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An Efficient Solid State Circuit Breaker for Low Voltage Circuit Protection

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Abstract

The general trend in electrical appliances is to go for electrical equivalents of mechanical or electromechanical gadgets. One of the long standing electronic component is the circuit breaker, a protective device that trips the ac supply once the current through the system goes beyond the rated value. In this paper an all electronic circuit breaker using bidirectional switch is demonstrated. The operation of bidirectional switch for low voltage applications in different operating conditions analyzed to determine the limitations of this design. The protection from short circuit and over voltage is also demonstrated Bidirectional ac switches with Triacs, IGBTs are commercially available however bi direction switch with MOSFETs is a new approach with two transistors and a simple resistor to identify the fault on the load side in order to achieve a fast turn off time .

Keywords: Bidirectional switch, sense resistor, control voltage, on resistance

Introduction

Circuit breakers are switching devices capable of making and carrying currents under normal circuit conditions and breaking current under specified abnormal conditions such as a short circuit. Circuit breakers protect electrical circuitry from damage due to an over current condition, such as an overload condition or a relatively high level short circuit or fault condition. Until recently few alternatives to electromechanical and magnetic circuit breakers existed. As the conventional circuit breaker is connected in series with the supply there is a need for fast acting circuit breakers[1]. Solid state technology applied to the traditional device has resulted in circuit breakers free from arcing and switch bounce. Most of the electronic circuit breakers are designed with IGBTs for fast acting and low losses.[2-4]. However, the IGBT still requires large drive current. The Bipolar Transistor was the only power transistor until the MOSFET came along in the 1970’s [5] . The Bipolar Transistor requires a high base current to turn on, has relatively slow turn-off characteristics and is liable for thermal runaway due to a negative temperature co-efficient. In addition, the lowest attainable on-state voltage or conduction loss is governed by the collector-emitter saturation voltage V_{CE}(sat). The MOSFET is a voltage controlled device . MOSFETs have a positive temperature coefficient, that stops thermal runaway. MOSFET offers low on resistance, low voltage drops, low EMI and faster switching time. The on-state-resistance has no theoretical limit, hence on-state losses can be far lower. MOSFET and IGBT structures look very similar. The IGBT technology is certainly the device of choice for breakdown voltages above 1000V, while the MOSFET is certainly the device of choice for device breakdown voltages below 250V. However, choosing between IGBTs and MOSFETs is very application-specific and cost, size, speed and thermal requirements should all be considered[6]. 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 MOSFETs especially suited for low voltage application switch.

Working of bidirectional switch

An all electronic Circuit Breaker has been designed for connecting a load to an ac voltage supply. This circuit basically consists a bidirectional switch that allows ac voltage, a sense resistor and a decision making circuit connected in series with the load. . The bidirectional switch includes two MOSFETs connected back to back to provide conduction in both positive and negative cycles of the ac voltage. A sense resistor is connected between the two MOSFETs and the voltage across the sense resistor is sensed and 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 gates of the bidirectional switch. Voltage across the sense resistor is measured and applied to the comparator. The two MOSFETs connected in series acts as an analog switch that closely models the ideal switch due to small voltage drop and less non linear switch transfer characteristic. Fig(1) shows the block diagram of proposed solid state ac circuit breaker. In order to fully evaluate the performance and determine control requirements for this switch, the operation of the device will be discussed for various conditions.

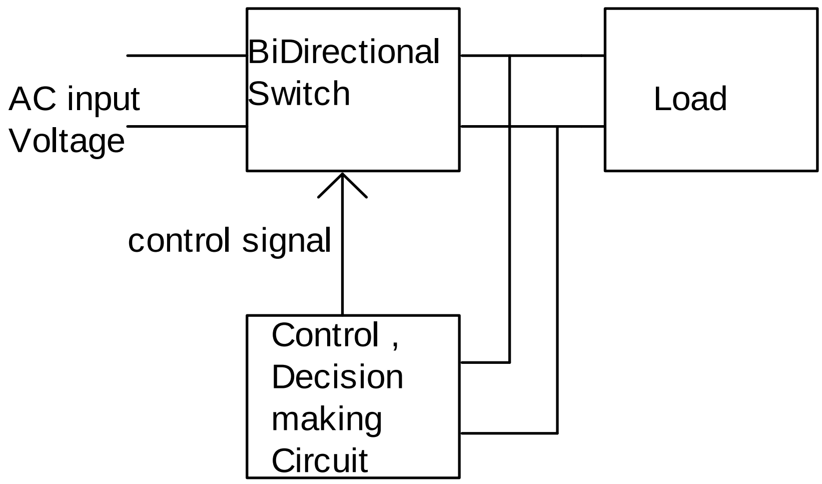


Figure 1: Block diagram of the circuit breaker

Design and application

Important ratings specifications of circuit breakers 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 connected between the two MOSFETs is sampled and applied to the comparator and the output of comparator controls the gates of the bidirectional switch. Operational amplifier is used as comparator. The required power supply to the operational amplifier is either derived 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 threshold 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 gate bias to the two transistors. Under normal condition the comparator output is high so the two gates get 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 transistors. A single MOSFET is sufficient to conduct the ac voltage equally for both the half cycles. But to stop the conduction two MOSFETs are needed each one to cutoff each half cycle. This is because of the forward biased diode existing between Source and Drain of the MOSFET. Though the gate bias is zero the first transistor conducts during the negative half cycle of the input voltage which is now blocked by the second transistor.

This turn off switching time must be shorter than the rise time of the circuit. The MOSFET switching time is determined by its capacitances. Therefore for fast switching, lower driving source impedance is required.

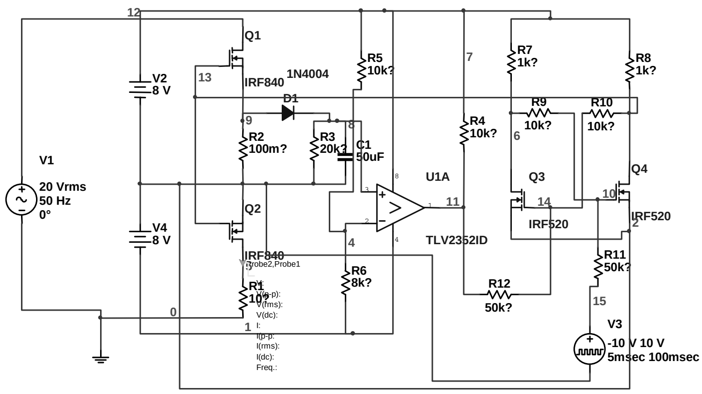


Figure 2 : circuit breaker with two mosfets

Figure2 is the proposed bidirectional switch. The two switches are controlled by the same control signal. The decision making circuit that senses the voltage drop across the sense resistor decides the strength of the control signal. that is 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 bidirectional switch turns off and disconnects the load from the power supply. These results are based upon the dc characteristics of the MOSFET that are shown in fig.3 The response characteristics when the bidirectional switch is in conduction is shown in fig 4 and when the fault is identified in fig 5

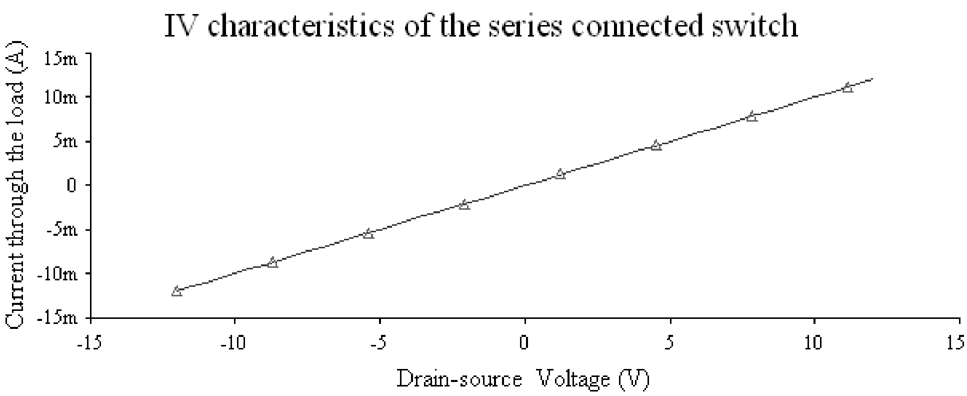


Figure 3: DC characteristics of mosfet

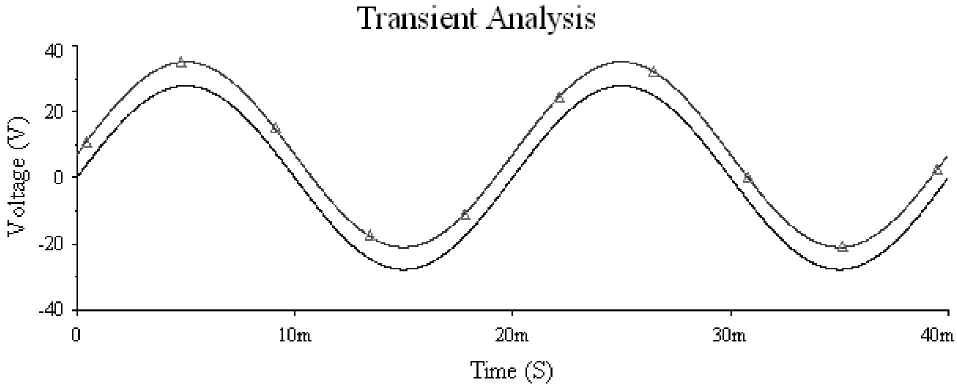


Figure 4: Response when the switch conducts

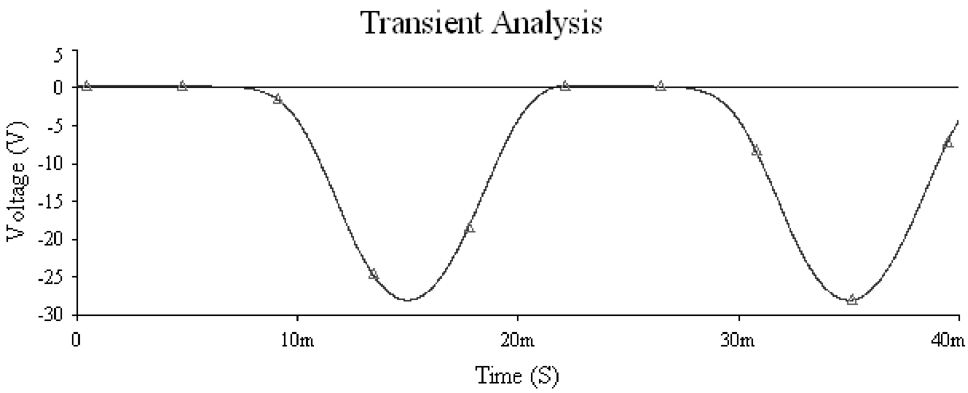


Figure 5: Response when the switch disconnects the load

Results and Discussion

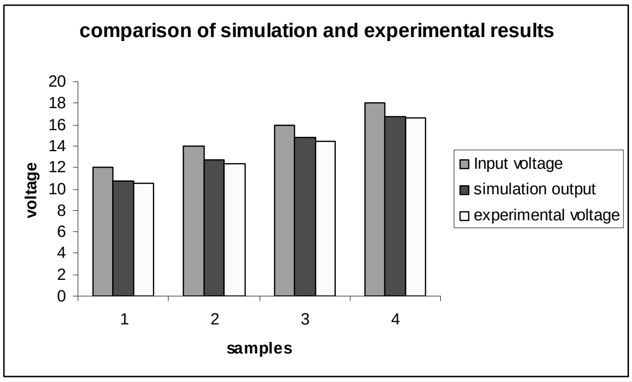
This circuit has been simulated with Multisim and verified experimentally using IRF 840 MOSFETS.

Multisim is a 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[7}.Two N channel DMOSFEts are used for experiment in order to attain fast response and the following parameters are observed.

R_DON =5Ω
Time delay = 400µS
V_{DS} =0.7V

The following chart gives the comparison of simulation and experimental results

Comparison of simulation and experimental results



Conclusion

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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