Voltage Based Electronic Fuse for Safety from Short-Circuit Currents Based on Ohm's Law

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***Abstract*— This paper introduces a newly developed electronic fuse circuit namely "voltage based electronic fuse circuit" for the purpose of providing safety to electrical equipments from the short-circuit currents. The design and the working of this circuit is wholly based on Ohm's law. Also in this paper, working and operation of the fuse circuit is examined in detail with the help of simulated results. Further these results are supported by the technical experimental results. The simulated results and experimental results are validated by user defined measurements and Voltage based Electronic Fuse circuit simulation is done by using NI multisim software 11.0.1 and the respective output characteristics are plotted. This model can be used as a safety device in the place of circuit breakers and electrical fuses and to reduce cost, size and also to increase reliability, control of electric energy and speed action of closing and opening of circuit automatically when fault is occurred.**

Keywords— ***Electronic fuse, Voltage based electronic fuse, Electric fuse, Short-circuit currents, Regulated DC Power Supply(RPS), OP-AMP 741, BC 107 IC, 7408N IC .***

I. Introduction

Fuses are of very high interest for electrical safety purposes both for persons and systems and widely used in the low and middle voltage systems[1].In spite of the efforts made for the development in the electrical safety circuit systems, several accidents are witnessed in the both domestic and industrial sectors due to short-circuit currents. To provide safety from such hardships and fatal accidents, steps have been in progress to develop self functioning safety circuits and methods [2][3]. In this present paper a more safety and accurate functioning voltage based electronic fuse circuit is designed and experimentally tested on the basis of Ohm's law and it may be considered as a better safety circuit than the existing electrical safety devices and methods. It is very clear that for every safety device like fuse, it is a must to be considering not only the materials and methods but also the construction of fuse [4].This paper also clearly deals with the technical content recorded from the lab experimental study which supports the simulation results.

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II. Voltage based Electronic Fuse – Application of Ohm's Law

The electronic circuit is designed with a firm intension to provide safety to electrical equipments and other circuits. The supported results are obtained from the simulated circuit, and the model of the proposed circuit is given in fig.1.

According to Ohm's law, the current through a conductor between two points is directly proportional to the potential difference across the two points. Introducing the constant of proportionality, the resistance, [5] one arrives at the usual mathematical equation that describes this relation. [6].

$$I(current) = \frac{V(voltage)}{R(resistance)}$$

In a balanced system each line will produce equal voltage magnitudes at phase angles equally spaced from each other.

$$V_1 = V_{LN} \ at \ 0^\circ$$

$$V_2 = V_{LN} \ at \ -120^\circ$$

$$V_3 = V_{LN} \ at + 120^\circ$$

Whereas current ratings are

$$I_1 = \frac{V_1}{|Z_{total}|} \ at \ angle \ (-\theta)$$

$$I_2 = \frac{V_2}{|Z_{total}|} \ at \ angle \ (-120^\circ - \theta)$$

$$I_3 = \frac{V_3}{|Z_{total}|} \ at \ angle \ (120^\circ - \theta)$$

Where Z_{total} is the sum of line and load impedances and θ is the phase of the total impedance (Z_{total}).

The electric power 'P', in watts produced by an electric current *I* consisting of a charge of *Q* coulombs every *t* seconds passing through an electric potential (voltage) difference of *V* is

$$P = \frac{Q}{T} V = IV$$

Where

Q is electric charge in coulombs.

T is time in seconds.

I is electric current in amperes.

V is electric potential or voltage in volts.

In the case of resistive (Ohmic, or linear) loads, Joule's law can be combined with Ohm's law ($V = I·R$) to produce alternative expressions for the dissipated power.

$$P = I^2 R = \frac{V^2}{R}$$

Where *R* is the electrical resistance.

The real power ***P*** in watts consumed by a device is given by

$$P = \frac{1}{2} V_p I_p \cos\theta = V_{rms} I_{rms} \cos\theta$$

Where

$\boldsymbol{V}_p$ is the peak voltage in volts

$\boldsymbol{I}_p$ is the peak current in amperes

$\boldsymbol{V}_{rms}$ is the root-mean-square voltage in volts

$\boldsymbol{I}_{rms}$ is the root-mean-square current in amperes

$\boldsymbol{\theta}$ is the phase angle between the current and voltage sine waves.

In case of supply, the real power is as follows

$$P = \sqrt{3} \times (\frac{1}{2} V_p I_p \cos\theta)$$

$$P = \sqrt{3} \times (1 - \emptyset\ real\ power)$$

Hence from the above discussions, it is evident that if there is a change in current value, then there must be a change in the voltage value and the difference in both voltage and the current values leads to the difference in power rating. Therefore, at the time of short-circuit a large current variations take place and then the respective voltage values are observed. The voltage based electronic fuse thus works depending on such changes in voltage.

The circuit design of Voltage based Electronic Fuse is illustrated in fig.1.In the circuit an A.C source electrical equipment is taken and the proposed voltage based electronic fuse is placed in between the supply and load, shown in fig.1.The voltage based electronic fuse consists of an AC-DC converter circuit for the operation of electronic IC's. The operational amplifiers 1 and 2 compare the DC voltages between the converted voltage and to the reference voltage. These compared outputs are connected to an AND-gate which will give the required operation action either to open or close the connection in between the supply and to the load.

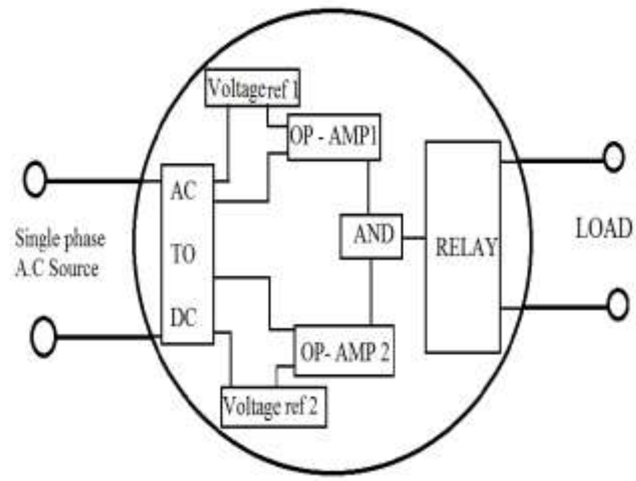

Figure 1. Model of Voltage based electronic fuse.

The open and closing of the circuit is done by the solenoid type relay. If the AND-gate enables high then the relay closes the circuit connection and passes the supply through it, else in case low, the relay opens the circuit. In any operation electronic components perform high speed of response with respect to the time. Hence at the time of short-circuit a large variation currents are seen and drawn by the connected load or equipment. Then this will be compensated by the rapid fast action of the electronic components in the voltage based electronic fuse and the damages take place by such dangerous faults or short-circuit currents are avoided.

A. ***Simulation Results***

The simulation results and their respective DC sweep analysis characteristics, response of close and opening operation with output voltages of OP-AMP 1, 2 are shown in fig.2-5.The voltage based electronic fuse circuit is designed and tested by considering single phase A.C supply as the input in both ON and OFF condition with voltage range 220V-240V,shown in fig.2 and fig.4. The required A.C source is provided by the function generator in the simulation. The AC-DC converter is shown by the arrangement of step down transformer with turn's ratio of 41 along with a rectifier circuit in order to get pure DC supply from the connected A.C source. At the beginning the voltage reference values V1 and V2 are to be determined for design the voltage based electronic fuse to a required equipment or load. The voltage references can be obtained by giving the minimum and maximum voltage ranges of the supply connected to the equipment.

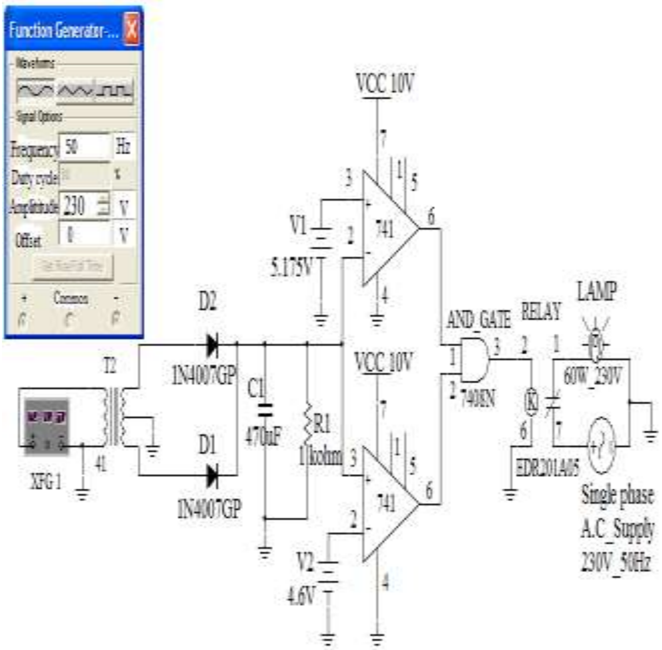

Figure 2. Voltage based Electronic Fuse circuit ON condition.

If the minimum supply voltage is connected then the minimum voltage reference value V2 is derived by measuring DC supply at the rectifier output and that value is given as a fixed input to operational amplifier-2, whereas the voltage reference V1 is derived by respective DC voltage at the output of rectifier circuit when maximum supply voltage is given.

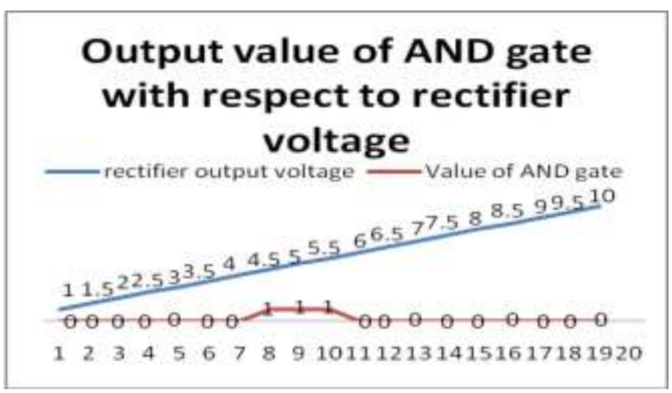

Figure 3. Output of AND-gate with different rectifier output voltage values.

The voltage V1 is a fixed input to the operational amplifier-1.Hence providing reference voltages accurately, a range can be defined for the input supply. In between the specified range the voltage based electronic fuse allows the supply to the connected equipment or to the load, if the incoming supply is not in the defined range then the voltage based electronic fuse will perform its operation and disconnects the supply path from the source to the load. The other two inputs of both operational amplifiers-1 and 2 are taken with the output of the converted DC voltage at the output of rectifier circuit.

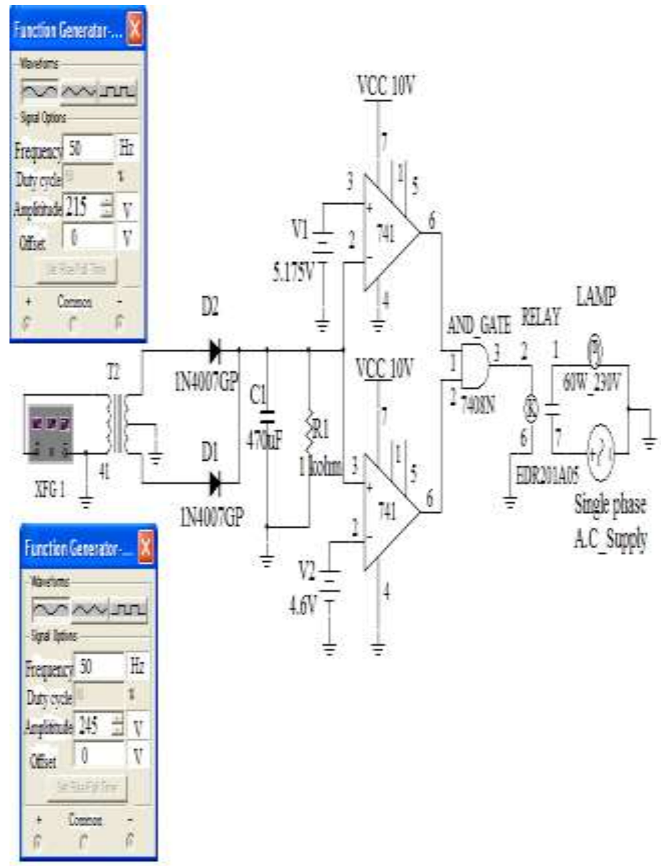

Figure 4. Voltage based Electronic Fuse circuit OFF condition.

At the two operational amplifiers a comparison between reference voltages to the rectifier output voltage takes place and the obtained results are connected as inputs to the AND-gate 7408N IC. If the value given by the rectifier output to the operational amplifier-1 and 2 is in the specified range of voltage reference then both the operational amplifiers produce the VCC voltage at the output. The 7408N IC AND-gate takes the input as in digital format and depicts high value as 1, low as 0.If the outputs of both the operational amplifiers-1, 2 are within the range and gives VCC at output terminals, then the AND-gate is going to be considered those two values as high and gives output, else if any one of the output value of OP-AMP is low then 7408N IC doesn't creates an output. The output of 7408N AND-gate IC is given to perform opening and closing action of the circuit with the help of solenoid type relay. Hence one end of the relay is connected to the 7408N AND-gate of the voltage based electronic fuse circuit and other end is provided for the required equipment which is to be protected. The AND-gate performs the operation of relay with the comparative result obtained of the op-amp-1, 2 either closing the circuit and provides path in between supply to the equipment or open the path and provides safety for the equipment.

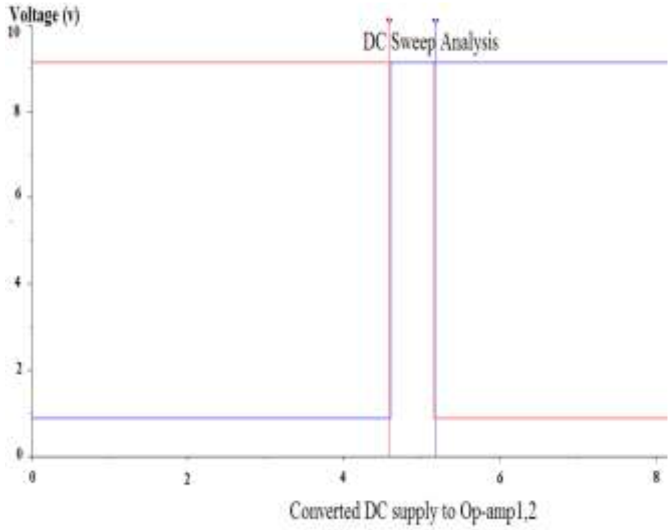

Figure 5. DC Sweep analysis between rectifier output, OP-AMP voltages.

The output characteristics of 7408N AND-gate IC is discussed in fig.3 with the various values of rectifier DC output voltage, shown in table.1.

TABLEI. OUTPUT CHARTERSTICS OF 7408N IC

Rectifier Output voltage(V)	7408N AND-GATE Output
1	0
1.5	0
2	0
2.5	0
3	0
3.5	0
4	0
4.5	1
5	1
5.5	1
6	0
6.5	0

The above table clearly explains the output characteristics of the AND-gate in which the output enables high in the range of 4.5v to 5.5v. From fig.2 and fig.4 the voltage reference ranges are defined in between 4.6v to 5.175v and in that period only the 7408 AND-gate IC gives 1 as output, shown in the table.1.In fig.5 the DC sweep analysis of the designed circuit is explained by taking the output variables as operational amplifiers 6th - terminal voltage and voltage of the rectifier output, as shown in table.2. The DC sweep analysis is determined on the basis of fig.2 and fig.4, in which the voltage VCC is appeared across the output terminals of the operational amplifier-1, 2 in between the range of 4.6v to 5.175v and in other remaining voltage range of the supply, the output of OP-AMP1, and 2 is zero, shown in table.2.

TABLEII. DC Sweep Analysis

Rectifier Voltage(V)	Output Voltage(v) of OP-AMP-1,2
0	0
2	0
4	10
6	10
8	0

B. *Experimental Results*

The voltage based electronic fuse circuit is constructed by the experimental method and tested on the basis of Ohm's law. The technically supported experimental results are obtained by the experiment and the structural arrangement of the voltage based electronic fuse circuit is constructed on the bread board, shown in fig.6.

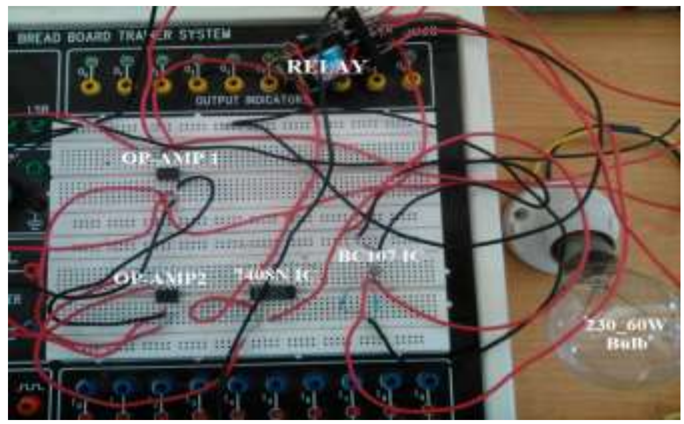

Figure 6. Voltage Based Electronic Fuse Circuit.

The total construction of fuse circuit is represented in the block diagram and the conversion of A.C to D.C supply in lab experiment is done by the regulated DC power supply (RPS), shown in fig.7.

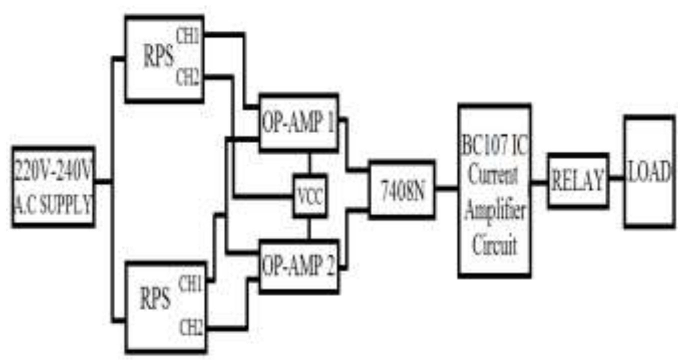

Figure 7. .Block representation of voltage based electronic fuse circuit experimental process.

The two RPS ch1, ch2 channels are connected to the voltage reference values v1, v2 and for input, VCC voltages of op-amp 1, op-amp2.The given range of the A.C supply is in between 220V-240V, assume the converted d.c voltage range for the voltage based electronic fuse circuit of voltage reference V1 is

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3.9V to voltage reference V2 is 6V instead of 4.6V to 5.175V as per simulation results, due to instability of RPS d.c voltage in the lab experiment. If the converted supply d.c voltage is in between 3.9V to 6V range then the relay closes the circuit and allows the supply from source to the load, else the relay opens the circuit. In this lab experimental process a BC 107IC transistor circuit is used for amplification of current from micro to milli-amperes range for the functioning of relay. If the converted input d.c voltage is below or above the specified voltage range even with the point variations the voltage based electronic fuse is in open condition, shown in fig.8 and fig.9.If the converted input d.c voltage is in between 3.9V to 6V then voltage based electronic fuse closes and passes supply to the 230V_60W bulb.

Figure 8. Voltage based electronic fuse circuit operation below the specified voltage range. (Off Condition)

Figure 9. Voltage based electronic fuse circuit operation above the specified voltage range. (Off Condition)

The above two voltage based electronic fuse circuit connections shown in fig.8 and fig.9 are applied with the 3.8V, 6.1V and the respective relay operation is observed. The connection between the supply to the load is in the open condition and provides safety to the bulb connected as load. The voltage input within the specified voltage range of the 3.9V to 6V operates the voltage based electronic fuse in ON condition, where the relay closes the circuit and provides the supply to the load, shown in fig.10. Hence from these observations the voltage based electronic fuse circuit is operated in ON condition if the converted d.c input voltage is within the specified range, for other input d.c voltage values the voltage based electronic fuse is in OFF condition, due to the changes in the supply voltage when short-circuit current occurs.

Figure 10. Voltage based electronic fuse circuit operation in between the specified voltage range. (On Condition)

III. Conclusion

It can be concluded that the time taken by an electrical safety device must be minimum when fault occurs to avoid damage from short-circuit current. The designed and constructed voltage based electronic fuse significantly provides safety, if the supply is not within the minimum and maximum voltage range of the load. Even with point variations in the supply this fuse circuit provides accurate and fast response for the safety of the load. From the simulation and the lab experimental results, this paper very clearly supports the concept of voltage based electronic fuse.

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