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APPLICATION OF BJT AS A BIDIRECTIONAL SWITCH FOR LOW VOLTAGE CIRCUIT PROTECTION

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ABSTRACT

In this paper the function of an all electronic circuit breaker has been demonstrated. Till recently the alternatives to electromechanical and magnetic circuit breakers are very few. Solid state devices are reliable and have high life time. This circuit breaker is demonstrated with BJT as a bidirectional switch. The operation of the bidirectional switch is analyzed for different operating conditions to determine the limitations of this design. Bidirectional switches with TRIAC, IGBT are commercially available however circuit breaker with BJT as a bidirectional switch is a new approach for low voltage circuit protection.

Keywords: electronic circuit breaker, BJT, bidirectional switch, sense resistor, base control voltage, on resistance, circuit simulation.

INTRODUCTION

Circuit breakers protect electrical circuitry from damage due to an over current condition, such as a relatively high level short circuit or fault condition. Circuit breakers act as protecting switches capable of connecting and allowing currents to flow through loads under normal circuit conditions and disconnecting the load under specified abnormal conditions such as a short circuit. Electronic Circuit Breakers generally use electromechanical switches. The conventional circuit breaker is connected in series with the supply so the response time of the circuit breakers is a very important performance parameter [1]. Since this switch has to work with AC rather than DC the conduction characteristics of the switch must be the same in both the directions. One can think off semiconductor devices that results bidirectional and symmetrical characteristics. The circuit breaker designed with Solid state technology has free from arcing and switch bounce. [2-5] Solid State Circuit Breakers have reduced switching surges and high reliability. Many types of power devices like IGBTs, BJTs and MOSFETs are available with different specifications. Most of the electronic circuit breakers are designed with IGBTs for fast acting and low losses [6-10]. However, the IGBT still requires large drive current. But the choice of technology for a power switch is not always clear cut. Whilst MOSFETs have become the default choice for many designers, bipolar transistors have many useful attributes which can be used beneficially in certain applications. Understanding the technological and parametric differences between MOSFETs and bipolar transistors is key to making the right choice for a given application. Higher voltage MOSFETs also suffer from the high resistance of the lightly doped drain region, and according to theory on-resistance typically increases with breakdown voltage according to the relationship

$$\mathbf{RDS\ (on) \propto BV^{2.6}}$$

Over the same period bipolar transistors have developed too and given appropriate drive conditions have matched or bettered MOSFETs in terms of die area specific on-state resistance. By careful optimization of process and chip layout, voltage biasing and current flow is evenly distributed across the chip area, leading to better silicon utilization. Furthermore, when a bipolar transistor is operated as a saturated switch the collector base junction becomes forward biased and results in minority carrier injection into the resistive collector region as the collector-emitter voltage collapses to its VCE (sat) value. The lowest attainable on-state voltage or conduction loss is governed by the collector-emitter saturation voltage V_{CE} (sat). The MOSFET and BJT is certainly the device of choice for device breakdown voltages below 250V. However, choosing between BJTs and MOSFET s is very application-specific and cost, size, speed and thermal requirements should all be considered [6]. BJTs are very much suitable for low voltage applications. This circuit results a fast turn off time in the range of few micro seconds as opposed to milliseconds for a mechanical circuit breaker. The present work progresses an all electronic circuit breaker based on BJTs especially suited for low voltage application switch.

WORKING OF CIRCUIT BREAKER

An all electronic Circuit Breaker has been designed to connect a load and an ac voltage supply. This circuit basically requires a bidirectional switch that allows ac voltage, a sense resistor and a decision making circuit connected in series with the load. The bidirectional switch is needed to connect the source to the load both for the positive and negative half cycles of the input voltage under normal conditions. The bidirectional switching is performed by two BJTs. A sense resistor connected between the two transistors determines the voltage that has to be applied to the comparator and is used to determine the output of the decision making circuit which further disconnects the power supply from load when a fault

occurs. The control signal from the output of the decision making circuit controls the base drive of the bidirectional switch. When the circuit works normally the BJT is in saturation mode and so the load is connected with the source. Under any faulty condition the output of the decision making circuit goes low then base voltage drives the BJT to cutoff region. Therefore the load has to be now disconnected from the source. The output of the comparator is connected back to the base of the two transistors. Figure-1 shows the block diagram of proposed solid state ac circuit breaker. In order to fully evaluate the performance of this switch, the operation of the device will be discussed for various conditions.

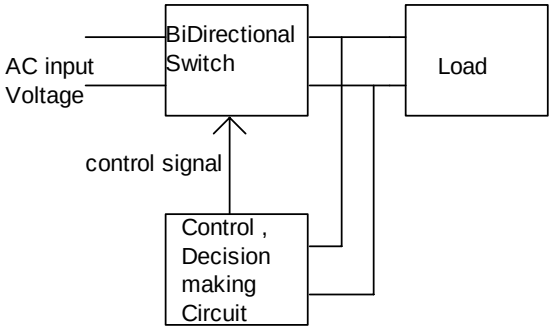

Figure-1. Block diagram of the circuit breaker.

DESIGN AND APPLICATION

The electronic circuit breakers specifications include rated ac voltage, rated dc voltage, continuous current rating, and rated breaking capacity (I_{cn}). In this design the input power supplied to the load is controlled by the bidirectional switch. It is required to turn off the switch when a fault is identified or the input voltage exceeds beyond the rated value to safeguard the load. Under normal conditions the switch connects the input ac voltage to the load. Otherwise the switch completely disconnects the load from input. The voltage drop across the small sense resistor is sampled and applied to the comparator and the output of comparator controls the base of the BJT. Operational amplifier is used as comparator. In this circuit the comparator and the latch is powered from the same power supply. The required power supply to the operational amplifier is derived either from a separate battery or from the ac input it self. In the second case an isolation Transformer and a rectifier with a filter is needed. The comparator compares the voltage drop across the sense resistor with a reference voltage. Since the comparator compares the dc voltages the sense voltage is connected to the comparator through a diode and RC network. The output of the comparator is given to a bistable latch. The output of this latch is high as long as the comparator output is high and provides the required base bias to the transistor. Under normal condition the comparator output is high so the base gets the required biasing voltage and the ac input is coupled to the load. When a fault occurs the high voltage across the sense resistor crosses the threshold voltage therefore the comparator output is low and the latch now goes to a low output state thus switching OFF the transistor. This turn off switching time must be shorter than the rise time of the circuit. The BJT switching time is determined by its impedance and capacitances. Therefore, for fast switching, lower driving source impedance is required.

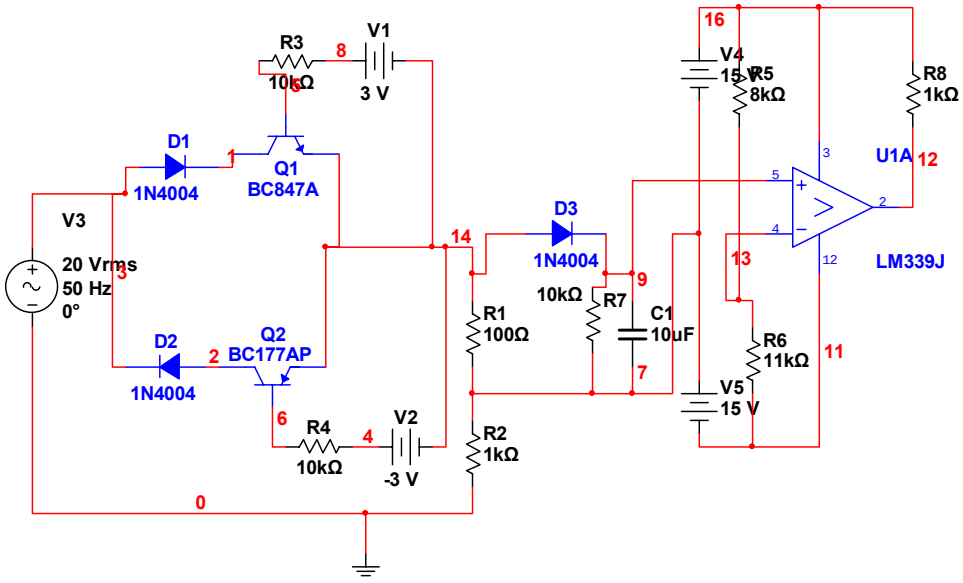

Figure-2. Circuit breaker with BJTs.

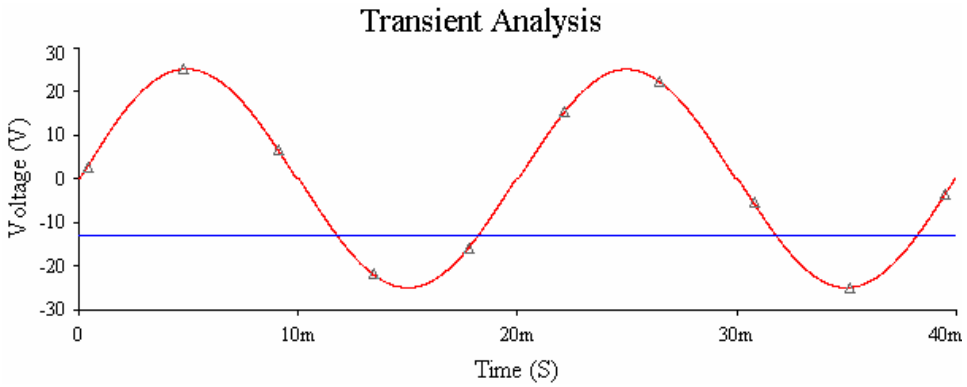

Figure-3. Response of the circuit under normal condition.

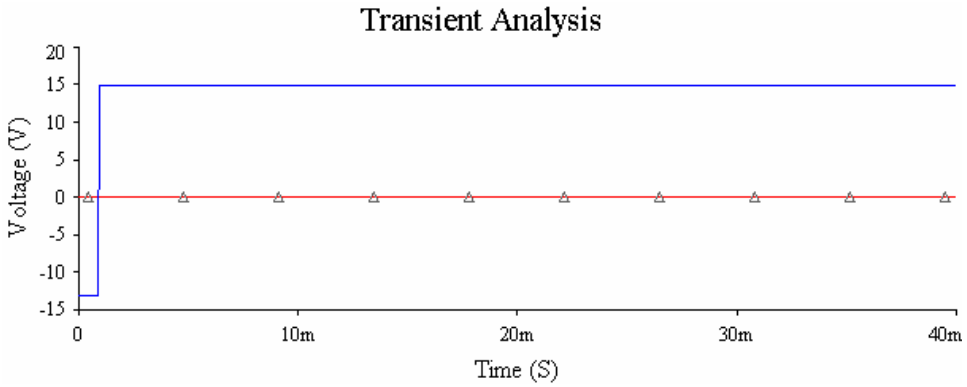

Figure-4. Response of the circuit when a fault is identified.

Figure-2 is the proposed circuit breaker. The decision making circuit is a comparator that senses the voltage drop across the sense resistor decides the strength of the control signal. It gives a high voltage under no fault condition that keeps on the switch and the ac power is connected to the load with out any disturbance. Where as when a fault occurs the output of the decision making circuit goes low so that bjt turns off and disconnects the load from the power supply. These results are shown in Figures 3 and 4. The first response is the output across the load and comparator under normal conditions. The load voltage is equal to the input voltage and comparator gives the high dc voltage. This voltage is applied to the bistable latch in order to retain the voltage. The second Figure shows the response of the circuit under faulty condition. The voltage across the load goes low and comparator output goes in the opposite direction. Bidirectional operation is not possible with a single transistor. This is because the emitter and collector doping and active areas are different. This leads to the design of a symmetrical bjt with equal doping on emitter and collector side. Another requirement is the emitter and collector areas are also equal. The symmetrical vertical or lateral bjt serves this purpose.

RESULTS AND DISCUSSIONS

This circuit has been simulated with Multisim and verified experimentally using simple BC177 and BC847.

These two transistors have almost equal beta. The latch circuit is not shown in this diagram. When the latch is connected to the output of the comparator the output from the latch is connected to the base of the transistors. Since two transistors are used two opposite voltages are needed. Multisim is simulation software that models the behavior of a circuit contain analog and digital devices. It runs both basic and advanced analysis. Basic simulation examples are DC operating point, DC sweep, AC sweep, Noise analysis and Fourier analysis and Mante Carlo, sensitivity are the advanced analyses [11].

CONCLUSIONS

This circuit is a simple ac circuit breaker for low voltage analog circuit applications. A simple BJT bidirectional switching operation is demonstrated. The response time in microseconds indicates that a short circuit can be detected very fast to prevent damage is an improvement.

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