernstein, "Electrical Shock Hazards and Safety Standards", *IEEE Transactions on Education*, vol. 34, no. 3, August 1991.
- [5] Biegelmeier G., "Discrimination and nuisance tripping of residual current operated devices in domestic and similar installations", *Proceedings of Third International Conference on Installation Engineering Designing and Maintaining Successful System*, 1988.
- [6] Brennan, P.V., "Residual Current Devices with high immunity to nuisance tripping", *IEE Proceedings on Circuits, Devices and Systems*, vol. 140, issue 2, April 1993.
- [7] F.P. Dawalibi, R.D. Southey, and R.S. Baishiki, "Validity of Conventional Approaches for Calculating Body Currents Resulting from Electric Shocks", *IEEE Transactions on Power Delivery*, vol. 5, no. 2, April 1990.
- [8] Magda S. Hammam and Rod S. Baishiki, "A Range of Body Impedance values for Low Voltage, Low Source Impedance Systems of 60 Hz", *IEEE Transactions on Power Apparatus and Systems*, vol. PAS-102, no. 5, May 1983.
- [9] Trevor W. Dawson, Kris Caputa, and Maria A. Stuchly, "High Resolution Organ Dosimetry for Human Exposure to Low-Frequency Electric Fields", *IEEE Transactions on Power Delivery*, vol. 13, no. 2, April 1998.